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Title: *Revised Bedrock Geology of the Danforth, Scraggly Lake, Forest, Waite, Vanceboro, and Kellyland 15' Quadrangles, Maine: Report of Mapping Progress, June-August, 1989*

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Revised Bedrock Geology of the Danforth, Scraggly Lake, Forest, Waite, Vanceboro, and Kellyland 15' Quadrangles, Maine: Report of Mapping Progress, June-August, 1989

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INTRODUCTION

This report summarizes progress in bedrock mapping in eastern Maine over a 16-year period (1974-1989), and presents an updated version of the geology described in last year's progress report (Ludman, 1988). The area discussed in detail in this report (Figures 1, 2) spans three of the lithotectonic tracts that comprise southeastern Maine—the Aroostook-Matapedia belt, Miramichi anticlinorium, and Fredericton trough—although some mention will be made of advances in understanding of two additional belts—the Kearsarge-central Maine synclinorium and St. Croix belt. Each of these tracts contains a unique combination of stratigraphy and deformation history, and each may therefore be considered as a separate terrane as described by Coney et al. (1980) and Williams and Hatcher (1982). The quadrangle maps that accompany this report show that each of these terranes is fault-bounded and may be exotic with respect to at least some of its neighbors. The nature of many of the boundary faults has been determined and will be described in this report, but further work is needed to resolve the remaining ambiguous relationships.

Mapping during the summer of 1989 was focused primarily in the Scraggly Lake, Danforth, Waite, Forest, Vanceboro, and Kellyland quadrangles, with only a few traverses in the adjoining Springfield, Wytopitlock, and Amity quadrangles. Although I did no new fieldwork in the Calais and Big Lake quadrangles, the interpretation of their geology has been changed significantly by the discovery in New Brunswick of graptolites in one of the formations that comprise the Cookson Group of the St. Croix terrane (Fyffe, pers. commun., 1989). Figure 3 includes the revised stratigraphy of the St. Croix belt, based on faunal evidence from two of the three formations present. Only a brief description of the tectonic implications of the revised stratigraphy is given in this paper; interested readers are referred to Ludman (1990) and Ludman and Hill (1990) for detailed discussions of the St. Croix belt and the southern part of the Fredericton trough.

I have made no significant changes in my preliminary map of the Springfield quadrangle, and therefore have not included an updated version with this paper. John Hopeck has continued to refine the geology of the Wytopitlock quadrangle; see Hopeck (in preparation) for the most up-to-date version of that bedrock map.

Interpretation of the tectonic history of the region has been aided immeasurably by a seismic reflection traverse conducted across the Bottle Lake pluton by John Costain, Cahit Çoruh, and Bill Doll (Costain et al., 1990; Doll and Potts, 1990). A paper describing the tectonic features imaged by that line is in the final stages of preparation for submission to Geology, but some of its conclusions will be summarized later in this paper.

SUMMARY OF MAJOR ADVANCES IN 1989

Mapping in the Aroostook-Matapedia, Miramichi, and Fredericton trough tracts in 1989 has generally supported the stratigraphic models described last year (Ludman, 1988; see also Hopeck et al., in review). Most of the changes involve an improved understanding of the tectonic vs. stratigraphic nature of some formation contacts and have been brought about by a large number of exposures along new logging roads throughout the re-

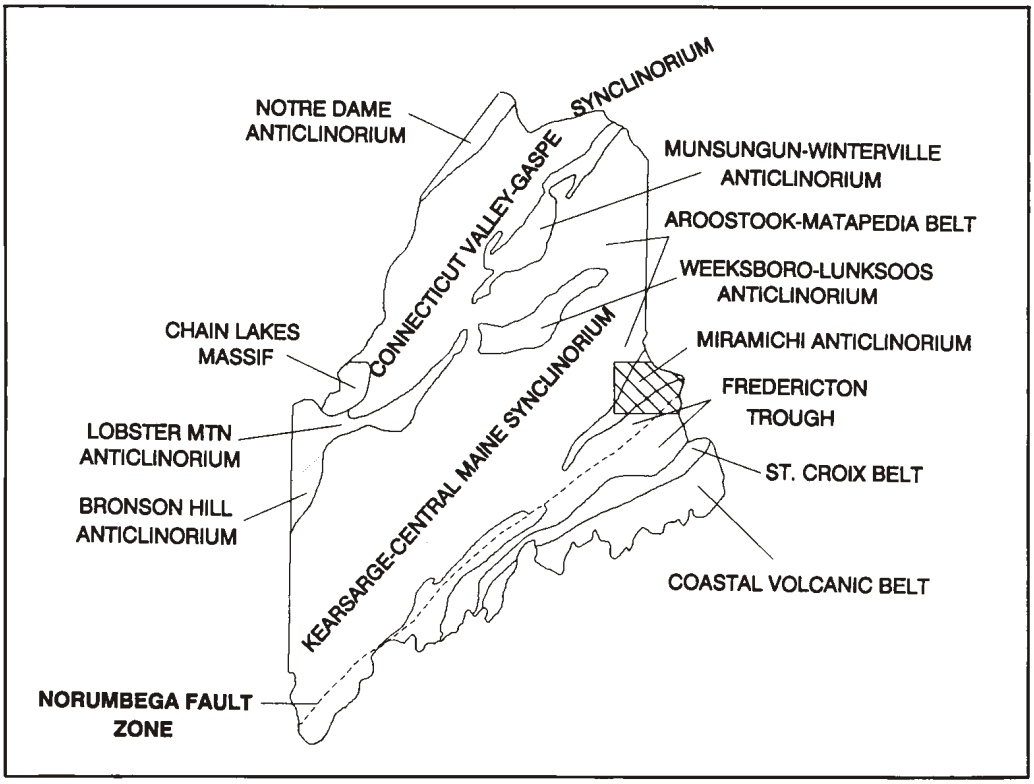

Figure 1. Simplified tectonic framework of Maine. Shading indicates area covered in this report.

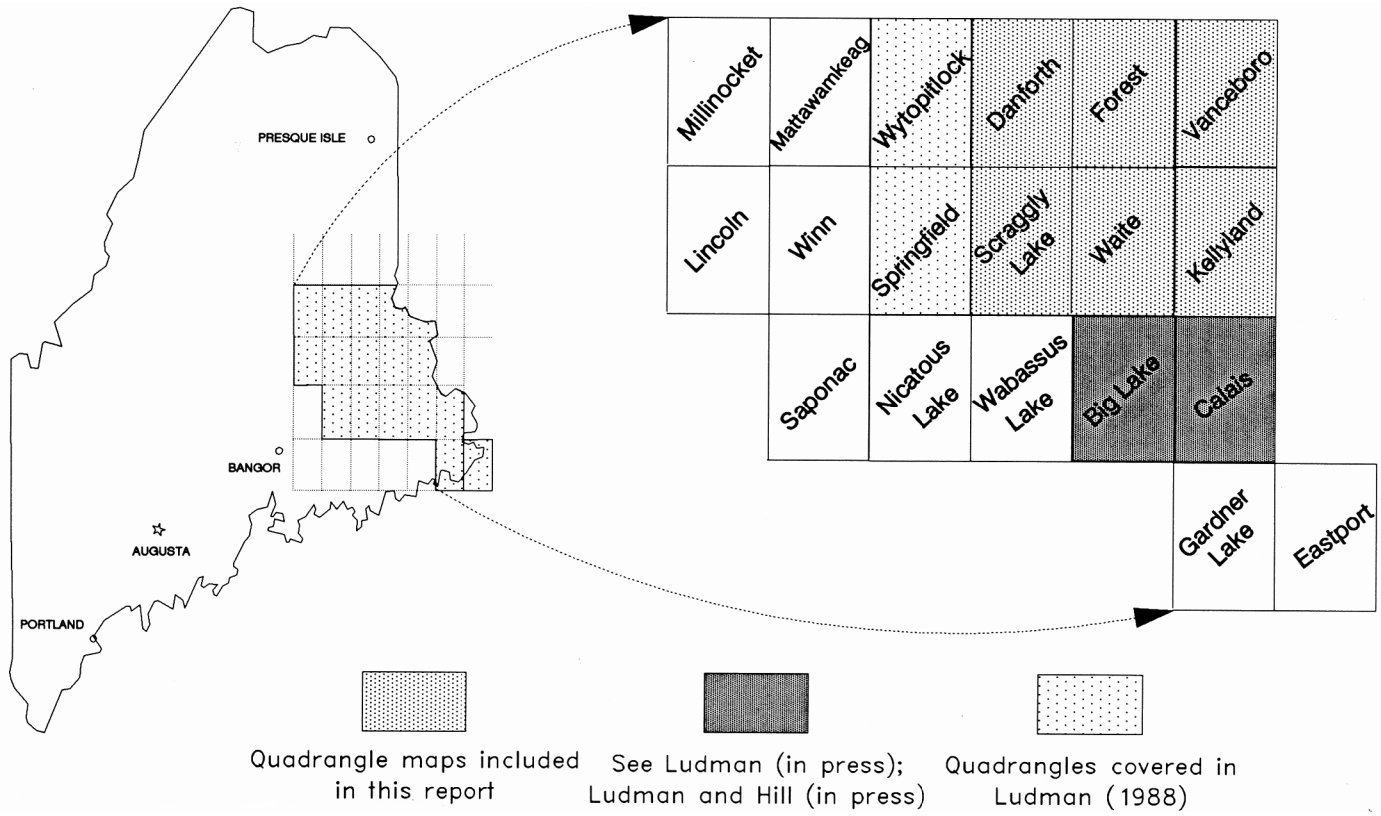

Figure 2. Area covered in this report.

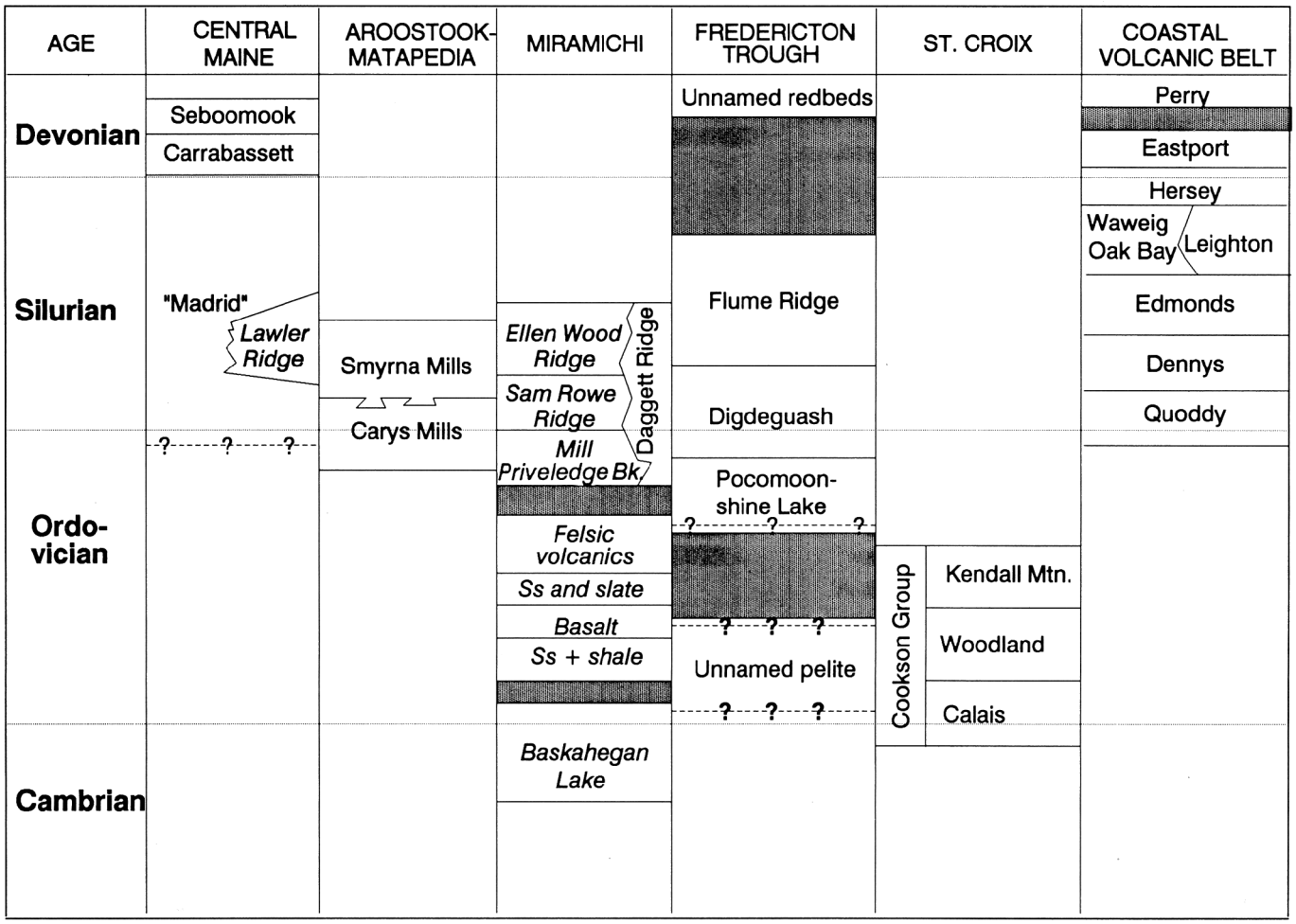

Figure 3. Simplified stratigraphy of eastern Maine.

gion. The stratigraphic details will he discussed later; here I will briefly summarize the larger conceptual advances.

