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Bedrock Geology of the Big Lake 15' Quadrangle, Maine

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INTRODUCTION

Eastern and southeastern Maine are underlain by northeast-trending lithotectonic tracts, each of which contains a distinctive suite of rocks (Fig. 1). The Big Lake quadrangle straddles the boundary between two of these tracts—the Fredericton trough and St. Croix belt—and contains important information about their evolution and the nature of their contact. On a regional scale, the St. Croix belt is the westernmost component of the coastal lithotectonic belt (Osberg et al., 1985), a complex region containing several tracts often described as "mini-terranes." Rocks of the Big Lake quadrangle provide insights into regional stratigraphy as well as the nature of accretion during the Early Paleozoic.

Location and Topography

The Big Lake quadrangle is located in Washington County between 45° 00 and 45° 15 north latitude and 67° 30 and 67°45 west longitude. The area has been intensely glaciated and consists of a few prominent hills and ridges that rise as much as 600 feet above gently rolling, till-covered lowlands. Resistant bedrock supports the highest hills, with plutonic rocks beneath Amazon and Pocomoonshine Mountains, and high grade hornfelses beneath Harmon Mountain, Hawkins, Huntley, and Seavey Ridges. The lowest elevations in the quadrangle are occupied by several lakes and extensive swamps.

Bedrock exposures comprise less than 1% of the total area of the Big Lake quadrangle and are most numerous on glacially scoured hilltops and along lake shores. The shores of Pocomoonshine Lake, in particular, provide excellent exposures of both metasedimentary and plutonic rocks. Construction of lumber roads has uncovered many new outcrops, most commonly at the crests of low hills where the till cover is relatively thin. Most of such outcrops are two-dimensional "pavement" exposures.

The quadrangle is sparsely populated, with most people concentrated in the town of Princeton in the northeast corner, in

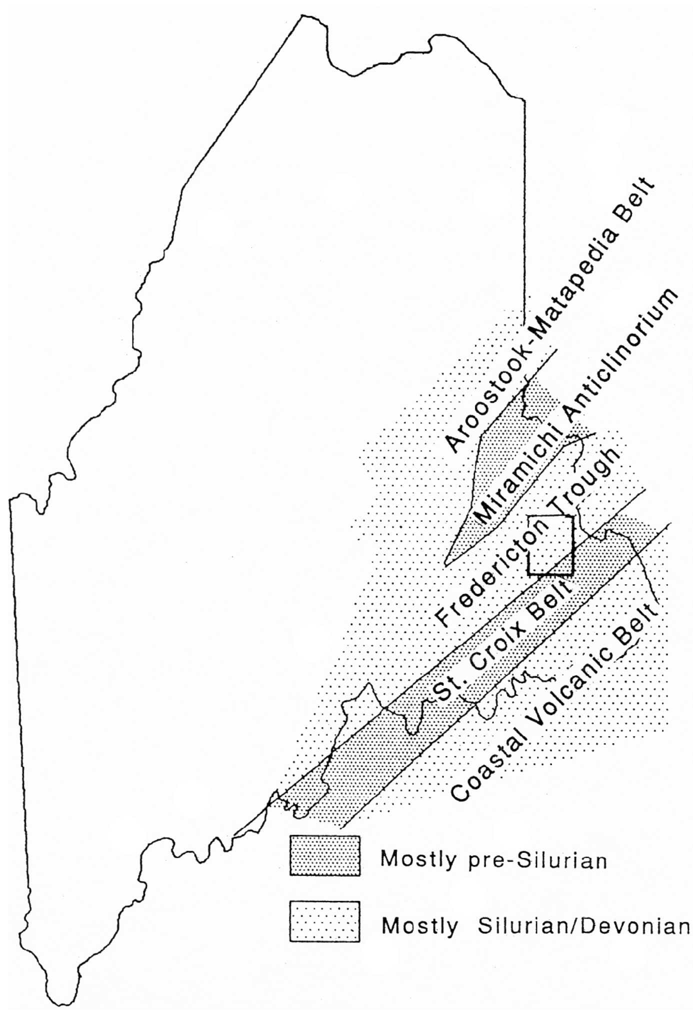

Figure 1. Tectonic setting of the Big Lake quadrangle in southeastern Maine.

the Passamaquoddy Indian settlement at Peter Dana Point, and in the small hamlets of Crawford, South Princeton, and West Princeton. Access to the area is provided by U.S. Route 1, Maine Route 9, paved and unpaved county roads, and a complex network of lumber roads, winter roads, and skidder trails built by the Georgia-Pacific Company.

Previous Work

Alcock (1946) divided the stratified rocks of nearby Charlotte County, New Brunswick, into the "Pale Argillite and Dark Argillite Divisions of the Charlotte Group," and his map units were adopted in the Big Lake area by American geologists. Larrabee (1964) and Larrabee and others (1965) carried out the only previous structural and stratigraphic study of the quadrangle, and used Alcock's interpretation of stratigraphic relationships. They introduced the name Kellyland Formation as a substitute for the informal term "Pale Argillite" and inferred an angular unconformity between the Kellyland Formation and the Dark Argillite. Larrabee (1964) recognized a large mafic body, the Pocomoonshine gabbro-diorite, and several smaller felsic plutons in the quadrangle, and mapped contact aureoles around them.

Amos (1963), mapping in the Calais area to the east, and Westerman (1972) in the Big Lake and Wesley quadrangles, focused on the plutonic rocks of the region, using either Alcock's or Larrabee's nomenclature for the stratified rocks. Westerman mapped the Pocomoonshine gabbro-diorite in detail, delineated several lithologic zones in it, and suggested a differentiation scheme for its evolution. He also mapped mineral zones in the contact aureole around the body and identified faults at its eastern margin.

Ludman (1974) mapped three units of formation rank in the quadrangle and correlated them with the revised stratigraphy of southwestern New Brunswick proposed by Ruitenberg (1967). Ruitenberg and Ludman (1978) suggested abandoning the names previously used for the stratified rocks since none of those units corresponded with any of the newly-described formations. Ludman (1977) and Ruitenberg and Ludman (1978) inferred a complex tectonic contact rather than an unconformity between the Fredericton trough and St. Croix belt. Further refinements in the stratigraphy and structure of the area have been made by Ludman (1975, 1977, 1978, 1985a, 1987), Senz (1978) and Senz and Ludman (1978). Recent mapping in New Brunswick by Fyffe (pers. commun., 1989) has led to discovery of fossils that help date the strata in the Big Lake quadrangle and require a revision of both the sequence and age recently reported by Ludman (1987).

Acknowledgments

I have been mapping in eastern Maine since 1974, with field support from the Maine Geological Survey under the supervision of State Geologists Robert Doyle and Walter Anderson. Field and laboratory work have also been supported by NSF Grant EAR-780329, PSC-CUNY Grant 12315, and several grants from the Smith College Committee on Aid to Faculty Scholarship. I have been ably assisted in the field by several former students: James DeMartinis, Dolores Garcia, Frieda Malcolm, Anne Pickering, Maria Terres, and Sarah Walen. I am grateful to the Georgia-Pacific Company for providing up-to-date maps and aerial photographs of its operations roads, for allowing access to restricted locations, and for its cooperation in all phases of the research. I am indebted to many colleagues for lively discussions concerning the rocks of the region, and wish to thank Les Fyffe, Olcott Gates, Richard Gilman, George Pajari, Nick Rast, A. A. Ruitenberg, Steven McCutcheon, Peter Stringer, Woodrow Thompson, and David Westerman for their counsel.

STRATIGRAPHY

The stratified rocks have been tightly folded, and in some instances refolded, intruded by mafic and felsic plutons, and subjected to several episodes of faulting. As a result, it is difficult to unravel the internal stratigraphy of some units, and estimates of their thickness can only be rough approximations. Regional metamorphic grade in the area is very low, generally chlorite zone (lower greenschist facies), but contact metamorphism has been both severe and widespread around the mafic bodies. Each of the formations can be traced from the chlorite zone into the sillimanite-potassic feldspar zone in the Big Lake-Calais area, but primary sedimentary features are preserved in all but the innermost parts of the contact aureoles. Fossils have not been found in rocks of the Big Lake quadrangle. Ages for the pre-Silurian strata are based on graptolites found in rocks of New Brunswick continuous with those of the Big Lake quadrangle as reported by Ruitenberg (1967), Ruitenberg and Ludman (1978), and Fyffe (pers. commun., 1989).

Five formations are now recognized in the Big Lake quadrangle instead of the two described by earlier workers. Poor outcrop control and apparently different contact relationships between some units in Maine and New Brunswick prevent precise definition of the stratigraphic sequence. The section proposed here (Fig. 2, Plate I) is inverted from that which I described earlier (Ludman, 1987) because of new faunal age data provided by Les Fyffe and John Riva (pers. commun., 1989).

The Flume Ridge, Digdeguash, and Pocomoonshine Lake Formations comprise the Fredericton trough sequence in this area, while the St. Croix belt contains the Cookson Group, consisting of the Calais, Woodland, and Kendall Mountain Formations. The Pocomoonshine Lake Formation was previously described as part of the Cookson Group (Ludman, 1985a, 1987); its inclusion here in the Fredericton trough sequence is based on a reinterpretation of structural data along the St. Croix/Fredericton contact. The Calais Formation does not crop out in the Big Lake quadrangle, but is included here for completeness.