Nature of the Relationship Between Miramichi Strata Deposited Before Middle Ordovician Deformation and Those Deposited Later.

Hopeck (1988, 1989) unraveled a complex stratigraphic package in clastic sediments along the western margin of the Miramichi anticlinorium. These rocks were fitted into four formations of inferred Late Ordovician through Early Devonian age, the informally named Mill Priveledge Brook, Sam Rowe Ridge, and Ellen Wood Ridge Formations, and the Daggett Ridge Formation named by Larrabee and Spencer (1963). It had become obvious last year that these units shared complex facies relationships with one another, but their relationship to the underlying pre-Late Ordovician volcanic and sedimentary units of the Tetagouche Group was unclear.

Petrographic examination now reveals that the younger suite contains clasts of every formation present in the older Tetagouche Group. Structural analysis shows that the four formations named above have been deformed only once, by upright open to isoclinal folds, whereas the older rocks have been deformed at least one additional time. The contact between the two suites was mapped last year as an unconformity in which the basal clastic suite derived from the Tetagouche Group had transgressed upon part of its erosionally truncated source region.

Detailed mapping in the northern part of the Danforth quadrangle and the north-central part of the Scraggly Lake quadrangle suggests that although the sedimentary linkage between the two suites is inarguable, their present contact is probably a thrust fault. This is indicated by deformation features on both sides of the contact and by the fact that contacts within both suites truncated along their boundary in the Danforth quadrangle. Reconstructed facies relationships suggest that the thrusting was east-vergent, bringing distal strata of the Sam Rowe Ridge Formation eastward over its volcanic source region. Later

high-angle dip-slip faulting isolated these allochthonous rocks as klippen in the Scraggly Lake and Danforth quadrangles. The amount of transport cannot be determined, but does not seem to have been considerable. The timing of thrusting is not fully constrained, but appears to have been an early Acadian event since Silurian rocks (Daggett Ridge Formation) are involved and the thrust was itself folded by Acadian-aged folds.

Refinement of the Map Pattern of this Thrust Fault.

Last year's progress map was characterized by several dotted lines filled with question marks, primarily because of very poor outcrop coverage in large areas of the Danforth and Scraggly Lake quadrangles. Three extensive sets of logging roads (1) in the vicinity of Jimmey Mountain in the Danforth quadrangle, (2) north of the Danforth-Bancroft road in the Danforth quadrangle, and (3) a new logging "highway" connecting Route 6 in the Scraggly Lake quadrangle with Route 169 in the Danforth quadrangle have opened previously inaccessible areas and at the same time have provided hundreds of new outcrops.

There is now no doubt that much of the northwestern part of the Scraggly Lake quadrangle is underlain by rocks of the Sam Rowe Ridge Formation, and that these rocks truncate members of the unnamed Middle Ordovician (Caradocian) felsic volcanic formation (Ovf). The Baskahegan Lake Formation underlies a larger expanse in the north-central and northeastern parts of the Danforth quadrangle than had been thought in previous years. Reexamination of pelitic rocks north of Danforth at the contact with the Pokiok pluton has led me to indicate that slates with sparsely interbedded sandstones, shown last year as possible equivalents of the Scott Siding Slate of New Brunswick, are actually continuations of the Sam Rowe Ridge Formation. This has simplified the map pattern significantly.

Original Relationship Between the Miramichi Anticlinorium and Aroostook-Matapedia Belt, and Age of the Mill Priveledge Brook, Sam Rowe Ridge, Ellen Wood Ridge, and Daggett Ridge Formations.

Most of the evidence for the ages of these units comes from the work of Hopeck (1989; in preparation) in the adjacent Wytopitlock and Springfield quadrangles. In at least three separate traverses, it can be demonstrated that the Mill Priveledge Brook Formation interfingers with micritic limestones of the Carys Mills Formation. The age of the Carys Mills Formation has been much debated, but is now relatively well established as Ashgillian to Llandoverian (Late Ordovician to Early Silurian; see Osberg et al., 1985). Although there are no fossils in the Mill Priveledge Brook Formation, the field relationships indicate that it has a comparable age. The Carys Mills Formation is overlain by the Llandoverian-Wenlockian Smyrna Mills Formation, while the Mill Priveledge Brook Formation is overlain by and interfingers with the Sam Rowe Ridge, Ellen Wood Ridge, and Daggett Ridge Formations. Figure 3 shows the inferred age relationships and correlations of these other units.

These facies relationships are of critical importance in tectonic reconstructions for the region. It is now clear that the Aroostook-Matapedia and Miramichi terranes were linked stratigraphically by at least the Late Ordovician. Although there is evidence that the former was thrust eastward over the latter, and despite the fact that the two are now separated locally by the Stetson Mountain and North Bancroft fault zones, it is clear that the two terranes are not and were not exotic relative to one another after the Middle Ordovician.

Nature of the Basement Beneath the Fredericton Trough

The nature of the basement beneath the Fredericton trough has been one of the hottest items for debate among regional tectonic modelers, some calling for an ocean basin and others for an ensialic environment. Prior to the summer of 1989, there was little if any information within the tract to help resolve the debate—the Fredericton trough continued as a nearly homogeneous, monotonous sea of calcareous quartzofeldspathic wacke for nearly 30 miles across strike from the Codyville fault at Topsfield to the South Princeton-Crawford fault at Woodland. Downdropped fault slivers of post-Acadian molasse exposed along branches of the Norumbega fault zone revealed what had lain above these wackes, but there was no indication of their substrate.

Things changed drastically when Fyffe (pers. commun., 1989) discovered a sequence of pelitic rocks with minor calcareous sandstones at the New Brunswick-Maine border. I have now traced these rocks some distance into Maine and agree with Fyffe's conclusion that these must be much older (probably Ordovician) than the Flume Ridge Formation that comprises most of the Fredericton trough in Maine. The evidence is both structural and metamorphic. The Flume Ridge Formation has essentially been deformed only once, by upright Acadian folds. The unnamed pelites (Opx on the accompanying maps) have been deformed at least once and probably twice prior to the Acadian deformation. They reveal recumbent isoclinal folds that have been refolded about the same upright folds as are found in the surrounding Flume Ridge Formation. In addition, these recumbent folds typically deform a previously existing foliation defined by medium to coarse-grained muscovite flakes, suggesting a yet earlier folding event. In addition, rocks mapped as Opx contain foliated flakes of biotite, clearly the product of regional metamorphism accompanying one of the two folding events—probably the earlier. In contrast, none of the rocks of the Flume Ridge Formation that are in contact with Opx contain any biotite. The only biotite found in wackes of the Flume Ridge Formation is in contact aureoles; regional metamorphic grade in these wackes is always chlorite zone or lower.

Nature of the Norumbega Fault Zone

The juxtaposition of Opx and unmetamorphosed redbeds of probable Carboniferous age across a branch of the Norumbega fault zone suggests significant dip-slip motion on the fault zone. Independent verification of this conclusion comes from the seismic reflection line across the Bottle Lake pluton (Costain et al., 1990; Doll and Potts, 1990). This line crossed two branches of the Norumbega fault zone and imaged them clearly throughout the entire crust. Indeed, they cut the entire crust and offset the Moho vertically by as much as 1.5 km.

The significance of this observation is that it suggests a very late date for motion along faults of the Norumbega fault zone. Stewart (1989) has postulated that the strongly reflective lower crust and the configuration of the Moho result from Mesozoic extension. If this is correct, it is unlikely that Moho offset now observed on the Norumbega fault zone could have survived such extension. At least some of the dip-slip offset on the Norumbega fault zone must be more recent than the formation of the observed Moho; Cenozoic or Late Mesozoic offset is a definite possibility.

STRATIGRAPHY

There has been little change in the regional stratigraphic model presented in my most recent progress report (Ludman, 1988), other than the discovery of the Opx unit and reversing the sequence of formations in the Cookson Group of the St. Croix belt. The discussion that follows is a brief description of stratigraphic relationships in southeastern and east-central Maine and covers the Kearsarge-central Maine and St. Croix terranes for completeness.

Kearsarge-Central Maine Synclinorium

The strata of the Kearsarge-central Maine synclinorium include intermediate and distal turbidites in central (Osberg, 1980; Pankiwskyj et al., 1976) and north-central Maine (Roy, 1981; Neuman 1967). More proximal facies crop out along the west flank of the synclinorium in western Maine (Moench and Pankiwskyj, 1988). The distinctive Perry Mountain - Sangerville - Smalls Falls - Madrid - Carrabassett - Seboomook sequence defined in central and west-central Maine does not appear to be present in the present study area; neither are the fossils that provide the critical ages for those units.

The central Maine sequence is represented in the Wytopitlock and adjacent quadrangles to the west and north by an apparently monotonous sequence of generally thick bedded calcareous quartz-feldspar wackes interbedded only rarely with appreciable amounts of pelite. These wackes have been mapped as belonging to the Siluro-Devonian Madrid Formation (Osberg et al., 1985), but have been referred to locally as the Lawler Ridge Formation by Roy (1981). The wackes underlie all or nearly all of several quadrangles just west of the present study area and are in apparent fault contact with the Matapedia belt in the Wytopitlock quadrangle.

In previous reconnaissance studies I suggested that this pile of wackes might be subdivided based on a variably calcareous nature and on bedding style (Ludman, 1985). Two units are tentatively broken out of this sequence and are mapped provisionally as members of the Madrid Formation. One, DSmc, is a punky orange-brown weathering, calcareous quartz-feldspar wacke with abundant detrital muscovite flakes. Fresh rock, often difficult to find in deeply weathered exposures, is invariably medium to light gray. Beds are generally homogeneous, with few sedimentary structures, little if any variation in grain size, and little pelite between sandstone beds. Thickness of individual beds ranges from 5 cm to over 3 m, with most beds greater than 20 cm thick. Homogeneity of the wacke makes it difficult to identify bedding and/or facing in many instances.

The second unit, DSmf, is a chalky white weathering, generally non-calcareous, quartz-feldspar wacke that lacks the muscovite content of DSmc. It contains more feldspar than DSmc and less (if any) of the pyrite and ankerite that cause that member to weather orange-brown. The range of bed thickness is comparable to that in DSmc, but graded bedding is somewhat more common and DSmf appears to be slightly more coarse-grained.

Current mapping suggests that DSmc and DSmf are in conformable contact. Reversals of graded bedding and evidence from rare load casts suggest that DSmc is older than DSmf, but much more work is needed to confirm this hypothesis. It is unlikely that simple "layer-cake" stratigraphy will explain relationships between these members, and a complex interfingering of facies developed on a terrace formed by coalescing deep-sea fans is envisaged for the Madrid Formation.

The age of these units is not well defined. If they are indeed part of the Madrid Formation, and if that unit is not time-transgressive, a Late Silurian to Early Devonian age is indicated. Middle Silurian fossils found just below basal wackes of the Lawler Ridge Formation by Roy (1981) suggest that age relationships are not as simple as the state map has suggested. The pile of calcareous and non-calcareous wackes described here may be equivalent to the entire Sangerville-through-Madrid sequence further west and thus span nearly the entire Silurian.

The contact between the central Maine and Matapedia belts is shown on the state map as a fault of unspecified type (Osberg et al., 1985), primarily based on my reconnaissance mapping. This fault is now informally named the central Maine boundary fault. Units of both belts are truncated by the central Maine boundary fault and the early (syndepositional?) Kingman fault zone is also cut by the fault. The central Maine boundary fault is itself folded in the Mattawamkeag Lake quadrangle northwest of the area covered in this year's report and is believed to be of Early Acadian affinity. Sense of displacement along the fault is not well constrained at this point; Hopeck and I favor a west-over-east thrust sense in our modeling, but other possibilities cannot be ruled out.

Aroostook-Matapedia Anticlinorium ("Matapedia Belt")

Much of the Springfield and Wytopitlock quadrangles west of the area covered in this year's detailed report is underlain by thin-bedded strata shown on the state map as unnamed limestones and pelites of presumed Silurian age. It was mentioned in previous reports (Ludman, 1988; Hopeck, 1988) that the limestones are equivalent to the Late Ordovician-Early Silurian Carys Mills Formation and the pelites are comparable to the Smyrna Mills Formation of the Aroostook-Matapedia belt in the Houlton area as defined by Pavlides (1974). This conclusion changes the map pattern of the Aroostook-Matapedia belt significantly. A southern lobe of the belt now extends southeastward of the Kearsarge-central Maine synclinorium into the present study area.

Carys Mills Formation (SOcm). A large portion of the Matapedia belt in the study area is composed of very fine-grained gray argillaceous micritic limestones. These rocks have not had a distinguished place in regional mapping history. Larrabee et al. (1965) completely ignored them, lumping this lithology with similarly gray but non-calcareous rocks of presumed Silurian age. Doyle and Hussey (1967) showed small outcrop areas of this unit in the contact aureole north of the Bottle Lake pluton in the Winn and Springfield quadrangles, and referred to it as Ordovician-Silurian unnamed limestone. My reconnaissance and semi-detailed mapping in these quadrangles as well as in the Wytopitlock and Amity quadrangles revealed that argillaceous limestones are far more widespread than previously suspected (see Osberg et al., 1985). They suggested a Silurian age, but did not attempt correlation with either the Carys Mills Formation to the north or the ribbon limestones of the Waterville or Sangerville Formations to the southwest.

The distinctive bedding style that characterizes limestones of the Carys Mills Formation in its type locality near Houlton is rarely preserved in the study area. It is replaced by one or more sets of transposed layering created during folding and/or faulting. Bedding is observed in less than 5% of the outcrops of the Carys Mills Formation in the study area. Where present, beds are 2-5" thick and consist of variably dolomitic and calcitic micrite separated in some instances by thin layers of pelite. These pelitic layers are probably pressure-solution residues rather than primary beds. Differential weathering (buff vs. medium gray) distinguishes the two types of carbonate beds.

Smyrna Mills Formation (Ssm; Ssmg). Very thinly layered pelites with subordinate sandstone comprise the rest of the Matapedia belt in the study area, particularly near the contact with the Kearsarge-central Maine suite. By analogy with the Matapedia rocks of the Houlton area, these pelites are assigned to the Smyrna Mills Formation (see Pavlides, 1974). The Smyrna Mills Formation is divided into two members (Ssm and Ssmg) in the study area based almost entirely on color .

<u>Ssm</u> is a generally monotonous sequence of thin-layered medium gray slates intercalated with subordinate amounts of gray-weathering, fine-grained quartzose sandstone and siltstone. Transposition has affected these rocks also, and it is difficult to demonstrate conclusively that layering in most outcrops is true bedding. Most layers range from 0.5 to 2.5 cm, and slate accounts for approximately 65-75% of this member. It can be difficult to distinguish deeply weathered limestones of the Carys Mills Formation from slates of Ssm if weathering has leached out calcite from the former. Zones of intense disruption have been found locally in Ssm, and the disruption is attributed to early-stage syndepositional faulting. Small(?) lenses of fine-grained limestone similar to those of the Carys Mills Formation occur within the gray pelites of the Smyrna Mills Formation , but are not abundant.

<u>Ssmg</u> differs from Ssm in a few distinctive ways: (1) it is highly chloritic and hence green in most of its outcrops, except for those that are hematitic and reddish-maroon; (2) sandstones are more feldspathic than those in Ssm, and as a result weather to a chalky buff color rather than gray; (3) sandstones are perhaps slightly more abundant than in Ssm and occur locally in thicker beds (up to 7 cm).

Ssmg and Ssm are distributed geographically in a regular manner that suggests either stratigraphic or consistent structural control. Ssm is most prominent in the eastern part of the Matapedia belt, adjacent to the Carys Mills Formation, and Ssmg is absent from this area. Ssmg occupies the western (upper?) part of the Matapedia belt, and the red horizons seem to be restricted to locations near the central Maine boundary fault. Syndepositional faulting has severely disrupted Ssmg, as along the Kingman fault zone, and this member is further complicated by as many as three sets of transposed layers.

Contact Between the Matapedia and Miramichi Belts. The contact between Matapedia and Miramichi lithologies is a tectonic one everywhere. Locally, the North Bancroft and Stetson Mountain fault zones separate rocks of the two belts, and in my earlier modeling I had considered these faults as possible terrane-bounding sutures. It has become apparent in the past two summers, however, that Matapedia rocks crop out on both sides of the North Bancroft fault, and possibly on the east side of the Stetson Mountain fault as well. These north-trending faults are relatively late in the regional tectonic history; juxtaposition of the two tracts is thought to have occurred along earlier east-directed thrusts that have since been offset by the later faults. It presently looks as if the early thrusts were early Acadian features, and that they are in turn deformed by late Acadian folds (see below).

Miramichi Anticlinorium

The Miramichi anticlinorium in Maine is divided into two unequal parts by the Bottle Lake Complex, a small segment south of the pluton near Orono (the Greenbush segment), and a larger area (the Danforth segment) between the Bottle Lake Complex and the Canadian border. Larrabee and Spencer

(1963) and Larrabee et al. (1965) mapped several formations in the Danforth segment, including an unnamed volcanic unit. Unfortunately, few of those units have stood the test of subsequent mapping, and those that are now recognized bear only a slight resemblance to the group originally proposed. This report will focus on rocks of the Danforth segment; although most of the lithologies found there are also present in the Greenbush area, I have not done enough detailed work to confirm a similar stratigraphic sequence.

The Danforth segment of the Miramichi anticlinorium contains a wide variety of rocks ranging in age from Cambrian(?) through Siluro-Devonian, and in lithology from mafic volcanic rock to limestone conglomerate. As shown in Figure 3, two unconformities divide the sequence into three distinct parts; from oldest to youngest these are the Baskahegan Lake Formation (equivalent to the Lower Tetagouche Group of New Brunswick), the Upper Tetagouche Group, and a package of conglomerates, grits, and slates here informally named the Prentiss Group.

Baskahegan Lake Formation (OCbl). Rocks of the Baskahegan Lake Formation are thought to be the oldest in the region. They occur in two belts (see attached quadrangle maps) in the Danforth, Scraggly Lake, Forest, and Waite quadrangles, separated by the younger sedimentary and volcanic rocks of the Tetagouche and Prentiss Groups. The formation is named from superb exposures along the eastern shore of Baskahegan Lake near Brookton in the Danforth quadrangle, and many spectacular pavement outcrops have been exposed east of that lake on a new network of lumber roads.

The Baskahegan Lake Formation contains massive to well graded, generally thick-bedded gray, green, and maroon quartzose and quartzofeldspathic sandstones and wackes, interbedded with green and maroon slate. Two members are recognized, with distinctions made by color, bed thickness, and proportion of sandstone and pelite.

Lower Member (OCblm). The lowest exposed part of the formation consists of pink to deep red-maroon sandstones and interbedded red-maroon slates, indicated as OCblm on the accompanying maps. These crop out in the cores of anticlines south of Brookton. They have not been found in the northern belt of the Baskahegan Lake Formation, suggesting that the rocks north and west of Danforth represent only the upper part of the formation. Sandstones and coarse siltstones dominate this lowermost member of the Baskahegan Lake Formation, and probably comprise 80-85% of its outcrops. Sandstones of OCblm are generally thick-bedded; they range from 10 cm to as much as 3 m, but most are between 20 cm and 1.0 m thick. The clasts consist of quartz and feldspar in varying proportions, but are typically more quartzose than in the overlying OCblg member. The bases of some beds contain granule-sized clasts (up to 4.5 mm), but these are rare. The matrix consists of muscovite, chlorite, and variable amounts of hematite that control the redness of the rocks.

Most beds are homogeneous, but some display excellent graded bedding, with granule-sized particles at their bases passing upward through sand-sized grains to silt or slate at their tops. Color also tends to grade upward in these beds, from pinkish gray at the base to deep maroon at the top as hematite content increases. Slate occurs most often in OCblm as the tops of these graded sets, and only rarely forms separate beds between sandstone layers.

Upper Member (OCblg). The vast bulk of the Baskahegan Lake Formation is made up of granule conglomerates, sandstones, siltstones, and pelites that are nearly identical to those of OCblm except for the fact that they are green. These rocks, designated OCblg, lie conformably and apparently gradationally above the red varieties. The transition is well exposed on lumber roads east of Route 1 just south of Jackson Brook Lake, and west of Route 1 near the Kossuth town line, and consists of interbedded green and red lithologies. Well developed graded beds in both areas indicate that OCblm lies beneath OCblg.

Most of the sandstones of OCblg weather chalky white because of their high feldspar content. Bed thicknesses are comparable to those in the lower member, but some massive quartz-feldspar wackes in OCblg attain thicknesses of 5 m. Most of the sandstones are featureless, but a few soft-sediment slump folds have been identified in the thicker beds. As in OCblm, pelite beds are rare, and most shale/slate occurs at the tops of graded beds.

Wackes of both OCblg and OCblm display a distinctive solution cleavage that is well developed in most outcrops. It is commonly regularly spaced (1.0-2.0 cm), giving the sandstones a unique "sliced bread" appearance that I have not seen in any other formation in the region. Pelitic insoluble residue is concentrated along the "breadslicer" cleavage planes, and these secondary layers may locally be mistaken for bedding. This cleavage is commonly refracted within a single graded bed, and in some exposures has clearly been folded. This characteristic cleavage is preserved even in high-grade hornfelses adjacent to the Bottle Lake and Pokiok plutons, but the basic color difference between OCblg and OCblm is destroyed by metamorphism at the biotite isograd.

Age and Correlation. No fossils have ever been found in the Baskahegan Lake Formation, and the complexity of its contacts with adjacent units destroys any certainty of a continuous sequence. As a result, the inferred position of the formation below the Caradocian fossils of the volcanic unit cannot be demonstrated unequivocally. In the Canadian Miramichi exposures, the most similar sandstone-dominant unit has been mapped as unnamed Cambro-Ordovician sandstones (OCs) immediately across the border (Venugopal, 1978; Lutes, 1979), and has been correlated with the lower part of the Tetagouche Group as described by Fyffe (1982). Bedding styles and thicknesses, color, and proportions of sandstone and pelite of the lower Tetagouche Group are locally identical to those of the Baskahegan Lake Formation (see descriptions by Irrinki, 1980). There are, however, a few important differences. Lower Tetagouche rocks exposed along the Trans-Canada Highway between Temple and the Houlton turnoff are more quartzose and less feldspathic than

most of the Baskahegan Lake wackes, and as a result weather gray rather than chalky white. A few similar horizons have been observed in the Baskahegan Lake Formation, but are relatively minor. "Breadslicer" cleavage has been observed in some of the Canadian Miramichi exposures, but is not nearly as pervasive as in the rocks in Maine. Finally, many of the rocks of the lower Tetagouche Group are a deep olive-green that contrasts with the paler green of OCblg.

The next belt of Pre-Silurian rocks to the northwest, the Weeksboro-Lunksoos Lake anticlinorium, also contains a similar unit—the Grand Pitch Formation (Neuman, 1967). The Grand Pitch is also unfossiliferous, other than the presence of the trace fossil *oldhamia*, but it lies below Arenigian fossils, and Neuman has suggested a Cambro-Ordovician age. Lithologic similarity and regional relations thus tend to support the proposed age of the Baskahegan Lake Formation, but I have also worked with a model in which the formation is post-volcanic and either of Silurian or late Ordovician age. This concept can not be ruled out, but my preference at this time is for the Cambrian to Early Ordovician age shown in Figure 3.

Upper Tetagouche Group. The upper contact of the Baskahegan Lake Formation is complicated locally by faulting, so that what is preserved probably does not represent a continuous stratigraphy. Although the Baskahegan Lake Formation passes into volcanic units on both the west and east, the sequences are different in the two areas. To the east, OCblg passes into feldspathic sandstones with carbonaceous pelite (OCr) and then into mafic volcanic rocks. To the west, the formation is in apparent fault contact with a sequence of black, carbonaceous pelitic rocks (Or); or thin bedded gray slates with minor sandstone (Op); or an alternation of these two units that may be the result of either folding or interfingering. Rocks of Or pinch out in tight folds in the Springfield and Scraggly Lake quadrangles, presumably because of minor slippage along their contact with Op and Ovf during folding. Alternatively, there may be a complex facies relationship among these three units.