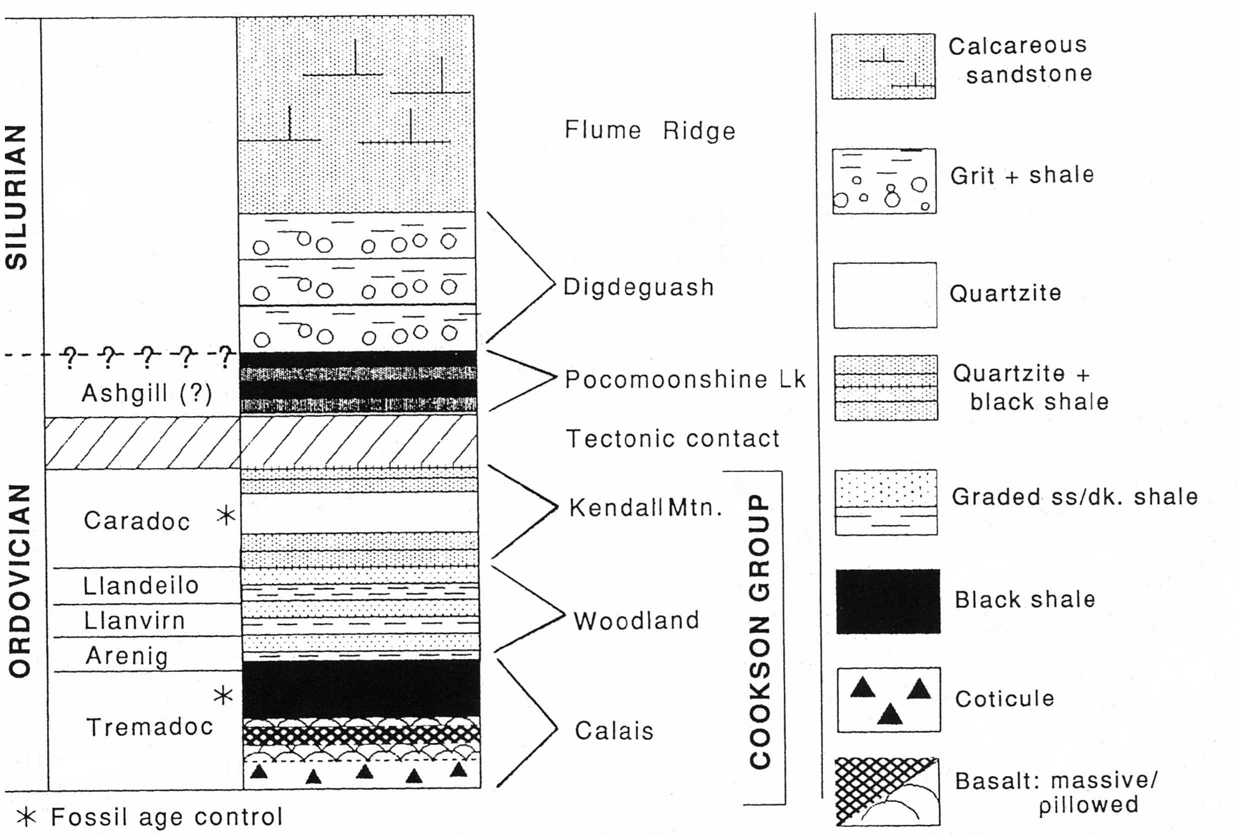

Figure 2. Stratigraphy of the Big Lake quadrangle.

Rocks of the St. Croix Belt: The Cookson Group

Rocks of the St. Croix belt had previously been mapped as the Cookson Formation, but with elevation of the unit to group status, members described earlier have been formally named as formations (Ludman, 1987). The Cookson Group consists of three formations, two of which crop out in the Big Lake quadrangle. All three are sulfidic and rusty weathering to some extent, contain at least minor amounts of carbonaceous pelite, and were presumably deposited in anoxic conditions. Fossils in New Brunswick show that the Cookson Group extends from the Tremadocian (Earliest Ordovician) to the Middle Caradocian (lower Upper Ordovician).

Calais Formation (OCc). The term Calais Formation has been applied to rocks in the Calais quadrangle that lie between outcrops of sandstones of the Woodland Formation and those of the Silurian Oak Bay Formation (Ludman, 1987). These rocks, dominantly black, highly sooty hornfelses, are particularly well exposed in the St. Croix River at Calais and can be traced directly into the type locality of the former Cookson Formation on Cookson Island in Oak Bay, New Brunswick. The Calais Formation is not exposed in the Big Lake quadrangle, but crops out along new lumber roads a few miles to the east in the southwest corner of the Calais quadrangle.

The Calais Formation is divided into three members. The lowest is a distinctive coticule section that lies adjacent to the Oak Bay Formation. Thin bands of garnet-quartz coticule occur within a quartzofeldspathic wacke host and are thinned and fragmented by faulting associated with the Oak Bay contact.

The middle member consists of pillowed and massive basalts, locally and rarely interbedded with black shale. These rocks are well exposed in the St. Croix River at Calais and St. Stephen, and in the southwestern corner of the Calais quadrangle where basaltic tuffs are also intercalated. Contact metamorphism in both areas has converted the basalts to plagioclase-actinolite hornfels, but primary flow features are preserved in many instances. These include radial and concentric pillow structures, vesicle and vug fillings, and even sodium-enrichment of pillow rims. Pillow shapes define reversals of facing within this member, indicating otherwise unseen folds.

The uppermost member consists almost entirely of black, highly graphitic pyritiferous slate with subordinate beds of quartzofeldspathic wacke. The sandstones amount to only about 15% of the formation as a whole and are commonly 2.5 to 10 cm thick. Pelites of the Pocomoonshine Lake Formation are similar to those of the Calais Formation, but are intercalated in graded beds with much more abundant sandstone and siltstone, show finely delineated bedding features, and are less carbonaceous.

The contact between the Calais and Woodland Formations is sharp, and has been located to within a few meters in the St. Croix River at Calais, where sandstones and pelites of the Woodland Formation pass abruptly into black shales of the Calais Formation with only a small covered interval. There is no evidence of faulting, and a conformable contact is inferred. The contact between the Calais and Oak Bay Formations is also covered. On Cookson Island, just a few miles to the northeast, the coticule and basalt members are not present and the contact is an unconformity between black shales of the Calais Formation and conglomerates of the Oak Bay Formation. In the St. Croix River, disruption of coticule bands in the Calais Formation and flattening of pebbles and cobbles in the Oak Bay Formation suggest that a fault locally separates the two units.

Age of the Calais Formation. Graptolites were reported by Cumming (1965) from highly carbonaceous slates on Cookson Island now assigned to the Calais Formation. A re-examination of the fauna by Dr. John Riva of Université Laval indicates a Tremadocian age (earliest Ordovician) for the uppermost member of the formation (see Ruitenberg and Ludman, 1978). The ages of the basalt and coticule members are unknown, but their stratigraphic position suggests a range of latest Cambrian through earliest Ordovician.

Woodland Formation (Ow). Interbedded metasandstones and metapelites of the Woodland Formation are by far the most abundant rocks of the Cookson Group, although they crop out only sparsely in the southeast corner of the Big Lake quadrangle. There, they are at high metamorphic grade and in the South Princeton-Crawford fault zone, and occur as strongly foliated greenish gray mylonites and as sillimanite-rich restite locally injected by mobilizate. Primary sedimentary features can rarely be recognized, but excellent exposures of lower grade and unsheared Woodland strata are readily observed in many places in the Calais quadrangle (Ludman and Hill, 1990). The appearance of the Woodland Formation in these areas will be described here for the sake of completeness.

In the Calais quadrangle, the Woodland Formation consists almost entirely of rhythmically interbedded, sparsely sulfidic, metamorphosed quartzofeldspathic wacke and slightly carbonaceous and non-carbonaceous slate or phyllite. Beds range in thickness from 2 mm to 50 cm, but most are between 2 and 20 cm. Each bed is typically a couplet of sandstone grading into pelite, and the two are present in variable proportions. Roughly equal amounts occur in the thinner bedded varieties, but sandstones dominate the thicker beds by as much as 4:1. Fine laminae defined by mica concentrations are abundant and generally parallel bedding, but cross-laminae are also found. Soft-sediment slump and fold structures are visible in some of the larger exposures, particularly at Woodland Dam and on the north slope of Robb Hill. Discoid calcareous concretions composed almost entirely of calcite are found in some of the thickest bedded rocks, and are as large as 50 cm in diameter and 15 cm thick. Ellipsoidal calcareous concretions 25 cm long are associated with the discs, but both are very rare.

Three subordinate rock types are intercalated locally with these wackes and slates in the Calais quadrangle, but the three amount to less than 1% of the formation. The most abundant is a quartzwacke that is irregularly interlayered with the graded couplets throughout the formation. It is a dense quartz-biotite feldspar granofels with very little of the muscovite that is present in the more typical wackes. It occurs in beds 15-50 cm thick that are thicker than the enveloping graded beds, and commonly exhibits cross-laminations defined by concentrations of biotite flakes. Far less abundant is a thinly banded calc-silicate rock that has been seen only in one 7.5 meter thick horizon. It consists of alternating layers of calc-silicate granofels (actinolite-calcite-diopside grossularite) and biotite-quartz-feldspar granofels, and was exposed briefly in a road-metal quarry adjacent to the Woodland town dump. It is also present, at this writing, in a small quarry just across the St. Croix River from Woodland (Fyffe, pers. commun., 1989). The third unusual rock type is a highly carbonaceous pelite that locally forms the tops of graded beds. Most pelites of the Woodland Formation are less carbonaceous than those of the other units of the Cookson Group, but these are sooty black beds with little muscovite or biotite.

Sandstones of the Woodland Formation differ from those of the Kendall Mountain Formation in three distinctive ways. Prior to metamorphism, sandstones of the Woodland Formation contained a highly argillaceous matrix now reflected by high biotite content and a purplish color, whereas most sandstones of the Kendall Mountain Formation were arenites and now contain little, if any, biotite. Graded beds are abundant throughout the Woodland Formation, but are uncommon in most of the Kendall Mountain Formation except near its contact with the Woodland Formation. Finally, the Woodland Formation has far more interbedded pelite. The rare calc-silicate rocks are the only calcareous lithologies in the Cooskon Group.