OCr (Unnamed Anoxic Pelitic and Arenaceous Rocks in the Forest and Waite Quadrangles). Pelite-rich horizons assigned to OCblg in the northwest corner of the Waite quadrangle pass eastward into a sequence of thin-bedded feldspathic sandstones and pyritiferous, variably carbonaceous pelite designated as OCr. Outcrop control is poor, but the transition appears to be conformable. The sandstone weathers buff to chalky-buff, is generally fine-grained, and exhibits poorly developed graded bedding. Beds range from 2.5 to 12.5 cm in thickness, but pinch and swell in the area where they are best exposed. Disruption of bedding becomes extreme near the adjacent mafic volcanic rocks of Ovm, and because the Codyville fault is nearby, I had originally attributed the disruption to effects of that structure. Further analysis suggests more ductile deformation than that associated with the Codyville fault elsewhere, and it is possible that syndepositional faulting was responsible.

Pelitic beds range from highly carbonaceous, sooty types to barely carbonaceous, medium gray slates. Both extremes contain euhedral pyrite crystals approximately 1.5-5.0 mm across. Proportions of sandstone to pelite vary considerably within the small outcrop area of OCr and it is difficult to generalize beyond that statement.

Age and Correlation. The age of this unit is poorly constrained. It lies above the Baskahegan Lake Formation and below(?) adjacent mafic volcanic rocks, but none of these units is fossiliferous. If the Baskahegan-Grand Pitch correlation is correct, an Early Ordovician age is suggested. OCr would then be equivalent to the Arenigian Shin Brook Formation of Neuman (1967), and the mafic rocks could correlate with massive basalts described by Neuman in the same stratigraphic position.

Unnamed Mafic Volcanic Rocks (Ovm). Brown-weathering, dark gray to black metabasalt and metadiabase crop out east of OCr in the Waite quadrangle, and similar rocks have been found in the Mattawamkeag River in the northwest corner of the Danforth quadrangle and southwest corner of the Amity quadrangle. In the latter instance, however, OCr is absent and the mafic rocks directly adjoin sandstones of the Baskahegan Lake Formation. In many exposures these rocks are massive and may have been either lava flows or hypabyssal dikes and sills, but pillow-like structures and well defined layering in a few places indicate that at least some of them were eruptive.

Most of the mafic rocks are fine-grained, aphyric metabasalts, now converted to actinolitic greenstones in the contact aureole of the Bottle Lake pluton. Some, however, are porphyritic and contain plagioclase phenocrysts up to 7.5 mm long. Parallelism of plagioclase laths in some specimens suggests primary flow banding. A tuffaceous origin is probable for some of the rocks, which now appear as actinolite-plagioclase greenstones with very fine-grained and complexly sutured textures. A unique lithology associated with the mafic rocks is a strongly pitted (informally "Swiss cheese rock") rock which is composed of two thoroughly intermixed, but very different components: dark green actinolite-plagioclase layers anastomosing with light gray to white calcite-epidote-actinolite layers. It is difficult to pinpoint the protolith of this mixed rock. It may be (a) a mixture of basaltic material and limestone, caused by eruption of lava into unconsolidated muds, (b) a strongly sheared volcanogenic breccia, (c) strongly sheared limestone conglomerate intruded by basalt, or (d) something completely different.

Age and Correlation. As discussed above, there is little age control for this unit other than the fact that it is intruded by the Bottle Lake pluton, and must therefore be older than Early Devonian. A tentative Early Ordovician age is suggested here, based more on possible correlation with the Weeksboro-Lunksoos Lake anticlinorium than on reliable information.

Unnamed Carbonaceous, Sulfidic Pelites (Or). Along the western (faulted) flank of the outcrop belt of the Baskahegan Lake Formation, in the Springfield, Scraggly Lake, and Danforth quadrangles, OCr and Ovm are absent. The Baskahegan Lake Formation is separated from a dominantly felsic volcanic section by pelitic rocks locally separated into carbonaceous types (Or) and non-carbonaceous types (Op).

Or consists of sulfidic, rusty weathering pelites intercalated with subordinate amounts of quartzose sandstone. These rocks crop out well in the aureole of the Bottle Lake pluton in the Scraggly Lake and Springfield quadrangles, where they appear to define a complex map pattern involving at least two generations of folds. Similar rocks are found in the same stratigraphic position further north in the Danforth quadrangle just south of the town of Danforth, but it has not been possible to trace the rocks continuously from one area to the other.

Pyritiferous quartzose sandstone occurs in beds 2.5 to 30.0 cm thick that are of uniform grain size and texture. Locally, either these psammites or the interbedded pelite may be the dominant lithology, but pelite dominates for the unit as a whole. The pelite varies considerably in the amount of carbon and pyrite that it contains. Black, soft, sooty shales/hornfelses generally contain little if any sandstone and only small amounts of sulfide. Dark gray to black pelites are less sooty, contain thin beds of quartzose sandstone, and tend to be more sulfidic. As a result, they weather to a more rusty appearance.

Or differs from OCr in three ways: (1) it is generally thicker bedded, (2) its sandstones are less feldspathic, and (3) the sandstones are not as well laminated or graded.

*Unnamed Gray Pelite and Siltstone (Op)***.** Or passes upward, and locally seems to interfinger with gray slates and siltstones of Op. Gray, non-sulfidic and non-carbonaceous slate and phyllite comprise most of this formation (60-70%), with the remainder being a gray-weathering quartzofeldspathic siltstone and fine-grained wacke. Wacke and pelite generally occur in well graded beds with pelite slightly more abundant than the coarser material, but massive horizons containing only the pelite are also common. The formation is thinly bedded. Most beds are 1.5 to 5.0 cm thick, but a few wacke beds reach 15 cm. Most of the wackes and siltstones, and all of the pelites, are non-calcareous.

Graded beds of Op locally pass upwards, and may also interfinger with a gray matrix-supported conglomerate that I have not separated on the accompanying maps. Exposures of this conglomerate are limited to the Danforth quadrangle just south of Kinney Cove on both sides of Route 169; it does not appear to be present further south in either the Scraggly Lake or Springfield quadrangles. Clasts are up to 30 cm in diameter and include cryptocrystalline volcanic rock, slate chips similar to most of Op, and some manganiferous siltstone.

Ages of Op and Or. Or lies at the base of what seems to be a continuous sequence of Or-Op-Ovf. No fossils have been found in Op, but Caradocian graptolites have been identified in Ovf (Larrabee and Spencer, 1963). Brad Hall and Phil Osberg (pers. commun. 1987) mentioned that graptolites had been collected from "volcanic rocks near Tolman Hill" (in the Springfield quadrangle) and that these had also yielded a Caradocian age. A large series of exposures of Or and Op is found near Tolman Hill, and it is likely that the graptolites came from one of these. Accordingly, Op and Or are considered to be Llandeilian or Caradocian.

Unnamed Felsic Volcanic Rocks (Ovf). This unit was originally referred to by Larrabee et al. (1965) as "rocks of Snow Mountain." It forms a distinctive outcrop band that is traceable from the Pokiok pluton just east of Danforth through the Danforth, Scraggly Lake, and Springfield quadrangles into the Bottle Lake pluton. Identical rocks emerge from the pluton in the Greenbush area where they are in contact with wackes of the Vassalboro Formation (Osberg et al., 1985).

Three members have been recognized in the Danforth area, and are labeled Ovf_1, Ovf_2, and Ovf_3 on the accompanying maps, in order of decreasing age. Ovf_1 consists almost entirely of chalky white weathering, greenish gray cryptocrystalline volcanic rock, but in a few exposures, these rocks are pale red. Bedding is only rarely identifiable; when present it is revealed by slight differences in grain size and weathered color. These rocks are brittle, extremely hard, and support the elongate ridge locally named Owl Mountain and Stetson Mountain in the Danforth quadrangle, as well as Bowers Mountain and Tolman Hill in the Springfield quadrangle. They also underlie Baker, Bennett, and Howard Ridges in the Danforth quadrangle.

In a unit as homogeneous as Ovf_1, a few "strange" rock types stand out sharply. Coarser (up to 2.5 cm long) fragmental volcanic rocks are present in some outcrops, and probably represent ashflow tuffs deposited along with the ashfall tuff (and lava?) that make up most of the member. Fragments are largely endogenetic, but a few sedimentary clasts are also present. Two different types of spots are present in the cryptocrystalline rocks of Ovf_1. Small (0.5mm) ovoid spots probably represent lapilli flattened during compaction, and slightly larger (0.75-1.0 mm) spots prove to be euhedral to subhedral ferroan carbonate rhombs. Sedimentary rocks are rare, and consist of carbonaceous pelite and saccharoidal volcanogenic arenites.

Petrographic examination of Ovf_1 is hampered by its small grain size. Most of the rocks consist of cryptocrystalline aggregates of sutured quartz and feldspar, although there are a few microporphyries with euhedral quartz and feldspar phenocrysts. Chemical analyses of five samples from Ovf_1 show that the rocks are rhyolites and rhyodacites.

Ovf_2 is one of the most distinctive units in the region, and contains several unique rock types. The diagnostic lithology is a massive, fine-grained, dark gray to black rock with abundant euhedral magnetite octahedra. It is associated with beautifully banded iron-formation consisting of alternating red, hematite-rich layers in which there are few magnetite crystals, and black, magnetite-rich layers rich in manganese oxides and hydroxides. Also present are thinly (1 to 2.6 cm) bedded manganiferous siltstone and pelite, and minor ashflow tuffs. Some of the siltstones contain 1.0 mm spherical aggregates of ferroan carbonate that display a strongly developed radial structure. Rock types and textures found in Ovf_2 are remarkably similar to some collected in New Brunswick along the Trans-Canada Highway near Temple, in rocks assigned to the red manganiferous chert member of the Upper Tetagouche

volcanics (Caradocian; Venugopal, 1979). The differences are apparently due to a more complicated diagenetic and metamorphic history for the rocks of the Danforth area.

Ovf_3 comprises the bulk of the felsic volcanic unit, and contains a more varied lithologic assemblage, including a large proportion of volcanogenic sedimentary rock. It also has the coarsest grained volcanic material in Ovf. The differences make it much easier to identify original layering/bedding than in Ovf_1. Rock types identified in Ovf_3 include: cryptocrystalline rhyolites and rhyodacites identical to those in Ovf_1; microporphyries in which 0.5 to 3.0 mm phenocrysts of subhedral feldspars and rounded or embayed quartz are set in a fine-grained to cryptocrystalline matrix; clast-supported conglomerates composed mostly of volcanic fragments; volcanic agglomerate similar to the conglomerate, but with a rhyodacitic matrix; lithic and quartzofeldspathic arenites; coarse-grained pink agglomerate with red chert, red tuff, and gray chert fragments up to 0.5 m in length; small lenses of carbonaceous pelite. In two localities, thin basalt flows (?) have been observed.

Petrographic examination shows that shard outlines are preserved in several of the Ovf_3 fragmental rocks, as are collapsed pumice fragments and lapilli. Scour-and-fill features and flame structures at the Ovf_2/Ovf_3 contact provide the vital facing evidence for the volcanic section, as do distinctive fragments of Ovf_2 incorporated in coarse Ovf_3 agglomerates. The basalts display a well developed primary flow foliation of feldspar laths.

Age and Correlation. No new fossil localities have been found in Ovf, and its Caradocian age is based on graptolites from an outcrop of carbonaceous pelite just north of Danforth (Larrabee and Spencer, 1963) and from the Tolman Hill fossils described above. This age and the lithologic assemblage indicate correlation with the Tetagouche volcanic package of the Miramichi anticlinorium in Canada (Fyffe, 1982), and with volcanic rocks of the Weeksboro-Lunksoos Lake anticlinorium to the northwest.

Ovf records an important episode of pyroclastic eruptive activity accompanied by lava flows, and fits temporally into the mid-Ordovician volcanism described throughout the Northern Appalachians. It differs, however, in that mafic rocks are almost totally absent, whereas basalts comprise significant parts of other Caradocian volcanic tracts in the region—including in the Canadian Miramichi to the northeast.

Prentiss Group. The Baskahegan Lake Formation and Upper Tetagouche Group are overlain, either unconformably or tectonically, by a complex assemblage of clastic rocks described previously by Hopeck (1989) and Ludman (1988), and here grouped informally as the Prentiss Group, after the township in which these rocks are well exposed. The Prentiss Group represents a sedimentary cover sequence eroded from the older Miramichi rocks; clasts easily recognizable as coming from the Baskahegan Lake Formation and the volcanic rocks of Ovf (including Ovf_2) have been identified in the coarser grained conglomerates. Detailed mapping by Hopeck in the eastern part of the Wytopitlock quadrangle has led to much of the new interpretation presented here and has been confirmed by this past summer's mapping.