The contact between the Woodland and Kendall Mountain Formations is of two types. In many places it appears to be gradational, with sandstones in the Woodland Formation becoming less micaceous and pelites less abundant as the Kendall Mountain Formation contact is approached. In a few areas, however, the contact is sharp and may locally be a fault. On the northeastern face of Kendall Mountain, for example, distinctive graded couplets of the Woodland Formation are in sharp contact with arenites and volcanic rocks of the Kendall Mountain Formation. Small-scale structures there indicate slight overthrusting of the Kendall Mountain Formation by the Woodland Formation.

Age of the Woodland Formation. No fossils have been found in the Woodland Formation, but its age is constrained to the Early Ordovician by graptolites in the overlying (Caradocian) and underlying (Tremadocian) units. A span of Arenigian through Llanvirnian and Llandeillian is indicated, although an age as young as Early Caradocian is possible (see below).

Kendall Mountain Formation (Ok): The Kendall Mountain Formation is named for extensive exposures along the

northwest slope of that hill in the adjacent Calais quadrangle, but is very well exposed just east of Pocomoonshine Lake along a series of camp and lumber roads connecting the lakeshore with the road from South Princeton to Alexander. It contains the most varied lithologic suite within the Cookson Group, including quartz arenites, quartzofeldspathic and lithic arenites, wackes, and granule conglomerates, very subordinate black shales and siltstones, and an apparently unique horizon of felsic tuffs. Three features clearly set the Kendall Mountain Formation apart from the other rocks of the Cookson Group: (1) pelites make up only a small portion of the formation (%); (2) the sandstones are chemically distinct in that they do not contain biotite even at elevated metamorphic grade. As a result they remain pale gray at cordierite and andalusite grades, whereas the other units are pale purplish due to finely disseminated red-brown biotite; (3) it contains felsic volcanic rocks. Figure 2 shows the inferred internal stratigraphy of the formation.

Metasandstones comprise most of the formation, generally occurring in thick beds (20cm-1.5 m). Thinner sandstone beds (10-20 cm) intercalated with thin (5 mm-2.0 cm) rusty weathering carbonaceous pelite and siltstone layers characterize the lower part of the formation. These sandstones commonly display well-developed convolute bedding and ball-and-pillow structures typical of turbidites. Sandstones in the middle of the formation occur in relatively featureless, massive beds with very small amounts of pelite. Most of the western peak of Kendall Mountain, for example, is underlain by massive sandstone beds over 1 m thick, with only one or two horizons of carbonaceous slate.

There are several types of sandstone, but it is difficult to estimate their proportions. Most are buff to pale gray, chalky weathering quartzofeldspathic wackes, with a matrix of small white mica flakes. Quartzofeldspathic arenites are also present, with very little matrix, and a few true quartzite beds have been found which contain more than 90% quartz. These lack the chalky weathering typical of feldspathic rocks and are bluish gray on both fresh and weathered surfaces. One of the quartzite horizons had been mapped as a separate, informal member of the Cookson Formation (Ruitenberg, 1967; Ruitenberg and Ludman, 1978), but new exposures and bedrock cores from the Calais quadrangle reveal that it is interbedded with more typical arenites and wackes. A few lithic wackes and arenites are also present and contain clasts of felsic volcanic rocks as well as quartz and feldspar. Most clasts in the sandstones range from 0.25 to 0.75 mm and individual beds are generally homogeneous in grain size. Graded bedding is best developed in the lower part of the formation, and is less abundant than in either the adjacent Pocomoonshine Lake or overlying Woodland Formation.

Granule conglomerates occur in the thicker bedded parts of the Kendall Mountain Formation, and near the contact with the Pocomoonshine Lake Formation. They crop out sparsely along the ridge between Pocomoonshine Lake and the eastern edge of the quadrangle. These rocks are composed of the same clasts as the lithic arenites, but are much coarser—typically ranging from 1-5 mm. Even coarser beds, with clasts up to 2.5 cm in diameter, have been observed in float at the Whippoorwill Lodges near the shore of Pocomoonshine Lake, but have not been found in place. Most clasts are well rounded, although tectonic flattening is common in the South Princeton-Crawford fault zone and associated faults. The conglomerates occur in massive beds up to 2 m thick, as graded units 25 cm to 1 m thick, and as the bases of rare graded sequences that include sandstones and laminated carbonaceous pelites.

The volcanic component is restricted to the lowermost part of the formation, within a few meters of the contact with the Woodland Formation. It is not exposed in the Big Lake quadrangle and is represented in only three small areas in the adjacent Calais quadrangle. It consists of thinly banded (1-5 cm) to more massive (15 cm) chalky white weathering, light to medium gray felsic tuffs. Most are very fine-grained to cryptocrystalline rocks with a characteristic conchoidal fracture. In thin section these rocks are very fine-grained, sutured arrays of quartz and feldspar grains with rare feldspar microphenocrysts (up to 0.025 mm long). Small (0.5 mm), slightly elongate white spots visible in outcrop are pumice lapilli, and light/dark interdigitations similar to those in modern pumice flows have also been identified. Chemical analyses of these tuffs from the Calais quadrangle shows that they are rhyodacites (see Ludman and Hill, 1990, Table 1).

The nature of the contact between the Kendall Mountain and Pocomoonshine Lake Formations has been reinterpreted to be a fault based on the much more complex deformation history of the former. Strata of the Kendall Mountain Formation have been folded at least two and probably three times, whereas slates of the Pocomoonshine Lake Formation exhibit only a single penetrative cleavage. Misidentification of carbonaceous pelites now assigned to the Kendall Mountain Formation led to inclusion of the Pocomoonshine Lake Formation in the Cookson Group, and suggested a gradational contact between the Kendall Mountain and Pocomoonshine Lake Formation (Ludman, 1987).

<u>*Age of the Kendall Mountain Formation.*</u> Graptolites have been discovered in a black shale horizon lying between massive quartz arenites in New Brunswick, on strike and continuous with rocks of the Kendall Mountain Formation (Fyffe, pers. commun., 1989). The faunal assemblage has been assigned to the Middle Caradocian by John Riva (pers. commun. to Fyffe, 1989). This has necessitated inversion of the sequence reported earlier (Ludman, 1987).

Thickness of the Cookson Group. In addition to the complex polydeformational history experienced by the Cookson Group, neither the top nor bottom of the group has been observed in the field. Thus, only a minimum value for its thickness can be proposed. Based on the exposed outcrop widths of formations and their inferred deformational history, estimated thicknesses are: Kendall Mountain Formation—between 500 and 700 m

(minimum thickness); Woodland Formation—800-1000 m; and Calais Formation—1000 m (minimum). Estimated thickness for the Cookson Group is thus approximately 2,700 m.

Correlation of the Cookson Group. To the southwest, rocks of the Cookson Group had been traced into the Wesley quadrangle by Westerman (1978) as the Cookson "Formation." I would now interpret the map pattern drawn by Westerman as containing two bands of dominantly pelitic rock (Pocomoonshine Lake Formation to the north, Calais Formation to the south) separated by a small outcrop area of Kendall Mountain Formation and a large expanse of mafic and felsic plutons. Farther southwest, the Penobscot Formation of the Penobscot Bay area as described by Stewart and Wones (1974) appears to correspond to the Calais Formation. Basalts of the Gushee Member of the Penobscot Formation are probably equivalent to the middle member of the Calais Formation (Fyffe et al., 1988). Strata of the Woodland Formation do occur there as well (Wones, pers. commun., 1984). Along the west shore of Penobscot Bay, quartzose rocks of the Megunticook Formation (Berry, 1986) appear to be correlative with the Kendall Mountain Formation.

Cross-strike correlations are more ambiguous and much more difficult, particularly in view of the faults that now separate the St. Croix belt from the nearest pre-Silurian tracts—the Miramichi anticlinorium to the northwest and the Saint John tract to the northeast. These correlations are hotly debated because of their implications for regional tectonic evolution (see Fyffe and Pickerill, 1986, and Ludman, 1986) and are summarized in Ludman (1987).

Briefly, the question is whether the Cookson Group was originally associated with the Cambrian—Earliest Ordovician Saint John Group as described by Pickerill and Tanoli (1985), or to the Late Cambrian through Middle Ordovician Tetagouche Group of the Miramichi anticlinorium. The Saint John Group contains some similar rocks, but is much thinner, less complexly deformed, and was deposited in shallow water. The Miramichi tract contains a thick wacke section overlain by black shales and a widespread bimodal volcanic sequence.

I proposed (Ludman, 1987) that the Saint John Group represents the west-facing continental shelf of an Early Paleozoic Avalonian continent, and that the Cookson Group represents the associated continental slope deposits. Alternatively, the Cookson Group could be deep-sea deposits formed off the Miramichi arc (Fyffe and Pickerill, 1986). The fossils that date the Kendall Mountain Formation provide two important pieces of information that help resolve this problem: (1) The Middle Caradocian age of the Kendall Mountain Formation makes it younger than anything now exposed in the Saint John area, preventing direct correlation. Nevertheless, equivalent strata in the Tetagouche Group are volcanic and volcaniclastic strata, making it very difficult to relate them to the quartz arenites of the Kendall Mountain Formation. Derivation from a shelf to the east seems to be the most reasonable explanation. (2) Riva's identification of the fauna of the Kendall Mountain Formation includes species "rarely found in North America" (Riva, commun. to Fyffe, 1989). This implies a "European" or "Avalonian" affinity, again suggesting correlation with the Saint John Group, rather than with the "North American" Miramichi strata.

Rocks of the Fredericton Trough

Rocks of the Fredericton trough are unfossiliferous, tightly folded turbidites. They differ from strata of the Cookson Group in that they have a much simpler deformation history and are inferred to be of latest Ordovician to Late (?) Silurian age. Three units have been mapped in the Big Lake-Calais area: the Pocomoonshine Lake, Digdeguash, and Flume Ridge Formations.