Mill Priveledge Brook Formation (SOmp). The Mill Priveledge Brook Formation is the oldest unit in the Prentiss Group. It consists for the most part of lithic sandstones and granule conglomerates interbedded with carbonaceous pelite. The sandstones and grits contain quartz, feldspars, and a variety of lithic fragments in sizes ranging from 0.25 mm to about 5 mm. Despite the relatively fine grain sizes, several different kinds of volcanic rock, all familiar from studies of Ovf, are represented in the clast population. Euhedral pyrite cubes up to 1 mm on edge are sparsely distributed in the grits and sandstones, and are not much more abundant in the pelitic interbeds. Slates associated with the coarser rocks are generally carbonaceous, but are not as sooty as those of Or.

Bedding style and thickness are variable. Some beds of both sandstone/grit and slate are massive, with little change in composition or grain size, and reach thicknesses of 75 cm. The slate beds are strongly cleaved, and in many instances it is difficult to identify bedding in slates where the cleavage is well developed. Many beds are graded, however, with coarse grit at the base passing through sandstone into carbonaceous slate tops. These beds range in thickness from 2 cm to nearly 1 m.

Cobble conglomerates with a highly carbonaceous matrix crop out in Baskahegan Stream in the Danforth quadrangle near the stream that drains the Hot Brook lakes, and I tentatively interpret these as a more proximal facies of the Mill Priveledge Brook Formation. The conglomerate is matrix supported and contains moderately well rounded clasts ranging from 2.5 cm to 35 cm in diameter. In addition to the volcanic clasts common to the finer grained grits, sandstone fragments apparently derived from the Baskahegan Lake Formation are also present in this conglomerate.

Age and Correlation. The presence of clasts from Ovf and the Baskahegan Lake Formation at least indicate that the Mill Priveledge Brook rocks are younger than the Caradocian volcanic suite. I have found scraps of graptolitic material in two outcrops, but nothing yet that was worth sending for identification. Mapping by Hopeck in the Wytopitlock and Springfield quadrangles shows that the Mill Priveledge Brook Formation interfingers locally with micrite and sandstone of the Carys Mills Formation. This indicates a Late Ordovician to Early Silurian age for the Mill Priveledge Brook Formation.

It is tempting to correlate rocks of the Mill Priveledge Brook Formation with the Belle Lake Slate of New Brunswick, a similar package of carbonaceous slate and lithic wacke eroded from the Tetagouche volcanic pile (Venugopal, 1978; Fyffe, 1982). Fyffe et al. (1983) report a Caradocian age for the Belle Lake Slate, suggesting that the formation formed by erosion of newly emergent volcanic islands. It is certainly possible for the Mill Priveledge Brook Formation to extend back as far as Caradocian times, but it must have been deposited following Middle Caradocian folding of the Baskahegan Lake and Upper Tetagouche strata.

Sam Rowe Ridge Formation (SOsr). The Mill Priveledge Brook Formation is overlain, apparently conformably, by the medium gray sandstones, siltstones, and non-carbonaceous slates of the Sam Rowe Ridge Formation. Beds are generally thin (2.0-8.0 cm) and well graded with nearly equal amounts of fine-grained sandstone/siltstone and slate. Sandstones of the Sam Rowe Ridge Formation contain few lithic fragments, perhaps because of their grain size, are quartzofeldspathic, and weather gray or chalky buff depending on quartz:feldspar ratio. Most of the formation is relatively fine-grained, suggesting decreased relief in the source area compared with the Mill Priveledge Brook source, or an originally more distal location in the depositional basin. In the vicinity of Tar Ridge in the NE corner of the Springfield quadrangle, graded sets of the Sam Rowe Ridge Formation contain small pyrite and ankerite crystals and weather to a unique limonite-spotted appearance. Neither pyrite nor carbonate are abundant elsewhere in the formation.

New exposures in the northwest part of the Scraggly Lake quadrangle and southwest part of the Danforth quadrangle reveal coarse grit and conglomerate horizons interspersed with the more fine-grained sandstones and siltstones of the Sam Rowe Ridge Formation. Disrupted bedding beneath the conglomerates suggests that the coarse rocks were emplaced as debris flows. In addition to the conglomerates, a few beds of volcanic rock are also found within the Sam Rowe Ridge Formation, but amount to less than 1% of the unit. These are generally orange-brown weathering, fine-grained basaltic flows or tuffs, but some coarser ashflow tuffs have also been observed.

The absence of carbonaceous pelite and grits clearly distinguishes the Sam Rowe Ridge Formation from the underlying Mill Priveledge Brook Formation. The Sam Rowe Ridge Formation is less feldspathic, finer grained, and gray, distinguishing it from the similarly bedded but chalky weathering green rocks of the overlying Ellen Wood Ridge Formation. Another characteristic of the rocks of the Sam Rowe Ridge Formation is that the pelite tops of graded beds are commonly burrowed. Long (7.5—2 cm) relatively straight burrows with one or two branches are found on many bedding planes, and have not been found in the other units of the Prentiss Group.

Age and Correlation. Constraints on the age for the Sam Rowe Ridge Formation are that it must be younger than the Mill Priveledge Brook Formation and older than the Ellen Wood Ridge Formation, and also older than the Daggett Ridge Formation (Silurian-Devonian). A Silurian age is most probable, but I have played it safe by suggesting an Ordovician-Silurian age. Neither the Sam Rowe Ridge nor the Ellen Wood Ridge rocks have close correlatives in the adjacent Canadian Miramichi.

Ellen Wood Ridge Formation (SOew). The Ellen Wood Ridge Formation consists of chalky weathering, greenish gray feldspathic wackes interbedded with greenish gray slates. Bed thicknesses are similar to those of the Sam Rowe Ridge Formation, but are more variable at a single outcrop so that the formation does not seem as rhythmically or regularly bedded as the Sam Rowe Ridge Formation. Grain size is also not as uniform as in the Sam Rowe Ridge Formation, and graded beds commonly have medium to coarse sandstones at their bases. Coarse conglomerates occur at several places in the formation, but appear to be channel deposits rather than reliable stratigraphic markers. These conglomerates contain clasts up to 50 cm long of felsic volcanic and hypabyssal (?) rocks, and a variety of sedimentary fragments. Some of the clasts are reminiscent of wackes of the Baskahegan Lake Formation, but the provenance of others is uncertain. Dense black manganiferous siltstone has been observed in two places along Ellen Wood Ridge, but is rare within the formation.

A thin horizon(s) of tuffaceous felsic volcanic rocks occurs near the uppermost exposed part of the Ellen Wood Ridge Formation. Although fine-grained, these rocks are fragmental and made mostly of endogenous fragments in a tuffaceous matrix.

Age and Correlation. The problems with dating this formation are by now familiar. The Ellen Wood Ridge Formation is unconformably overlain by the Daggett Ridge Formation, and lies conformably above the rocks of the Sam Rowe Ridge Formation; not much more can be said.

Parallels with gross variations in other rocks of the region lead to speculations about possible correlations, ages, and tectonic events. Smyrna Mills sandstone/pelite sequences are similar to those of the Sam Rowe Ridge graded couplets, but are thinner and even finer grained. The transition upward from gray (generally quartzose) to green (quartzofeldspathic) rocks in the Smyrna Mills Formation is mirrored by the Sam Rowe Ridge-Ellen Wood Ridge transition in which, once again, the rocks of the Ellen Wood Ridge Formation are coarser than the green rocks of the Smyrna Mills Formation (Ssmg). I currently favor a model in which the Sam Rowe Ridge Formation and Ellen Wood Ridge Formation represent a more proximal facies of the Smyrna Mills Formation. An eastern source — the Miramichi volcanic islands — is indicated.

Daggett Ridge Formation (DSd). Conglomerates along Jimmey Mountain and Daggett Ridge in the Danforth quadrangle were named the Daggett Ridge Formation by Larrabee and Spencer (1963) and Larrabee et al. (1965), but the outcrop belt that they mapped for this formation contained rocks assigned here to several other units. Their maps show the Daggett Ridge Formation crossing what is now recognized as the North Bancroft fault, and including what I map as the: Carys Mills limestones, Smyrna Mills slate/sandstone sequences, and much of the Prentiss Group. My work last summer and that by Hopeck (pers. commun.) suggest that the Daggett Ridge Formation may interfinger westward with the Mill Priveledge Brook Formation, and possibly also with the Sam Rowe Ridge and Ellen Wood Ridge Formations. An alternate explanation is that the Daggett Ridge Formation lies unconformably above these units. I had favored this latter interpretation in previous reports (Ludman, 1988), but currently feel that a facies relationship fits the outcrop pattern better than an unconformity.

The Daggett Ridge Formation, *sensu novo*, consists of pebble, cobble, and boulder conglomerates interbedded with subor-

dinate amounts of slate, siltstone, and sandstone. It is well exposed along Daggett Ridge, on Jimmey Mountain, in Baskahegan Stream, and along the Canadian Pacific tracks in the Danforth quadrangle, and across the Mattawamkeag River from Bancroft in the Wytopitlock quadrangle. Unless there are interbeds of finer grained rocks, it is usually difficult to identify bedding in the conglomerates. The rocks are strongly cleaved and clasts are flattened parallel to cleavage, particularly near the North Bancroft fault.

Conglomerates in the Daggett Ridge Formation are both clast and matrix-supported. The matrix in both types is green, chlorite-rich, variably calcareous, and generally quite fine-grained. Weathering of calcareous matrix material causes clasts to stand out in relief in many outcrops, and leads to disaggregation in some. Clasts tend to be well rounded in the finer grained types, more angular in the coarsest. Clast size ranges from a few centimeters in the finest grained rocks to over 2 m (yes, meters) in the coarsest rocks exposed on Jimmey Mountain. At one stage of my mapping I found myself measuring strike and dip on what turned out to be a large clast. Bedding within the Daggett Ridge Formation is revealed only by relatively rare interbeds of green, chloritic slate/phyllite, greenish grits and granule conglomerates, and even rarer alternations of green and red sandstones. The finer grained conglomerates were transported and deposited by water; the coarser types were probably debris flows.

Most of the Miramichi stratigraphy is recognizable as clasts in the Daggett Ridge conglomerate. Green quartzofeldspathic wackes of the Baskahegan Lake Formation comprise much of the clast population, as do cryptocrystalline Ovf_1, Ovf_2 iron formation, and coarsely fragmental Ovf_3 tuffs. Boulders of well-bedded sandstone and slate similar to Sam Rowe Ridge and Ellen Wood Ridge lithologies have also been observed. A few clasts of mafic rock are also present, but their textures do not match those seen in Ovm. Carbonaceous pelite clasts have not yet been found, so that Or, OCr, and the Mill Priveledge Brook Formation are apparently not represented. This may, of course, be due to the relatively easy transportation.

Age and Correlation. At last, some fossils! Larrabee and Spencer (1963) reported fossils from an outcrop in Baskahegan Stream, and later described them as "Silurian" (Larrabee et al., 1965). It was not clear from their description whether the fossils (brachiopods) were from the conglomerate matrix or clasts. Lumber roads in the northwest corner of the Danforth quadrangle have exposed a few more fossil localities from which I recovered pieces of brachiopods and rugose corals. These are assuredly from the matrix of the conglomerate, but were not particularly useful as age indicators. A Silurian through Early Devonian age is thus possible for the Daggett Ridge Formation. It is tempting to suggest a Late Silurian age so that the formation could be correlated with other conglomerates in eastern Maine whose deposition during that time is taken as indicating the Salinic Disturbance—and clearly I am tempted enough to mention the possibility. Similar rocks in the Canadian Miramichi near the Maine border are mapped as the Pocowogamis Conglomerate (Lutes, 1979).

Unnamed Conglomerates and Slates (DScgl). Coarse conglomerates interbedded with gray slate and siltstone crop out in the northwest corner of the Scraggly Lake quadrangle and southwest part of the Danforth quadrangle, and are among the most problematic rocks in the study area. In previous years I had lumped them with Ovf as the youngest member of that formation (Ludman, 1985), and recognized that they crosscut contacts between the older members. I now think that they, like the Daggett Ridge Formation, lie unconformably above the Ordovician volcanic section and are probably Silurian to Early Devonian in age.

The conglomerates are finer grained than all but the finest of the Daggett Ridge conglomerates, but still contain clasts up to 15 cm across. Most of the clasts are of volcanic rock types common in Ovf, although some slate chips and sandstone fragments are also present. The matrix of these conglomerates is strikingly different from that of the Daggett Ridge Formation: a tightly interlocking mosaic of quartz, feldspar, and minor calcite in some places, an apparently cherty material in others. I have wondered whether some of these might indeed be volcanic agglomerates, but textures generally suggest a sedimentary origin.

Interbedded slates and siltstones are medium gray and weather gray, suggesting a relatively low feldspar or ash content. They occur in regularly bedded graded sequences 10-20 cm thick, and exhibit little foliation of the fine-grained mica flakes that are present. Cleavage is strongly developed in the slates and passes into a broadly spaced jointing in the siltstones.

This unit seems to have been unusually little deformed, with evidence for only one set of relatively open folds. It is certainly not as tightly folded as rocks of Suite IIIa, and the lack of a foliation parallel to bedding indicates that it has not been subjected to the same intense isoclinal recumbent folding as the volcanic sequence.

*Unnamed Limestone Conglomerate (DSc)***.** This unnamed conglomerate is one of the most distinctive lithologies in the entire study area, but is best exposed only in a small area between U.S. Route 1 and the Pokiok pluton northeast of Danforth. The unit consists of buff-weathering, gray and white limestone and dolostone clasts in a dolomitic to calcareous and argillaceous matrix. In the aureole exposures, the clasts are recrystallized to white marble and the matrix to actinolite-bearing calc-silicate granofels. Clasts range up to 20 cm in diameter and are typically well rounded. The conglomerate seems to become more polymictic toward the southwest, and exposures near Croperly Turn contain felsic volcanic fragments as well as limestone and dolostone. Larrabee et al. (1965) reported that a brachiopod from one of the clasts was of Silurian age, suggesting a Siluro-Devonian age for the conglomerate.

Age and Correlation. There are no exposed limestones or dolostones in the study area that could have been the source for this conglomerate, but the Canterbury Limestone (Silurian-Devonian) of New Brunswick was deposited at about the same time (Venugopal, 1979; Lutes, 1981) and may well be related.

Fredericton Trough

Two important changes have been made in my interpretation of the stratigraphy of the Fredericton trough. One is the discovery by Les Fyffe of pelites of probable Ordovician age exposed as a fault slice within rocks of the Flume Ridge Formation in New Brunswick just east of the international boundary. These have now been traced into the Kellyland and Waite quadrangles, and probably represent part of the basement beneath the Flume Ridge Formation. The second is the recognition that the Pocomoonshine Lake Formation, hitherto assigned to the Cookson Group of the St. Croix terrane, is structurally and stratigraphically more logically part of the Fredericton trough suite and lies below the Digdeguash Formation.

The Fredericton trough terrane in Maine is now thought to contain five distinctly different formations, none of which are fossiliferous. Age constraints for these units are not very tight, and are discussed in detail in Ludman (1990) and Ludman and Hill (1990). As shown in Figure 3, unconformities are inferred to separate several of the formations from one another.

Unnamed Pelitic Rocks (Opx). This newly discovered formation consists for the most part (80%) of medium to light gray slate with subordinate thin siltstone laminae. Layering is generally very thin, commonly 2-5 mm. Contacts between siltstone and pelite layers are sharp in most instances, and grain size in each layer is uniform. I am not certain that this compositional layering is primary, although in some exposures it parallels thicker layers of sandstone. The sandstones form at most 20% of the formation and superficially resemble those of the surrounding Flume Ridge Formation in that they are faintly calcareous. They lack, however, the characteristic detrital muscovite flakes and weather gray rather than the orange-brown color typical of the ankeritic and pyritiferous sandstones of the Flume Ridge Formation. Opx sandstone beds range from 2 to 8 cm in thickness and appear to be randomly interspersed within the dominant slate/siltstone sequence.

Structural and metamorphic features distinguish Opx from the surrounding rocks of the Flume Ridge Formation. Layering in Opx is uniformly gently dipping—almost horizontal in several exposures and never more steeply inclined than 30°. This is in marked contrast with all other rocks exposed within the Fredericton trough, whose attitudes rarely deviate by more than 20° from vertical. Opx displays evidence for three episodes of deformation compared with the single penetrative event recorded in the Flume Ridge, Digdeguash, and Pocomoonshine Lake Formations. The thin laminae are tightly and recumbently folded in structures visible at the scale of a single outcrop; not enough outcrops have been mapped to determine the larger-scale sense of this deformation. Thin sections reveal that a well defined foliation is deformed by the recumbent folds as well as the layering. This foliation is defined by parallel alignment of fine-grained muscovite and biotite flakes. It is invariably parallel to the laminae, suggesting that the layering is a transposed fabric rather than bedding and that at least one episode of folding accompanied by regional metamorphism preceded the recumbent folding event. Gently plunging, open folds further deform the foliation, layering, and recumbent folds in Opx, and correspond to the folding seen throughout the rest of the Fredericton trough.

As cited above, the presence of regional metamorphic biotite immediately distinguishes Opx from the rest of the Fredericton trough—indeed, from any of the strata now known in eastern Maine. Rocks ranging from Cambrian through Early Devonian age in eastern Maine are invariably metamorphosed to conditions of the lower greenschist facies, regardless of their age or the number of deformations they have experienced. Ordovician rocks of the Miramichi anticlinorium in north-central New Brunswick, however, exhibit assemblages indicative of amphibolite facies metamorphism. The fact that Opx contains evidence for two episodes of folding and one of regional metamorphism that is not contained in any of the Fredericton trough strata, coupled with its distribution along a branch of the Norumbega fault zone, suggests that this formation has been uplifted from a position below the Fredericton trough strata. An Ordovician age is tentatively assigned to these pelites, based on a similarity to Op. There is no constraint at all on its maximum age.

Pocomoonshine Lake Formation (SOp). The Pocomoonshine Lake Formation crops out in the Big Lake and Calais quadrangles, and is not shown on the accompanying quadrangle maps. I now consider this formation to form the base of a continuous sequence exposed along the eastern margin of the Fredericton trough that includes the Digdeguash and Flume Ridge Formations. The Pocomoonshine Lake Formation is a sequence of dark gray to black, variably carbonaceous pyritiferous slate interbedded thinly (5 mm-10 cm) with quartzofeldspathic siltstone and sandstone in well graded beds. The sandstones are noncalcareous, and generally fine-grained. The rusty weathered surfaces typical of sulfidic black slates are present in nearly all outcrops. Carbon content varies within the pelites, but nowhere are the rocks as soft and sooty as in the Cookson Group of the adjacent St. Croix belt. Less carbonaceous varieties contain well foliated grains of white mica resulting in a phyllitic sheen absent from the darker types.

The Pocomoonshine Lake Formation is well exposed along the east shore of Pocomoonshine Lake and extends eastward to its fault contact with the Woodland and Kendall Mountain Formations of the Cookson Group. An outcrop exposed in the southeastern cove of Pocomoonshine Lake only at low water contains Pocomoonshine Lake and Digdeguash lithologies, apparently interbedded in normal stratigraphic contact. This suggests that the two are in gradational contact with one another.

Digdeguash Formation (Sd). The Digdeguash Formation is a thick sequence of generally very well graded beds containing lithic granule conglomerates or graywackes at their bases and passing upwards into medium gray slate tops. Turbidite features abound, including complete and several different types of incomplete Bouma sequences. Bottom features such as load casts, scour-and-fill, and flame structures are common, and nearly ev-

ery outcrop provides facing information. The formation consists of a very simple lithologic assemblage, but bed thickness and proportions of psammite and slate vary so widely that the Digdeguash Formation does not have a uniform appearance throughout its outcrop area.

Beds range from 1 cm to about 2.5 m. The grits and wackes weather buff to pale gray depending on feldspar content, and the slates weather dull gray, leading to a distinctive color gradation in well graded beds. Some horizons are homogeneous, and may be entirely composed of slate or grit, but most contain both pelite and a coarser clastic rock intercalated in well graded beds. Original textures are well preserved in low-grade outcrops, and the following clasts are abundant: quartz, plagioclase, felsic volcanic rock, hypabyssal felsic rock (quartz + plagioclase; quartz + perthite; quartz + perthite + muscovite), and polycrystalline quartz. A few muscovite+chlorite+quartz+feldspar clasts have also been observed in the coarsest Digdeguash Formation grits.

In high-grade exposures, the Digdeguash Formation remains distinctive, and small changes in initial bulk composition are heightened by recrystallization. Graded bedding is recognizable and "readable" into the sillimanite zone. The formation is characterized by the development of large chiastolitic andalusite prisms, some as long as 20 cm. The Digdeguash Formation has undergone contact metamorphic anatexis adjacent to the Pocomoonshine gabbro-diorite, and appears there as a migmatite. A melanosome composed of sillimanite-biotite muscovite is injected by a minimum-melt leucosome in, locally, a swirled irregular pattern or a gneissic banding.

Flume Ridge Formation (DSf). The Flume Ridge Formation is one of the most extensive in the map area, second only to the Madrid Formation of the central Maine sequence. In chlorite grade exposures, the Flume Ridge Formation consists of variably, but almost always at least slightly calcareous, uniformly fine-grained quartzofeldspathic wackes interbedded with calcareous and non-calcareous siltstone and only small amounts of non-calcareous pelite. Finely disseminated pyrite and/or ankerite grains weather to give the formation a distinctive appearance: a punky orange-brown weathering rind surrounding a light to medium gray fresh interior. The wackes are also characterized by large (easily visible with the unaided eye) detrital muscovite flakes.

In the biotite zone and higher grades of metamorphism, the Flume Ridge Formation is converted to a dense, purplish gray, biotitic quartz-feldspar granofels with more calcareous layers becoming calc-silicate granofels. Alternation of calc-silicate and quartz-feldspar-biotite layers gives the formation a distinctive "zebra-striped" appearance. A ribbed weathered surface is common in both high- and low-grade exposures.

Age and Correlation of Fredericton Trough Rocks. Rocks of the Flume Ridge Formation are similar in lithology and weathered appearance to those of the Madrid Formation, but are commonly thinner bedded. They are also similar to the calcareous rocks of the Hartin Formation, but lack the associated limestone conglomerates. They can be traced, almost continuously, into rocks mapped in central Maine as the Late Ordovician-Early Silurian Vassalboro Formation (Osberg, 1980), and in south central Maine as the Bucksport Formation (Osberg et al., 1985). The Digdeguash Formation, in contrast, is restricted to the eastern Maine-southwestern New Brunswick area.

Unnamed Red Conglomerates, Mudstones, Sandstones (CDm). Small slivers of red, unmetamorphosed conglomerate, sandstone, and minor mudstone are exposed in the Fredericton trough along the traces of some of the individual members of the Norumbega fault zone. These include cobble conglomerates, massive arkosic and lithic sandstones, cross-bedded sandstones, and finely laminated mudstones. The most abundant clasts are felsic volcanic fragments and green wackes typical of the Baskahegan Lake Formation. Other clasts appear to have been derived from a slightly older, also unmetamorphosed set of redbeds. None of the clasts appear to have been derived from the Flume Ridge Formation within which the redbeds are now located.

These red continental rocks are interpreted as post-Acadian molasse deposits derived from uplifted Miramichi strata, and may have formed a more extensive blanket before late dip-slip motion on the Norumbega fault system and subsequent erosion preserved them in their present position.

St. Croix Belt

The St. Croix belt stratigraphy has undergone two important changes: (1) the Pocomoonshine Lake Formation has been reassigned to the Fredericton trough, leaving only three formations in the Cookson Group; and, (2) graptolites found by Fyffe in the Kendall Mountain Formation prove that unit to be Middle Caradocian in age and thus younger than the Calais Formation rather than older as I indicated in previous reports (e.g. Ludman, 1987). This, in turn, required inversion of the entire Cookson Group sequence to that shown in Figure 3, above.

Calais Formation (OCc). The Calais Formation is now known to be the oldest formation in the Cookson Group. It consists of three distinctive members, best exposed in the St. Croix River at Calais-St. Stephen. The uppermost of the three is a very sooty, black, highly carbonaceous slate/phyllite with abundant pyrite cubes but very little interbedded sandstone or siltstone. It is traceable to Cookson Island, type locality of the former Cookson Formation, but with elevation of the name Cookson to group status, the new name had to be coined. Contact metamorphism in the type locality has produced many round cordieritie porphyroblasts and a few small andalusite prisms.

The middle member is a collection of metabasalts including well pillowed and massive varieties, all of which are tholeiitic. Despite metamorphic recrystallization to actinolite-plagioclase greenstones, concentric and radial pillow structures are preserved. Sedimentary materials between the pillows or massive basalt layers are black shales comparable to those of the upper member.