Pocomoonshine Lake Formation (SOp). Black and gray slates with subordinate siltstone and sandstone beds are well exposed along the east shore of Pocomoonshine Lake, for which the unit is named. They are separated by an inferred thrust fault from rocks of the St. Croix belt, and by a high-angle fault from the Pocomoonshine gabbro-diorite. A gradational contact with the Digdeguash Formation is suggested by an outcrop in the middle of the southeastern cove of Pocomoonshine Lake that contains lithologies found in both formations. Unfortunately, this outcrop can only be reached by boat and is only visible at low-water conditions. The Pocomoonshine Lake Formation crops out in chlorite grade exposures along the lake shore, but grade increases rapidly inland so that cordierite and cordierite + andalusite assemblages occur near the eastern edge of the quadrangle. Rocks of this formation are pyritiferous, rusty weathering, and dominantly pelitic, although there is an appreciable amount of fine-grained metasandstone and metasiltstone thinly interbedded with the slates.

Dark gray to gray-black, slightly to very carbonaceous slates are the most abundant rock types. They are well cleaved and generally contain both anhedral (primary) and euhedral (secondary) grains of pyrite. The more carbonaceous varieties are darker colored and sooty, while the less carbonaceous types are lighter gray, muscovite-rich, and develop a phyllitic sheen. These pelites are interbedded with thin (5 mm to 10 cm) beds of coarse metasiltstone and fine-grained metasandstone, with pelite:sandstone proportions of 6:1 being typical of the formation as a whole. Some horizons, however, contain nearly equal amounts of slate and siltstone. Many beds are graded and supply primary facing evidence. The pelite layers are strongly cleaved and break easily, whereas the coarser beds cleave poorly and are generally more resistant to weathering so that they stand out as ribs on weathered surfaces.

Most beds are in the lower end of the thickness range indicated above, but both bed thickness and amount of sandstone increase toward the east. The sandstones and siltstones are buff weathering, dark gray on the fresh surface, and are composed of quartz and sparse feldspar clasts in a finer grained quartz-feldspar matrix. The matrix also contains abundant small flakes of white mica and grains of limonite and carbon. The pyrite grains

(<0.25 mm) are disseminated throughout the sandstones and weather to produce a pale brown limonite rind. Secondary pyrite cubes up to 5 mm on a side are present in the sandstones, and larger crystals, up to 1.25 cm, characterize the pelites.

Age and Correlation. The age of the Pocomoonshine Lake Formation is uncertain, and its asssignment here to the Fredericton trough rather than to the Cookson Group is a departure from previous interpretations. With its carbonaceous, sulfidic slates, the formation is more similar to the Cookson Group than to the Digdeguash or Flume Ridge Formations (although the Digdeguash does have dark gray to black sandstone and slate), and this led to my earlier interpretation. Structurally, however, the Pocomoonshine Lake Formation more closely resembles the Flume Ridge and Digdeguash Formations in that it has experienced a relatively simple deformation history compared with the multiply folded rocks of the Cookson Group (see below). The boundary between intensely polydeformed and simply deformed strata in the Big Lake quadrangle coincides with the Pocomoonshine Lake/Kendall Mountain Formation contact, and this has led me to reassign the Pocomoonshine Lake Formation to the Fredericton trough.

The age of the Fredericton trough strata in southwestern New Brunswick and eastern Maine is problematical. The simpler deformation history of these rocks when compared with the Cookson Group suggests a younger age, and the Flume Ridge Formation is on strike with rocks near Fredericton that yield fossils ranging through the Silurian (Fyffe, pers. commun., 1989). The Pocomoonshine Lake Formation is tentatively assigned a latest Ordovician age on the basis that it is thought to be younger than the polydeformed Caradocian Kendall Mountain Formation and older than the Digdeguash and Flume Ridge Formations.

Digdeguash Formation (SOd). Ruitenberg (1967) applied the name Digdeguash Formation to a distinctive sequence of turbiditic graywackes and slates in Charlotte County, New Brunswick. This unit was recognized in the Big Lake area (Ludman, 1974), where it corresponded with parts of both the Kellyland Formation and Dark Argillite of the Charlotte Group as shown by previous mappers (Larrabee, 1964; Westerman, 1972). The Digdeguash Formation underlies most of the southwestern corner of the quadrangle and forms the core of the Huntley Ridge anticline. The formation is in apparently conformable contact with the Flume Ridge Formation to the northwest and is faulted against the Cookson Group to the east. It can be traced from chlorite grade near Second and Third Chain Lakes to an anatectic migmatite zone at the western margin of the Pocomoonshine gabbro-diorite along Seavey, Huntley, and Hawkins ridges. Over most of its outcrop belt, the Digdeguash Formation crops out in the andalusite zone and is characterized by large, euhedral chiastolitic crystals.

Lithologically, the Digdeguash Formation is a relatively simple package consisting of buff weathering, gray, non-sulfidic graywacke and polymictic granule conglomerates associated in well graded beds with non-carbonaceous, non-sulfidic gray slate. Like the Cookson Group, the Digdeguash Formation is basically non-calcareous; only two beds of calcareous wacke have been found in the formation, both near the contact with the calcareous sandstones of the Flume Ridge Formation. Although the Digdeguash Formation consists primarily of only two rock types (sandstone of variable grain size and pelite), bed thicknesses, grain size, and graywacke:slate proportions are so highly variable that the formation does not have a uniform appearance in the Big Lake quadrangle.

Beds vary in thickness from 1 cm to 2.5 m, but most are in the range of 15-60 cm, somewhat thicker than the beds of the Woodland Formation. The coarser clastic rocks weather pale gray to buff, the slates darker gray, so that a gradation in color accompanies the changes in grain size and composition within a graded bed. The thickest beds exhibit the best Bouma sequence features, with scour-and-fill and flame structures, load casts, and rip-up clasts at their bases; cross-, convolute, or bedding plane parallel laminations in their centers; and very fine laminae just below strongly cleaved, homogenous slate tops.

Lithic proportions vary widely and with no apparent relationship to stratigraphic position. A few horizons are homogeneous, consisting entirely of granule conglomerate, graywacke, or slate, but these are rare. Most of the Digdeguash Formation consists of graded beds of graywacke and slate, with proportions related to bed thickness. Thick beds are generally dominated by grits and graywackes (70-90%), whereas thin beds contain nearly equal amounts of sandstone and pelite or slightly more pelite than sandstone. For the formation as a whole, the grits and graywackes are more abundant than the slates by about 3:2.

Primary clast outlines, compositions, and textures are preserved in the low-grade exposures. Most of the coarser clastic rocks are graywackes composed of quartz, plagioclase, and polymineralic lithic clasts in a fine-grained detrital matrix composed of quartz, plagioclase, muscovite, and either biotite or chlorite depending on metamorphic grade. The quartz and lithic fragments suggest derivaton from a plutonic/metamorphic source area that yielded clasts of hypabyssal igneous rock (plagioclase + quartz; perthite + quartz; quartz + perthite + muscovite), very fine-grained aggregates of quartz and feldspar that are probably cryptocrystalline felsic volcanic rocks, and rare but distinctive muscovite-chlorite-quartz-plagioclase schist/phyllite.

These Digdeguash Formation lithologies are distinguished from those of the Flume Ridge Formation by being polymictic, poorly sorted, and non-calcareous, and from the Woodland Formation by their bedding style and thickness and by the absence of rusty-weathering and carbonaceous pelite. The coarser lithic arenites and granule conglomerates of the Kendall Mountain Formation superficially resemble those of the Digdeguash Formation, but differ in that they weather chalky white rather than buff, and contain little or no argillaceous matrix. Increases in metamorphic grade heighten the differences and reflect different bulk compositions. Cordierite, for example, is abundant in middle-grade pelites of the Cookson Group, but is present in the

Digdeguash Formation only rarely except in the innermost migmatite zones. Andalusite occurs in Cookson Group pelites as small, rice-shaped grains, but in the Digdeguash Formation it is almost always euhedral and forms chiastolitic prisms that range from 1.5 to 20 cm long.

Along Seavey, Huntley, and Hawkins Ridges, the Digdeguash Formation has been partially melted and converted to a gneissic rock in which buff-weathering quartzofeldspathic leucosome is interlayered with dark gray melanosome composed of muscovite, biotite, and sillimanite relict andalusite. The distinctive Digdeguash Formation bedding style and andalusite habit are preserved in all but the migmatites closest to the Pocomoonshine pluton, and even at these grades of thermal metamorphism the Woodland Formation and Digdeguash Formation are separable. Migmatites of the Woodland Formation, best exposed in the southwest corner of the Calais quadrangle, are generally highly sulfidic, weather with a deep red-brown rind, and typically preserve relict cordierite and andalusite porphyroblasts in their melanosomes. Migmatites of the Digdeguash Formation are low in sulfide and hence to not weather rusty, and contain only relict andalusites.

Thickness. It is difficult to estimate even the outcrop width of the Digdeguash Formation because of high-angle faults and disruption by the Pocomoonshine gabbro-diorite. In addition, mesoscopic isoclinal folding of the Digdeguash Formation is revealed by frequent reversals in facing sense within the turbidites. A minimum thickness of approximately 1,000 m is inferred for the formation, assuming that it has been penetratively folded only once.

***Age and Correlation*.** The age of the Digdeguash Formation is highly problematical. Ruitenberg (1967) originally stated that the Digdeguash Formation is overlain conformably by the Flume Ridge Formation in southwestern New Brunswick, but Fyffe (pers. commun., 1989) has demonstrated clear evidence that this contact is a fault. The contact between the two formations has not been observed in the Big Lake-Calais area, but has been approached to within 15 meters in a few places. In all instances, the contact is sharp or seems to be a rapid transition; in two places Digdeguash Formation-type pelites and Flume Ridge Formation-type sandstones are interbedded and Digdeguash Formation grits are unusual in being weakly calcareous. These observations, coupled with a lack of direct evidence for a fault, suggests that the contact in eastern Maine may be stratigraphic rather than tectonic, and thus different from the contact on strike and just a few kilometers to the east.

Recumbent folds visible in the Digdeguash Formation near the contact in New Brunswick are not present in Maine. I interpret this to mean that the contact in New Brunswick is locally a thrust fault, which passes southwestward into a strike-slip fault and eventually into a barely disturbed stratigraphic relationship in eastern Maine. This has bearing on the age assigned to the Digdeguash Formation as well.

Fossils have not been found in the Digdeguash Formation in Maine or New Brunswick so that direct faunal evidence for its age is lacking. Ruitenberg (1967) mapped the Digdeguash Formation as interfingering with the Waweig Formation, a unit with a well established latest Silurian (Pridoli) age. More recent mapping (Fyffe, pers. commun., 1989) suggests that this contact is a fault rather than a facies transition and indicates that the Digdeguash Formation cannot be correlated with any fossiliferous strata. In addition, Westerman (1973) reported K/Ar ages on hornblende (423 24 m.y.) and biotite 408 14 m.y.) that suggest a Silurian age for the Pocomoonshine Formation gabbro-diorite. Since that pluton cuts folded strata of the Digdeguash Formation, it would not be possible for the Digdeguash Formation to be Late Silurian as suggested by Ruitenberg.

Cambro-Ordovician rocks of the Cookson Group in Maine are more complexly folded than those of the Fredericton trough, and one episode of folding appears to have preceded deposition of the Flume Ridge and Digdeguash Formations*. That folding must be post-Middle Caradocian, the age of the Kendall Mountain Formation. Since early folding seems absent from the Digdeguash Formation in Maine, I feel that the formation must be post-Caradocian. A latest Ordovician to Early Silurian age is most likely, based on: similarities with the Silurian turbidites of central Maine, the apparent stratigraphic contact with the Flume Ridge Formation, continuity of the Flume Ridge Formation with the Vassalboro Formation of the central Maine turbidite belt, and the problems of excess argon common to dating mafic igneous rocks.

The Digdeguash Formation has been traced southwestward into the Wesley (Westerman, 1978) and Ellsworth (Gilman, 1974) quadrangles, but it is apparently absent from the shores of Penobscot Bay, where the Penobscot (Calais equivalent) and Bucksport (Flume Ridge equivalent) Formations are directly juxtaposed. Ruitenberg (1967) has traced the Digdeguash Formation along the west flank of the St. Croix belt in New Brunswick, but it does not appear to extend as far east as the Saint John area (McCutcheon and Ruitenberg, 1984). Aside from these short, direct continuations, there do not appear to be correlative units that are similar to the distinctive Digdeguash Formation suite, either along or across strike in the Fredericton trough.

Flume Ridge Formation (DSf). The Flume Ridge Formation is regionally the most extensive of the formations in the Big Lake quadrangle and comprises most of the Fredericton trough in eastern Maine. It extends nearly 35 km across strike from its contact with the Digdeguash Formation to the Codyville fault contact with pre-Silurian rocks of the Miramichi anticlinorium in the Waite quadrangle. The Flume Ridge Formation was named by Ruitenberg (1967) in southwestern New Brunswick;

*Different structural relationships in New Brunswick have led Fyffe to suggest an alternative series of correlations (pers. commun., 1989). The Digdeguash Formation north of St. Stephen appears to lie on strike with rocks correlated with the Woodland Formation of the Cookson Group. Along with the fault that separates the Digdeguash Formation from the Flume Ridge Formation, this suggests that the Digdeguash Formation may be a facies equivalent of the Woodland Formation, and thus be part of the Cookson Group. The issue is far from settled.

in eastern Maine, the name is now applied to rocks most of which were previously called the Pale Argillite Division of the Charlotte Group (Alcock, 1946) or the Kellyland Formation (Larrabee, 1964; Larrabee et al., 1965; Westerman, 1972). These names have been abandoned, as discussed above.

The Flume Ridge Formation is readily distinguished from all other units in the area because it alone is generally calcareous. The distinction can be made at all metamorphic grades, even though the appearance of the Flume Ridge Formation changes drastically from the chlorite zone to higher grades in the contact aureoles.

The Flume Ridge Formation consists of variably but generally at least slightly calcareous quartzofeldspathic wackes interbedded with calcareous and non-calcareous siltstones and non-calcareous slates. At chlorite grade the wackes are buff or orange-brown weathering, medium to light gray calcareous sandstones, typically with large (1-4 mm) detrital muscovite flakes. The weathered color is due to alteration of finely disseminated pyrite or ferroan carbonate grains (ankerite or siderite) that are present in addition to calcite. The weathered rind is commonly so well developed that it is difficult to collect fresh samples. The wackes are typically finer grained and better sorted than those of the Digdeguash Formation, consisting of fine sand-sized grains of quartz and feldspar in a finer grained quartz-feldspar-muscovite-chlorite-calcite matrix. Polymineralic lithic fragments, common in the sandstones of the Digdeguash Formation, are very rare in the Flume Ridge Formation, but have been observed in unusually coarse beds.

Non-ankeritic, slightly calcareous siltstones and green, chlorite-rich non-calcareous slates and siltstones are intercalated with the sandstones. Bedding style and thickness are of two general types within the formation. Thick beds (40 cm-2 m) of calcareous and ankeritic sandstone are abundant near the contact with the Digdeguash Formation. These beds are of uniform grain size, exhibit cross-laminae near their tops, and contain little pelitic material. The pelite occurs as paper thin partings parallel to cleavage and may represent a solution residue rather than originally deposited clays. The amount of pelite appears to increase toward the northwest, accompanied by a decrease in bed thickness, development of well graded beds, and appearance of more primary sedimentary features. Strata of the Flume Ridge Formation north of the Big Lake quadrangle are generally found in beds 2-10 cm thick containing equal amounts of light gray, slightly calcareous sandstone and green siltstone with subordinate slate. Although commonly well graded, the grain size range within a graded set is far less than in the Digdeguash Formation, often spanning only the medium silt through fine sand range. Laminations parallel to bedding planes are abundant and a few beds display convolute laminations, but the more complete Bouma sequences typical of the Digdeguash Formation are not developed.

At biotite and higher grades of metamorphism, the Flume Ridge Formation is drastically different in appearance. Muscovite reacts with ferroan carbonate to form biotite as described by Ludman (1975) for similar rocks in central Maine. As a result, there is no ankerite to alter to the limonitic weathering rind typical of low-grade exposures, and the finely disseminated biotite flakes yield a pale grayish-purple color on fresh surfaces rather than the pale gray of chlorite-zone outcrops. The higher grade exposures are commonly of massive-appearing, buff-weathering, slightly calcareous purple granofels. Layers that were originally more calcareous are recrystallized to white or greenish calc-silicate granofels layers which alternate with the purplish quartzofeldspathic granofels in a distinctive "zebra-striped" color banding. The presence of primary bedding can be demonstrated in only a few of the high grade exposures. The calc-silicate bands are generally discontinuous and anastomose, and in a few outcrops are demonstrably the results of transposition of original compositional bands to a position subparallel to dominant regional cleavage. The pelite in the high-grade exposures is a dense biotite-rich granofels with small cordierite crystals in a few instances. Neither sillimanite nor andalusite have been identified in pelites of the Flume Ridge Formation.

A ribbed appearance is typical of both chlorite and higher grade exposures. Calcareous layers weather rapidly in the low-grade rocks and the less calcareous wackes stand up as ribs. Relationships are reversed in the high-grade exposures; calcareous rocks have become more resistant calc-silicates that form ribs above the quartzofeldspathic beds.

Thickness. It is difficult to estimate the number of times that the Flume Ridge Formation has been repeated across the 35 km width of its outcrop belt because (1) bedding is not identifiable in all exposures and facing evidence is not very common, so that internal structural control is not as good as in other formations, and (2) the Flume Ridge Formation is cut by several northeast-trending faults associated with the Norumbega fault system. Further, while the lower contact with the Digdeguash Formation can be located to within a few feet, the upper contact is not recognized anywhere in eastern Maine. Based on those mesoscopic folds identifiable in the Flume Ridge Formation, its lithologic variability, and the structural style of the Digdeguash Formation, a thickness on the order of at least a few thousand meters is inferred for the formation.

Age and Correlation. Macrofossils have not been found in the Flume Ridge Formation, and the same uncertainties that were mentioned for the Digdeguash Formation apply to determining the age of this unit. Large float boulders with the typical mineralogy and weathering habit of the formation have yielded *Tentaculites*, suggesting a Silurian to Devonian age, but none of the fossils have been found in situ. A search for microfossils in the Flume Ridge Formation produced a variety of plant material. Fungal spores are present in some of the siltstones and slates, but are of little biostratigraphic value. Fragments of tracheid tissue, a primitive fluid-conducting tissue of vascular plants, have been discovered in sandstones of the Flume Ridge Formation in the Waite quadrangle. These suggest a Silurian or younger age for the formation, and a Silurian age is accordingly shown on the map. Since the Pocomoonshine gabbro-diorite, with its sup-

posed Silurian age, intrudes previously folded Flume Ridge Formation strata, there is a conflict between radiometrically and faunally determined ages. In this instance I have opted for the paleontologic control.

Rocks of the Flume Ridge Formation have been traced to the southwest into the Wesley (Westerman, 1978) and Lead Mountain (Gilman, 1974) quadrangles, and appear to extend through local plutons into the Bucksport Formation of the Penobscot Bay area. Exposures in the northwest part of the Flume Ridge Formation outcrop belt in the Waite and Scraggly Lake quadrangles are on strike with and similarly appear to be traceable into the Vassalboro Formation (Griffin, 1976; Osberg et al., 1985). Osberg (1968, 1980) has vacillated as to the precise position of the Vassalboro Formation within the central Maine Silurian section, but a latest Ordovician through Silurian age is most probable. To the northeast, the Flume Ridge Formation extends to a position almost due north of Saint John, a distance of nearly 140 km. The formation changes along strike, becoming less calcareous and increasing in its proportion of pelite toward the northeast. Fossils in the less-calcareous facies equivalent span the entire Silurian (Fyffe, pers. commun., 1989), supporting the age assigned above.