The lowest member is a thinly layered assemblage of pink coticule and biotite-quartz-feldspar granofels. There is some doubt about whether this member actually belongs with the others because of (1) a gap in the otherwise nearly continuous section and (2) disruption of the layering suggestive of faulting.

Woodland Formation (Ow). The Woodland Formation contains nearly equal amounts of quartzofeldspathic wacke interbedded in well graded sets with both carbonaceous and non-carbonaceous pelites. Pyrite is present in both psammites and pelites, and the formation accordingly exhibits a typical rusty weathering appearance. The wackes are of more uniform grain size than the arenites of the underlying Kendall Mountain Formation and are better graded. Sandstone/pelite couplets range from 2 mm to 50 cm, but most are between 2 and 20 cm. Soft-sediment slumping and disruption of bedding have been identified in several outcrops of the Woodland Formation. Although the vast majority of outcrops of the Woodland Formation is non-calcareous, one horizon of calc-silicate (garnet-diopside-actinolite-calcite) was discovered near the type locality.

Kendall Mountain Formation (Ok). The Kendall Mountain Formation is an assemblage of several kinds of sandstone with subordinate pelite and a single(?) horizon of felsic tuff near its base. The upper portion of the formation is mostly medium bedded (10-50 cm) quartz and quartz-feldspar arenite associated with thin siltstone/black shale couplets similar to those of the underlying Pocomoonshine Lake Formation. Spectacular soft-sediment structures, including ball-and-pillow features are abundant in this portion. A few 1-2 m thick beds of lithic pebble conglomerates (channel deposits?) occur near the highest exposed part of the formation, and contain a variety of felsic volcanic rock fragments.

The middle part of the unit is almost entirely composed of massive quartz arenites and quartzofeldspathic arenites in beds up to 2 m thick. Homogeneous grain size and composition make it difficult to identify bedding in many instances. Beds are most clearly defined by sparse layers of black, sooty carbonaceous shale/slate up to 1 m thick. It was one of these beds that yielded the fossils in New Brunswick.

The lower part of the Kendall Mountain Formation is similar to the upper, but its sandstones have a more argillaceous matrix than that of the lower arenites. The Kendall Mountain Formation passes downward into the Woodland Formation with an increase in amount of argillaceous material in the sandstones. Chalky white weathering cryptocrystalline felsic volcanic rocks occur in a 10 m thick horizon near the top of the formation. Preliminary chemical studies indicate that these rocks are rhyodacites, and although original textures are not well preserved, a few shards and lapilli have been identified, indicating a tuffaceous origin for these volcanic rocks.

DEFORMATION

Rocks of eastern Maine record a lengthy and complex deformation history, one that differs somewhat from tract to tract. Penetrative folding events ranging from Cambro-Ordovician(?) through Early Devonian have been identified; the pre-Silurian events are now recognized in the Miramichi and St. Croix belts, and in Opx within the Fredericton trough as well. Faults are much more abundant and significant than thought by previous workers. Their classification and timing are indicated in Figure 4.

Pre-Silurian Deformation

Miramichi Terrane. Rocks of the Miramichi terrane have been subjected to at least one and probably two episodes of folding and some faulting prior to deposition of the Prentiss Group. Evidence for these events is found in the Baskahegan Lake Formation, the Upper Tetagouche Group, and in clasts in Prentiss Group conglomerates that exhibit cleavages and mylonitic fabric distinctly different from those of the Prentiss Group itself.

Rocks of Ovf have been recumbently folded prior to deposition of the Prentiss Group. This is indicated by the complex map pattern shown in the Danforth quadrangle (modified after Sayres, 1986). The map pattern of the Baskahegan Lake Formation and of the pre-Ovf units of the Upper Tetagouche Group suggests that these too were involved in the early folding. The early recumbent folds were in turn folded by the same upright structures that deform Silurian and Early Devonian rocks. The age of recumbent folding of the Tetagouche Group is bracketed by the ages of deformed units and those unaffected by this event. Ovf is apparently the youngest formation thus deformed, and is of Caradocian (late Middle Ordovician) age. The Prentiss Group, whose oldest formation interfingers with the Ashgillian (Upper Ordovician) to Llandoverian (Lower Silurian) Carys Mills Formation, is not affected by this episode of folding. The recumbent folding is thus tightly constrained between Caradocian and Ashgillian times, and is here probably a middle to late Caradocian event.

Outcrops of the Baskahegan Lake Formation commonly contain evidence for several deformations, including multiple cleavages, folded cleavages, etc. It is difficult to sort out the exact number of events because some, such as late-stage faulting, produced only local effects, but the impression is that this formation has been more severely affected by folding than any other in eastern Maine. I have previously thought, and still do, that these rocks may have been affected by a deformation during Late Cambrian or Early Ordovician times—something comparable to the Penobscot event described by Neuman (1967) in the correlative Grand Pitch Formation of the Weeksboro-Lunksoos Lake tract.

Fredericton Trough. The recumbent folding of Opx has already been described above. The proximity of Ovf to the Miramichi terrane, the comparable style of its recumbent folding, and the similarity of Opx to Op lead me to postulate (albeit tentatively) a middle Caradocian age for the folding of Opx.

St. Croix Terrane. Rocks of the St. Croix terrane have also been recumbently folded prior to deposition of Silurian strata.

The entire Cookson Group (*sensu novo*) has been deformed into a series of large west-vergent recumbent folds (see Ludman, 1990; Ludman and Hill, 1990). The Calais Formation is the oldest unit in the Cookson Group, and is of Tremadocian (Earliest Ordovician) age. At Oak Bay, New Brunswick, it is overlain unconformably by the Oak Bay Formation which passes upward rapidly into the Waweig Formation. The Waweig Formation of Pridolian age (Uppermost Silurian) and the Oak Bay Formation are essentially a basal conglomerate. The youngest unit in the Cookson Group, the Kendall Mountain Formation, has been dated as Middle Caradocian as described above. Recumbent folding of the St. Croix terrane is therefore bracketed between Middle Caradocian and Pridolian.

Although it is tempting to assign this early event to the same forces that deformed the Miramichi suites in Caradocian times, there is no other firm evidence to link the two terranes during Ordovician times, and such correlation would be dangerous. At this time, I suggest that the two terranes were folded at similar but not identical times, and in different tectonic settings. Middle Caradocian deformation of the Miramichi terrane was part of the Taconian accretion of an ancient island arc system to the North American continent (see Hopeck et al., in review). The St. Croix terrane was probably part of a separate Avalonian continent at that time, separated from the Miramichi terrane (and ancestral North America) by a small ocean basin (the Fredericton trough). Pre-Acadian recumbent folding of the St. Croix may mark the onset of subduction of this ocean basin, or may indicate a sweeping up of small microplates by Avalon (see Brock, in prep.).

Silurian and Early Devonian Deformation

Acadian folding and faulting affected the entire study area during Late Silurian (?) through Early Devonian times. Acadian structures include, in interpreted sequence of events: (1) eastward thrusting of the central Maine and Aroostook-Matapedia tracts; (2) regional scale upright folding that affected the entire study area; (3) westward thrusting of the St. Croix terrane over the eastern margin of the Fredericton trough; (4) normal and then high-angle reverse faulting along north-trending faults such as the Stetson Mountain, North Bancroft, and South Princeton-Crawford; (5) local eastward back thrusting of the Fredericton trough over part of the St. Croix belt; (6) sinistral strike-slip fault reactivation of the South Princeton-Crawford fault zone.

The Acadian orogeny is interpreted here as resulting from the accretion of the Avalon continental block to North America. The complex faulting that immediately followed Acadian folding is thought to have been the result of transtensional and

AGE	OROGENY		STYLE	AREA AFFECTED
POST-MESOZOIC(?)	.....		High angle, dip-slip offset	Reactivate Norumbega Fault Zone
POST-EARLY DEVONIAN	Alleghanian? Palisades?		*[CLASS VI FAULTING]* NW-trending Sinistral strike-slip faults	All of Maine
	"NORUMBEGA"		*[CLASS V FAULTING]* Dextral strike-slip faults	Norumbega Fault Zone
DEVONIAN	ACADIAN	Late	*[CLASS IV FAULTING]* N-trending high-angle reverse faults later reactivated as strike-slip faults	All of eastern Maine
		Middle	*[CLASS IIIA FAULTING]* East-directed thrusting	St. Croix, Fredericton
			[CLASS III FAULTING] West-directed thrusting Upright tight to isoclinal folding	St. Croix, Fredericton All of eastern Maine
		Early	*[CLASS II FAULTING]* East-directed thrusting	Central Maine, Aroostook-Matapedia, Miramichi
SILURIAN	.....		*[CLASS I FAULTING]* Syndepositional normal faulting	Miramichi, Aroostook-Matapedia
ORDOVICIAN	"Taconian"		Recumbent isoclinal folding	Miramichi, St. Croix

Figure 4. Timing of faulting in eastern Maine.

transpressional forces caused by continuing interaction between Avalon and North America following their initial collision.

Timing of the Acadian event is clear-cut in some instances, but much less certain in others. In the coastal volcanic belt, it occurred after eruption of the Gedinnian (Early Devonian) Eastport Formation and before deposition of the Late Devonian Perry Formation. Similar timing is indicated in the Kearsarge-central Maine synclinorium. Recent reports of Silurian plutons that intrude folds previously attributed to the Acadian orogeny in New Brunswick (Bevier and Whalen, 1990) and Maine (Jurinski, pers. commun.) suggest that early Acadian events may have begun in the Late Silurian.

Post-Early Acadian Deformation

The Norumbega fault zone is a major structural feature of the study area, and of northern New England. It cuts plutons in central coastal Maine and eastern Maine that are of known Early Devonian age, and juxtaposes post-Acadian molasse deposits (CDm) against Acadian-deformed strata of the Flume Ridge Formation. Two significantly different stages of motion are now recognized on the Norumbega fault zone in eastern Maine. The first stage was one of dextral strike-slip movement, the second of dip-slip offset.

It has been nearly impossible to determine the minimum ages of these different stages because of the absence of any rocks younger than Pennsylvanian (in New Brunswick) affected by the faulting. Seismic reflection profiling (see below) has provided an excellent image of the two westernmost branches of the Norumbega fault zone south of the Bottle Lake pluton, and given a new view of the history of the faults. The early dextral separation was probably a continuing adjustment to the collision between Avalon and North America. Fabrics in the plutons suggest that this stage of the faulting may have begun prior to emplacement and continued through the final stages of cooling of the bodies to temperatures at which they behaved brittlely. This stage may have begun in the Early Devonian and continued through the Carboniferous.

I now believe that the dip-slip offset may have been much later. Figure 5 is a copy of the reflection profile across the Bottle Lake pluton and Norumbega fault zone (Figure 5a is a location map for the reflection traverse). The Norumbega fault zone clearly cuts the entire crust, offsetting the Moho by as much as .5 seconds, corresponding to about 1.5 km of vertical separation. Stewart (1989) suggests that the Moho beneath the Northern Appalachians is a Mesozoic feature formed by extension leading to the opening of the modern Atlantic Ocean. If so, the implication is that the late stage motion on the Norumbega postdates the formation of this Moho, and must be Mesozoic or younger!

There are other signs of very late faulting in the region. NW-trending faults are found in all terranes. These are sinistral strike-slip faults that rarely cause enough motion to show offset of mapped contacts. They affect all rock units, all plutons, and all structures with the possible exception of the Norumbega fault zone. There is little constraint on the ages of these faults; the cluster of earthquake epicenters along the NW-trending lineament that runs up the St. Croix River from Passamaquoddy Bay suggests that some of that deformation is still going on.

SEISMIC REFLECTION RESULTS

One of the most exciting recent advances in the region has been the completion of a seismic reflection line across the Bottle Lake pluton and Norumbega fault zone. The line was run by John Costain and Cahit Çoruh of Virginia Polytechnic Institute (Costain et al., 1990) and was accompanied by gravity analysis of the region by William Doll of Colby College (Doll and Potts, 1990). I have been collaborating with these geophysicists for the past three years in an attempt to fit the best possible interpretation to the results of the traverse. Figure 5a shows the location of the seismic line and Figure 5b is a much-reduced line drawing showing the most prominent reflectors.

A description of the methods used to process the data and discussion of the interpretation of the results is a paper in itself, and is being written by our research group. I have indicated some of our conclusions on Figure 5b and will briefly list them here.

(1) The floor of the Bottle Lake pluton is at approximately 3.5 km beneath the ground surface. The extremely clear record of the entire crust beneath the pluton precludes any deeper extension of the body.