STRUCTURAL GEOLOGY

The stratified rocks just described have undergone intense and complex deformation. Six tectonic events are recognized in the quadrangle, and are designated as D_1 through D_6 in order of decreasing age (see Fig. 3). The first three were largely ductile events involving penetrative folding, although D_3 probably included thrust faulting as well. D_4 through D_6 are restricted to linear domains and appear to have been dominantly episodes of faulting. All six events are recorded in the Cookson Group, but evidence has been found for only the last five in the Fredericton trough. This suggests that D_1 occurred before deposition of the Flume Ridge and Digdeguash Formations, and that the two lithotectonic tracts had been sutured since at least the time of D_2.

The earliest deformation recorded in the area was soft-sediment slump folding that is exposed in only a few large outcrops of the Woodland Formation in the Calais quadrangle. These are small-scale folds developed in a single bed or thin sequence of beds in the midst of an otherwise undisturbed section. Facing indicators in beds on opposite sides of these folds show no reversals, indicating the non-tectonic nature of these structures. The folds are tight to isoclinal with hinge surface attitudes that vary widely over a small area, detached noses, and non-systematic thickening and thinning of limbs. In contrast to the subsequent tectonic folds, these exhibit neither cleavage nor foliation parallel to their hinge surfaces.

D_1 Deformation

The earliest tectonic event was one of isoclinal folding (F_1) that is well displayed by graded beds of the Woodland Formation in its type locality in the Calais quadrangle, and by interbedded quartzite and slate in the Kendall Mountain Formation. A slaty cleavage (S_1) developed parallel to bedding is deformed by later folds, but only in a few instances can the early F_1 folds be seen. These folds are tight to isoclinal, with very small interlimb angles, and exhibit moderate thickening at their closures.

Attitudes of the few observed F_1 hinge surfaces and hinge lines are variable, due to subsequent refolding (Fig. 3) and to rotation by later faulting. An axial planar foliation of muscovite flakes is present parallel to S_1 in chlorite-grade outcrops, but has been destroyed in higher grade exposures. Deformed foliation interpreted to be S_1 has been observed in pelite of the Kendall Mountain Formation, indicating that D_1 has affected at least two of the three formations of the Cookson Group. Although there is no direct evidence of D_1 in the Calais Formation, the apparently conformable nature of its contact with the younger units of the Cookson Group suggests that it too was affected by D_1.

D_2 Deformation

A second episode of folding (F_2) observed in the Cookson Group produced northeast-trending upright folds and a spaced

FIGURE 3: DEFORMATION HISTORY OF THE BIG LAKE-CALAIS AREA

Event #	Description	Age
D_1	Isoclinal folding (F_1) and formation of S_1 cleavage in pelites of the Cookson Group	Post-Caradocian, but before Silurian strata
D_2	Isoclinal to open folding (F_2) of all rocks of the coastal volcanic, St. Croix, and Fredericton trough belts	Post-Eastport Fm. (Early Devonian); pre-gabbro, granite (Early Devonian)
D_3	F_3 recumbent folding related to SE-over-NW thrusting of the St. Croix belt over the Fredericton trough	After F_2; before Early Devonian granites
D_4	North-trending normal faults; local development of small-scale F_4 folds and cleavage	Synchronous with emplacement of gabbros
D_5	NE and N-trending strike-slip faults; mostly dextral, but some sinistral offset	Post-gabbro and granite. Related to Norumbega fault zone
D_6	NW-trending sinistral strike-slip faults; sinistral kinks	Postdates all other structures

Figure 3. Sequence of deformation events in the Big Lake area.

S_2 cleavage that cuts S_1 and both limbs of F_1 folds in several exposures along the eastern edge of the Big Lake quadrangle. F_2 folds range from open to tight depending on lithology and bed thickness, have hinge surfaces that trend 040-060°, and generally plunge gently to the southwest at 2-20°. A few northeast plunges have also been measured. Abrupt rotation of F_1 hinge surfaces to a nearly north-south attitude occurs near faults of the South Princeton-Crawford fault zone. S_2 and S_1 are nearly perpendicular, but the precise relationships depend on the position of S_1 on the F_2 folds. S_2 is not as well developed as S_1 and is somewhat more broadly spaced. Because of the poor outcrop control and the earlier episode of folding, it is difficult to trace map-scale F_2 folds through the St. Croix belt.

This difficulty does not arise in the Fredericton trough, however, because of the absence of deformation prior to F_2 in the Digdeguash and Flume Ridge Formations. Outcrop scale F_2 folds are not abundant, but those that have been found are similar in attitude and style to the F_2 folds in the Cookson Group. The presence of larger-scale structures is inferred from reversals of facing sense in the well-graded Digdeguash Formation turbidites. The Huntley Ridge anticline is the largest such structure recognized. It is cored by the Digdeguash Formation and has the Flume Ridge Formation on its western flank, but a tiny sliver of sandstone of the Flume Ridge Formation caught in the Pocomoonshine Lake fault is all that remains of the eastern limb. Reversals of facing sense in the Flume Ridge Formation in the northern part of the Big Lake quadrangle and farther north between Princeton and Topsfield show that F_2 structures predominate in the Fredericton trough.

S_2 cleavage is very well developed in Digdeguash Formation slates and moderately to weakly developed in siltstones and pelites of the Flume Ridge Formation. A poor foliation is defined by small muscovite and chlorite flakes in low grade outcrops of both formations. In the contact aureole of the Pocomoonshine gabbro-diorite, mimetic crystallization has produced a strong foliation in the Digdeguash Formation that is defined by coarse muscovite and biotite flakes. Consumption of muscovite and chlorite by prograde metamorphism in the Flume Ridge Formation destroys S_2 foliation, but some of the distinctive calc-silicate banding in these rocks cuts across bedding and parallels the axial planes of F_2 minor folds.

D_3 Deformation

D_3 produced recumbent to strongly inclined asymmetric (counterclockwise) folds in rocks of the Cookson Group, and locally generated a close-spaced cleavage in the Digdeguash and Pocomoonshine Lake Formations close to their contact with the St. Croix belt. Several outcrop-scale F_3 folds can be observed between the shore of Pocomoonshine Lake and the South Princeton-Alexander road, in the upper part of the Kendall Mountain Formation, and many more are visible in the Woodland Formation in the Calais quadrangle to the east. In all instances, the folds face upwards and tectonic transport is southeast-over-northwest.

F_3 folds deform bedding and earlier cleavages, but F_3 hinge surfaces are remarkably uniform in their gentle southeastward dips across most of the St. Croix belt. An associated spaced cleavage (S_3) is visible in most low-grade outcrops of pelitic rock; it generally strikes northeastward and dips from 5 to 30° to the southeast. S_3 is folded into a series of antiforms and synforms near faults associated with the South Princeton-Crawford fault zone.

On a regional scale, it appears that the Cookson Group has been deformed into a series of large-scale F_2 recumbent folds, and that the Calais-Big Lake area lies on the upright limb of one of these structures. Small-scale thrust faults visible in large exposures in the Calais quadrangle suggest that some faulting may have accompanied F_3, particularly where thick sequences of carbonaceous pelite are in contact with more massive, competent sandstones. Development of S_3 cleavage in the Digdeguash and Pocomoonshine Lake Formations near their eastern margin is inferred to indicate that the entire St. Croix belt has been thrust westward over the Fredericton trough during F_3. Subsequent fault uplift and erosion is thought to have removed the thrust plate and resulted in the currently observed relationships.

D_4 Deformation

North-trending high-angle D_4 faults cut all formations in the Big Lake quadrangle, as well as mafic rocks of the Pocomoonshine gabbro-diorite in the South Princeton-Crawford fault zone, and D_4 faults form the boundary between the Fredericton trough and St. Croix belt. These faults have a strong topographic expression, a series of aligned depressions that includes Crawford Lake, the easternmost part of Pocomoonshine Lake, and unnamed valleys connecting the two. One of these faults, the Pocomoonshine Lake fault, juxtaposes chlorite grade pelites of the Pocomoonshine Lake Formation with gabbros and andalusite-grade turbidites of the Digdeguash Formation. It crosscuts and deforms F_2 folds in both formations, and deforms S_3 cleavage in the Pocomoonshine Lake Formation slates east of the lake. This is most clearly seen in the progressive change in attitude of S_3 cleavage along the Whippoorwill Lodge road from Pocomoonshine Lake to the South Princeton-Alexander road.

Quartz veins are abundant in this fault zone, particularly in valleys east and southeast of Cedar Grove Ridge. Cataclastic fabrics are well developed in both metasedimentary and igneous rock, but blocks of rock between individual faults rarely display cataclasis. Shear zones 1 cm thick are close-spaced where faults cut the Pocomoonshine gabbro-diorite and are commonly chloritized or serpentinized. Several fault-related fabrics are found in the stratified rocks. Flattened and stretched clasts are characteristic of conglomerates of the Digdeguash and Kendall Mountain Formations in D_4 faults at Cedar Grove Ridge and

along the South Princeton-Alexander road, respectively, resulting in a very strong foliation. Arenites of the Kendall Mountain Formation and wackes of the Woodland Formation yield greenish gray vitreous mylonites in the vicinity of the Crawford church on Route 9.

D_4 faults of the South Princeton-Crawford fault zone have apparently been utilized during two separate episodes of displacement, because both subhorizontal and steep, downdip slickensides have been observed on shear surfaces. Small-scale drag folds are associated with both episodes in the sedimentary rocks. Most slickensides indicate sinistral strike-slip separation, but in three exposures these lineations cut an earlier set of nearly vertical slickensides in the same fault surface. Thus, while the most abundant slickensides record a late episode of strike-slip faulting, the less numerous ones probably reflect an earlier dip-slip event. The early event is what is termed D_4. Reactivation of these structures as strike-slip faults probably took place during a later, D_5 (?) event.

A second domain of D_4 faults is inferred in the southwest part of the quadrangle, between Third Chain and Silver Pug Lakes. Neither fault breccia nor mylonite have been observed there, but faults comparable to those in the South Princeton-Crawford fault zone are inferred because of: an alignment of valleys, lakes, and depressions in a NNE direction parallel to that described above; a late, north-trending cleavage developed strongly only in those areas; and small-scale, gently plunging folds with north-trending hinge surfaces that are also restricted to those areas. Outcrop control in the area is unfortunately poor, so that the nature of offset can not be demonstrated, even through the postulated faults would cut the Digdeguash/Flume Ridge Formation contact. The faults shown on the geologic map delineate regions where the late north-trending cleavage and minor folds are concentrated.

Migmatites in the Digdeguash Formation on the east flank of Huntley Ridge also record evidence of north-trending, clearly late generation folds attributed to D_4 faulting. Bands of melanosome containing andalusite, sillimanite, biotite, and muscovite, and preserving a strong S_2 schistosity, are folded about north-trending hinges. Leucosome material was injected in an axial planar relationship to these late folds, helping to constrain the timing of D_4. High grade hornfelses of the Flume Ridge Formation west of Pocomoonshine Mountain exhibit similar folds that are also aligned in narrow zones. These are on strike with strongly developed north-trending cleavage in low-grade sandstones and slates to the north, indicating yet another area of D_4 faulting.

D_5 Deformation

Northeast-trending high-angle faults grouped as D_5 structures cut stratified and plutonic rocks in several parts of the Big Lake quadrangle. Two D_5 faults shown cutting the Lead Mountain pluton in the northwest corner of the quadrangle are not actually exposed, but are extensions of the two southernmost branches of the Norumbega fault zone mapped by Wones (1978). D_5 faults exposed in the quadrangle parallel the Norumbega fault zone, are of similar position in the deformation sequence for the region, and many have the same sense of dextral strike-slip separation exhibited by faults of the Norumbega fault zone. They are therefore considered to be part of the Norumbega family of faults, thus widening that system by several miles to the southeast.

D_5 faults shown on the map are defined by the presence of one or more of the following features: offset geologic contacts; mylonite; gouge; abundant slickensided shear surfaces and zones; northeast-trending zones in which earlier structures are rotated into anomalous attitudes. Unlike the D_4 faults, these generally have no clear topographic expression, possibly because they are nearly perpendicular to the ice advance direction, whereas D_4 faults are at only a slight angle to that direction. One exception to this generalization is the northeast-trending lowland occupied by the group of large lakes that comprise the Big Lake Flowage. On strike with this lowland in the Kellyland quadrangle just northeast of Princeton, 14 small-scale D_5 strike-slip faults are well exposed at the Grand Falls of the St. Croix River. It is likely that rapid erosion of the crumbled rock in this zone is responsible for the lowland, but bedrock exposures are extremely rare in this valley and in the absence of supporting evidence of the types listed above, I have not shown this fault zone on the geologic map.

Small-scale dextral asymmetric folds are abundant in D_5 fault zones. Their steep plunges and sense of rotation, coupled with the nearly horizontal slickensides, indicate dominantly dextral strike-slip separation. Unfortunately, the faults parallel regional D_2 and D_3 structural trends, so that the amount of separation in the metasedimentary rocks can not be estimated. Offset of the contact between the gabbro and the Flume Ridge Formation, however, seems to be minimal, and also implies a small vertical component of motion not suggested by the slickensides alone. This is compatible with the history proposed earlier for the Norumbega faults in eastern Maine: early strike-slip separation followed by late dip-slip movement (Ludman, 1981).

Of all the faults now mapped in the quadrangle, only the D_5 Pocomoonshine Mountain fault shows significant mineralization. Quartz and copper sulfides fill mafic gouge where this fault cuts the pluton on the west flank of Pocomoonshine Mountain. The zone can not be traced far because of poor outcrop control beyond the contact aureole. Mylonite, gouge, and silicified shear zones in the Flume Ridge Formation near the west edge of the quadrangle are probably part of this fault zone, but can not be traced continuously to the mountain. Similarly, the Pocomoonshine Mountain fault zone is aligned with an abrupt change in the course of the St. Croix River in the Kellyland quadrangle south of Grand Falls, and with sheared rocks in the Calais quadrangle, but the continuity can not be demonstrated.

Most of the D_5 faults thus appear to be intraformational, lying within the Flume Ridge Formation in the Big Lake, Waite, and Kellyland quadrangles (Ludman, 1981). The bend of the

South Princeton-Crawford fault zone, and its inferred reactivation as a strike-slip fault is probably related to D_5. If so, it is the only D_5 fault that serves as a boundary between lithotectonic blocks in southeastern Maine. This fault zone, separating the Fredericton trough and St. Croix belt, extends several miles into New Brunswick, but was previously interpreted as a thrust (Ruitenberg, 1967; Ruitenberg and Ludman, 1978). Interestingly, most minor structures along the shore of Pocomoonshine Lake indicate that strike-slip separation was mostly of a sinistral nature in the Pocomoonshine Lake fault.

D_6 Deformation

Small scale asymmetric (sinistral) folds, kinks, and warps deform all other structural elements in the Big Lake quadrangle. They are found throughout eastern Maine, but are most abundant near NW-trending shear zones and are thought to have formed during a very late faulting event. The folds trend 280-295°, plunge very steeply (70-85°) to both northwest and southeast, and commonly have quartz-filled fractures parallel to their hinge surfaces. Near-vertical shears parallel the hinge surfaces and exhibit sub-horizontal slickensides. These slickensides and the uniformly sinistral rotation sense of the minor folds indicate left-lateral strike-slip separation.

There are few places where appropriately oriented faults produce mappable offset in eastern Maine, but two of these are in the Big Lake quadrangle. One offsets faults of the D_4 South Princeton-Crawford fault zone in the southeast corner of the quadrangle; the other displaces the contact between the Pocomoonshine gabbro-diorite and its host rocks just north of Seavey Ridge. Maximum offset is approximately 0.35 miles.

Timing of Deformation Events

The sequence and nature of events in the Big Lake quadrangle have been unraveled, but there is considerable regional tectonic significance to the timing of these deformations, and some of the implications of the scheme outlined in Figure 3 are controversial. Several tectonic models hold that pre-Acadian, post-Cadomian deformations did not affect rocks of the Avalonian block. Since the pre-Silurian rocks of the study area are considered correlative with those of the Avalonian Saint John Group, the postulated pre-Silurian age for D_1 contradicts those models. It is important to fully understand the current state of evidence for the timing of the deformation events described above, and the bases for both sides of the argument.

Evidence for D_1 is restricted to rocks of the Cookson Group. The Flume Ridge, Digdeguash, and Pocomoonshine Lake Formations are tightly folded, but display none of the folded cleavages and refolded folds observed in the Kendall Mountain and Woodland Formations. The absence of F_1 folds from the Fredericton trough can be explained in several ways, including the hypothesis favored here: that the D_1 event occurred prior to deposition of the Flume Ridge and Digdeguash Formations. The regional distribution of folds older than F_2 supports this hypothesis: there is no evidence of F_1 in either of the Silurian/Devonian tracts that flank the St. Croix belt. Most modelers agree that the coastal volcanic belt was erupted onto Avalon, so that if Silurian or post-Silurian deformation had caused F_1 deformation in the St. Croix belt, it would also have affected the Siluro-Devonian volcanic suite. Furthermore, pre-Silurian folds reappear north of the Fredericton trough in Middle Ordovician volcanic rocks of the Miramichi anticlinorium (Sayres and Ludman, 1985; Ludman, 1985b). This evidence strongly argues for a pre-Silurian age for F_1. Studies of the former Cookson "Formation" at its type locality have led Stringer and Burke (1985) to also conclude that there had been pre-Silurian deformation of the St. Croix belt in southwestern New Brunswick. How F_1 is related to the Middle Ordovician Taconic orogeny is unknown at this time, but its existence suggests interaction of some kind between Avalon and the terranes to the northwest during Ordovician times.

Previous studies in the Big Lake-Calais area, including my own, had not recognized the possibility of pre-Silurian folding, and all structures were thought to be Acadian or post-Acadian. In my earlier analyses, I had thought that recumbent folding (F_3) preceded the regional upright folding (here designated as F_2). I have reversed this order because the gently dipping S_3 cleavage appears to be unaffected by regional F_2 folding, and is only deformed locally in what are interpreted as D_4 faults.

Early Acadian recumbent folding and/or thrusting have been postulated for central Maine (Osberg, 1980), western New Brunswick and adjacent northeastern Maine (Rast et al., 1980), and coastal Maine near Penobscot Bay (Kaszuba and Wones, 1985), so that an early Acadian affinity for F_3 must still be considered. F_2 now appears to be older than the recumbent folding, and for reasons discussed below, is attributed to an early phase of the Acadian event. F_3 is tentatively assigned to a slightly later stage of the same orogeny.

An argument can be made (and has been) that the St. Croix and Fredericton trough belts are "exotic" with respect to one another, and were brought together along a transcurrent fault comparable to the suture proposed by Kent and Opdyke (1978) (the left-lateral episode of motion on the South Princeton-Crawford zone??). Zen (1983) and Naylor (1985) have argued that there are several sutures of this type in the northern Appalachians, but several points of evidence argue against this possibility. These include: the presence of the late Silurian Salinic unconformity on both sides of the South Princeton-Crawford fault zone, the similarity of F_2 folds from the coast to northern Maine, and the regional scale Early Devonian plutonic event throughout the eastern part of the state.