(2) The upper crust between 2 and 4 seconds (6.4-12.8 km) depth is very strongly reflective. In the southern Appalachians this type of shallow reflectivity has been interpreted to indicate the presence of major detachments, generally large-scale thrust faults. One possible thrust duplex is indicated on Figure 5b, and a northwesterly vergence direction is inferred for it.

(3) An east-vergent reverse fault appears to cut the Bottle Lake pluton. This comes to the surface along the projection of the North Bancroft fault, and is interpreted as a very late stage reactivation of that fault.

(4) A change in reflective character of the lower crust, from about 8 seconds depth on the left (north) side of the profile to 4.7 seconds on the right, is tentatively interpreted as marking the subsurface extent of Avalonian crust beneath the Fredericton trough, Miramichi terrane, and on into the Aroostook-Matapedia terrane. This boundary projects to the surface at the western edge of the St. Croix terrane, supporting this interpretation.

(5) The two branches of the Norumbega fault zone imaged by our line appear to cut the entire crust and offset the Moho as shown.

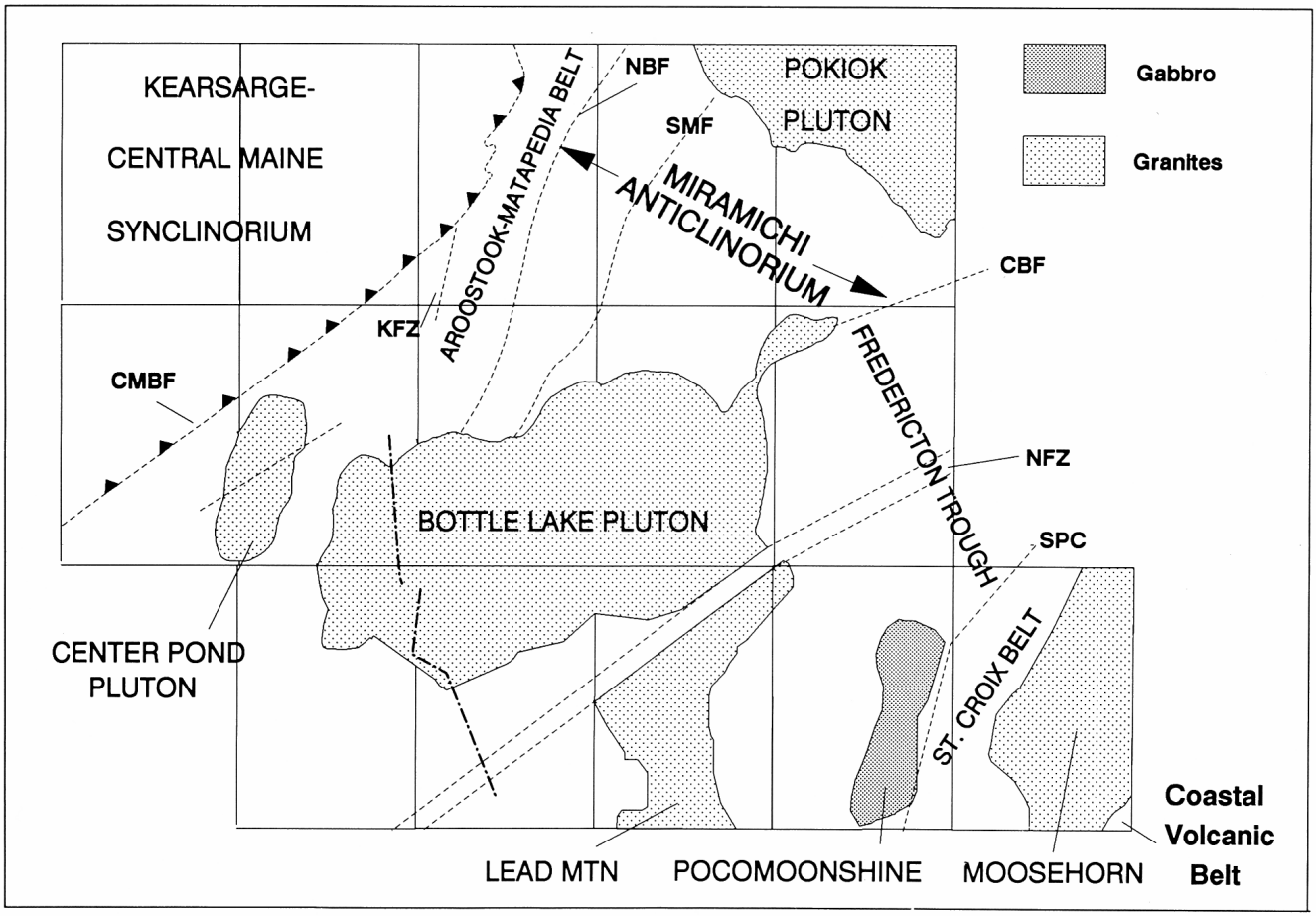

Figure 5a: Location of Bottle Lake seismic line. CBF - Codyville - Bamford Brook fault, CMBF - central Maine boundary fault, KFZ - Kingman fault zone, NBF - North Bancroft fault, NFZ - Norumbega fault zone, SMF - Stetson Mountain fault, SPC - South Princeton - Crawford fault zone.

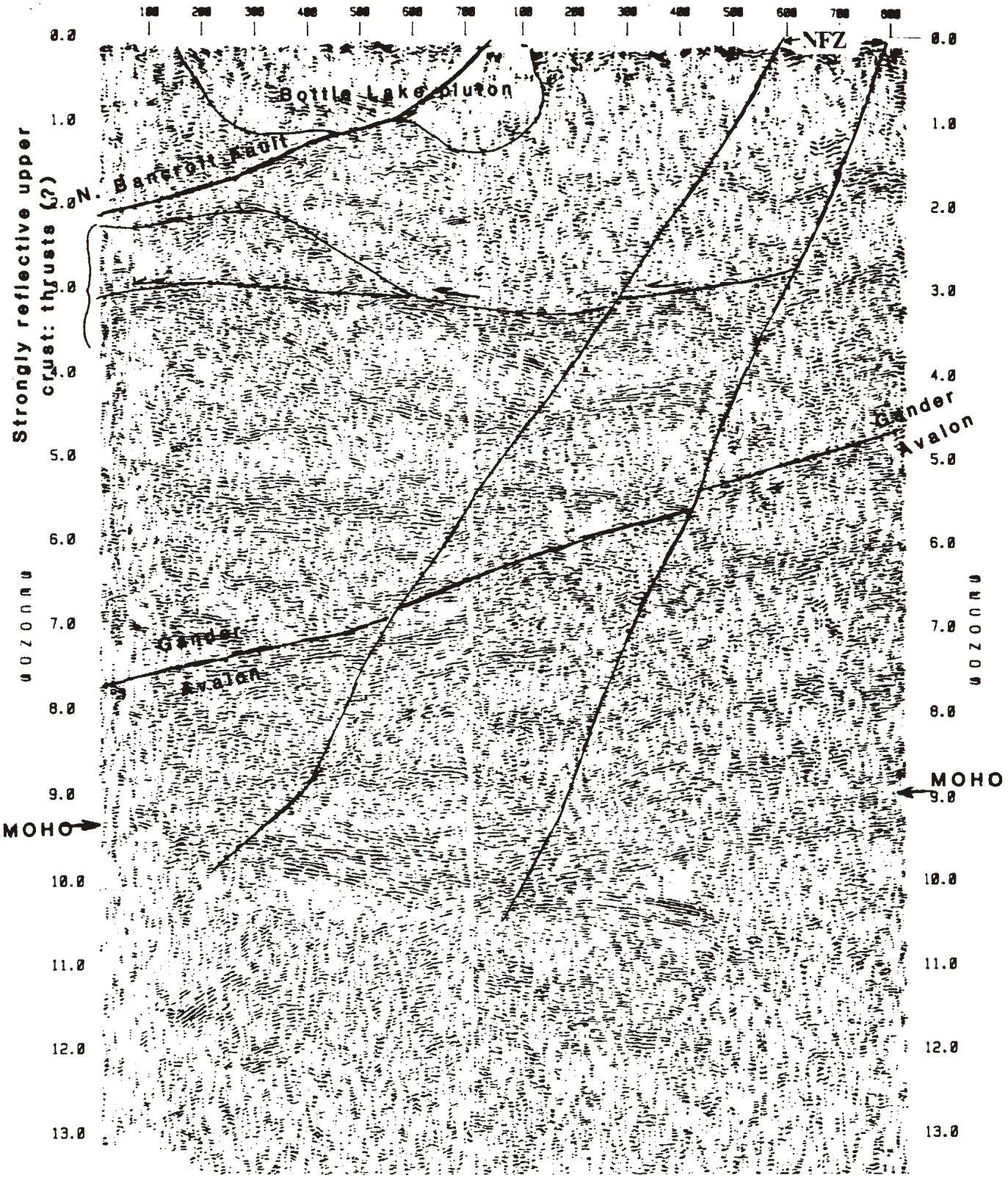

Figure 5b. Seismic reflection profile across Bottle Lake pluton. (Automatic Line Drawing of unmigrated reflection profile.) NFZ = Norumbega fault zone.

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BEDROCK GEOLOGY
of the
Danforth, Scraggly Lake, Forest, Waite, Vanceboro, and Kellyland 15′ Quadrangles, Maine

by

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DEPARTMENT OF CONSERVATION
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SCALE 1: 62,500

EXPLANATION

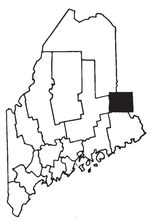
PLUTONIC ROCKS

- **Dg** — Granite, granodiorite, and quartz monzonite
- **Dgb** — Bottle Lake Complex, undivided
- **Dgp** — Pokiok pluton

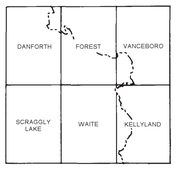
- **CDm** — **Unnamed redbeds** - Red cobble conglomerate, arkose, siltstone, mudstone
- **DSc** — **Unnamed conglomerate** - Limestone conglomerate
- **DScgl** — **Unnamed conglomerate** - Polymictic conglomerate, largely volcanigenic; siltstone, slate
- **DSd** — **Daggett Ridge Formation** - Polymictic pebble to boulder conglomerate with chlorite-muscovite-calcite matrix; minor slate, sandstone
- **DSf** — **Flume Ridge Formation** - Orange-brown weathering, gray calcareous quartz-feldspar wacke with prominent detrital muscovite; siltstone; very minor slate
- **SOsm** — **Smyrna Mills Formation** - Gray slate thinly interbedded with siltstone, sandstone
- **SOew** — **Ellen Wood Ridge Formation** - Greenish quartz-feldspar wacke and slate, minor conglomerate, felsic tuff
- **SOsr** — **Sam Rowe Ridge Formation** - Gray sandstone, siltstone, and slate; commonly burrowed
- **SOmp** — **Mill Priveledge Brook Formation** - Polymictic granule to pebble conglomerate interbedded with carbonaceous slate
- **SOcm** — **Carys Mills Formation** - Gray fine-grained limestone and dolomitic limestone; calcareous slate
- **SOp** — **Pocomoonshine Lake Formation** - Thinly interbedded carbonaceous and non-carbonaceous slate and siltstone
- **Op** — **Unnamed pelite** - Gray slate with thin beds of sandstone, siltstone
- **Opx** — **Unnamed pelite**
- **Or** — **Unnamed rusty-weathering rocks** - Sulfidic black, carbonaceous slate with quartzose sandstone
- **Ovf** — **Unnamed felsic volcanic rocks**
  - **Ovf1** — Cryptocrystalline tuff
  - **Ovf2** — Manganese-rich rock; iron formation
  - **Ovf3** — Coarse ashflow tuff, with volcaniclastic sedimentary rock
- **Ovm** — **Unnamed metabasalt** - Fine grained metabasalt with some porphyritic varieties
- **OЄr** — **Unnamed slate and sandstone** - Rusty weathering slate, sandstone
- **OЄbl** — **Baskahegan Lake Formation**
  - **OЄblg** — Green quartz-feldspar wacke and subordinate slate
  - **OЄblm** — Red-maroon varieties of same

SYMBOLS

- Lithologic contact, observered, covered
- Fault, observed, inferred
- Thrust fault, observed, inferred
- Shear zone
- Bedding, inclined, vertical, overturned (dot indicates facing direction)
- Trend of bedding in pavement outcrop
- Cleavage, inclined, vertical
- Bearing and plunge of minor fold
- Outcrop



Location Map



Quadrangle Location