IGNEOUS ROCKS

The Big Lake quadrangle lies just north of a zone of large mafic and felsic plutons assigned to the Bays-of-Maine Igneous Complex by Chapman (1962). In the Big Lake area, this com-

plex separates the coastal volcanic belt from the St. Croix belt and Fredericton trough (Osberg et al., 1985). Although igneous rocks are not as abundant or as varied as in several adjacent quadrangles, they do underlie a large portion of the Big Lake quadrangle. Ultramafic through intermediate rocks of the Pocomoonshine gabbro-diorite comprise the largest single pluton, and a small diorite body occurs near Love Lake in the southeast corner of the quadrangle. Small felsic plugs have intruded metasedimentary and mafic rocks in the southwest and south-central parts of the area, but their boundaries shown on the accompanying map are significantly different from those shown by Larrabee (1964) and Larrabee et al. (1965). Granitic rocks on Amazon Mountain at the extreme northwest corner of the quadrangle are part of the extensive Lead Mountain pluton (Osberg et al., 1985).

Plutonic rocks of eastern Maine have been the subject of several previous studies. Ayuso (1979, 1982) has mapped mineralogic, structural, and isotopic variations within the Bottle Lake Complex to the north, and Abbott (1977, 1978) has similarly subdivided the Red Beach granite in the Robbinston 15' quadrangle to the east. Amos (1963) carried out a survey of intrusive rocks in the Calais and Robbinston quadrangles, and radiometric ages of several of the granitoids have been reported by Amos (1963), Spooner and Fairbairn (1970), and Faul et al. (1963). Most recently, Hill has remapped plutons in the Calais area (Ludman and Hill, 1990), and Jurinski (in preparation) has studied granite-gabbro relationships in the east-central part of the same quadrangle.

Special attention has been given to the mafic plutons. Houston (1956) and Coughlin (1981) reported on the St. Stephen and Staples Mountain gabbros in the Calais quadrangle, and Larrabee et al. (1965) were the first to mention compositional variations in the Pocomoonshine gabbro-diorite. The most extensive and detailed studies of plutonic rocks in the Big Lake quadrangle have been by Westerman (1972, 1973, 1978), who recognized lithologic and chemical variations within the Pocomoonshine pluton, and postulated a differentiation model for its development.

My mapping has focused on stratigraphic and structural complexities of the stratified rocks of eastern Maine, and my studies of the igneous rocks have aimed at understanding their relationships to the rock units and structural elements described earlier. I have thus not attempted a detailed investigation of the plutons, and only a brief summary of their rocks will be presented here. Those interested in details of the mineralogy, chemistry, and textures of the igneous rocks are referred to the references cited above.

Sequence of Intrusion

Throughout eastern Maine, mafic magmas have consistently been found to be the earliest materials intruded, followed by progressively more felsic bodies (Amos, 1963; Abbott, 1978; Coughlin, 1981; Ludman, 1978; Ludman and Hill, 1990). The Big Lake quadrangle is no exception to this scheme. The small felsic plugs found in the Pocomoonshine gabbro-diorite clearly cut layering and enclose xenoliths of the mafic rock. Relationships between the Love Lake quartz diorite and the felsic rocks are less clear, since the two types are nowhere in contact. The diorite is thought to be older than the granitoids, based solely on regional relationships.

The relationships between plutonism and tectonism, however, are quite clear, and provide a method for dating the deformational events. The Pocomoonshine gabbro-diorite cuts F_2 folds in both the Fredericton trough and St. Croix belt, and other gabbros cut F_1, F_2, and F_3 in the Calais quadrangle. In contrast, high-angle D_4 and D_5 faults cut the Pocomoonshine pluton, so that the age of the body serves as a minimum age for D_2 and a maximum age for D_4. Some of the granitic rocks that intrude the Pocomoonshine gabbro-diorite have a foliation that parallels D_5 faults, suggesting that their emplacement may have been contemporaneous with or controlled by D_5. Northwest-trending shears of D_6 cut all rocks of the area, including the plutons, indicating that D_6 was the last deformational event.

Pocomoonshine Gabbro-Diorite

The Pocomoonshine gabbro-diorite underlies most of the lowland and lake area in the east-central and south-central parts of the quadrangle, including Crawford, Lower Mud, Upper Mud, and Pocomoonshine Lakes. Its western contact with the Digdeguash Formation roughly coincides with the 200 contour on Seavey Ridge and with the 300 contour along Huntley and Hawkins Ridges. The elevation of these highlands is due to the erosional resistance of the aureole surrounding the pluton, a relationship also reflected by Cedar Grove Ridge on the east margin of the body. Mafic rock supports Pocomoonshine Mountain, one of the highest points of the quadrangle. This was apparently also due to a resistant hornfels cap, but most of that protective rock has been removed by erosion. Only a few roof pendants remain, exposed at the very top of the mountain.

Similar hills consisting of hornfels or hornfels and gabbro mark the northern edge of the pluton, but the southern boundary is in an area of thick glacial cover and is far less definite. Westerman (1972, p. 120-121) presented arguments based on gravity surveys that indicated the southern terminus of the body to lie within the Big Lake quadrangle, north of Route 9. Larrabee et al. (1965) mapped the pluton as extending across Route 9 into the Wesley quadrangle, and later mapping by Westerman (1978) supports this view. There is no outcrop at all in the area in question, and in the absence of bedrock control I have mapped the pluton as extending into the Wesley quadrangle where it forms part of a large bimodal plutonic complex (Westerman, 1978).

Larrabee et al. (1965) mapped a surface connection between the Pocomoonshine and Love Lake mafic bodies, but I have found metasedimentary rocks in part of the supposedly igneous terrain. It is clear from the high grade of contact metamorphism in the southeast corner of the Big Lake and southwest

corner of the adjacent Calais quadrangles that one or more mafic bodies must lie close to the surface there. Sub-surface connection of the Pocomoonshine and Love Lake bodies is considered likely, but they are not joined at the surface.

Shape. The subsurface shape of the Pocomoonshine gabbro-diorite is interpreted primarily on the width of its contact aureole and on gravity data. Steep contacts are indicated to the east and north where D_4 and D_5 faults truncate the pluton and its aureole. The western contact, however, is much gentler because the andalusite isograd extends more than 2 miles from the last surface exposure of igneous rock and other contact effects even farther. Andalusite grade rocks near Hosea Pug Lake and on Love Ridge and Harmon Mountain seem to be related to a granitic stock, not to the Pocomoonshine body.

Westerman (1972) cited gravity data as evidence for a sheet-like shape for the pluton, and concluded that it is a floored intrusion with a likely thickness of 1.6-4.8 km. Heat flow models based on mineral assemblages and mineral chemistry in Digdeguash Formation hornfelses, along with estimated liquidus temperatures for the gabbro, suggest that the lower figure may be more reasonable (Bromble, 1983; Ludman et al., 1989). Smaller sheet-like bodies of layered gabbro also crop out just a few miles to the east in the Calais quadrangle (Ludman, 1974; Coughlin, 1981, 1982).

Lithology. A wide variety of rocks is found within the pluton, ranging from peridotite to quartz diorite. Larrabee et al. (1965, p. 119) noted this variation, but Westerman (1972) was the first to demonstrate that the pluton is systematically zoned. He showed that exposures at the highest elevations (e.g. on Pocomoonshine Mountain) and those in the northwest part of the pluton are the most mafic, and that outcrops at lower elevations and to the south are of progressively less mafic rock. His zones included troctolite at the top of Pocomoonshine Mountain; pyroxene, pyroxene+hornblende, and hornblende gabbros beneath the northern part of Pocomoonshine Lake; and a variety of hornblende diorites, some containing quartz and biotite, forming the bulk of the southern part of the body. My field work and preliminary petrographic examination generally agree with Westerman's (1978) conclusions. His modal analyses of representative rocks from each of the zones are summarized in Table 1. Those seeking more details of mineralogy and texture are referred to Westerman (1972).

Small, discontinuous ultramafic masses are found in several places in the pluton. Most are restricted to the more mafic upper part of the body, but three have been found at the level of Pocomoonshine Lake—at the north shore and on two of the more northerly islands. These rocks are very dark gray to black, and Westerman (1972) identified them as olivine norite and feldspathic hornblende-bearing mica peridotite.

The compositional variations in the pluton are clearly reflected by color changes from northwest to southeast. Melanocratic and mesocratic rocks underlie most of Pocomoonshine Mountain, whereas mesocratic and leucocratic rocks comprise most of the lake-level exposures. Diorites in the southeastern part of the body are particularly light colored, with a distinctive salt-and-pepper appearance.

Three types of foliation have been observed within the pluton. A primary compositional banding is weakly developed in the more mafic parts of the body near Pocomoonshine Mountain and is expressed as alternating bands of dark colored mafic rock and slightly lighter, somewhat more feldspathic material. Boundaries between layers are diffuse and do not display the sharp top and bottom contacts typical of the cumulate rocks of the Staples Mountain gabbro in the Calais quadrangle. Another primary foliation appears to be due to mixing or mingling of two different magmas. Leucocratic layers, some containing quartz, occur with meso- and melanocratic layers in which hornblende and pyroxene are abundant. Contacts are diffuse and some of the layers anastomose. A secondary foliation caused by shearing is also present in places. It is defined by parallelism of chlorite flakes and smearing of grains in mafic mylonites parallel to D_4 faults. Close-spaced fractures typify the Pocomoonshine Mountain fault where it cuts the mafic rocks, but no foliation has been observed along its trace.

Mineralization. Finely disseminated sulfides, including pyrite, pyrrhotite, pentlandite, and chalcopyrite, are found throughout the Pocomoonshine gabbro-diorite, but generally comprise less than 1% of the rock. These minerals commonly occur as small single crystals, but glomerocrysts as large as 3 cm in diameter may be present locally. Concentrations of these minerals have not been sufficient to warrant industrial interest.

Gossan associated with the Pocomoonshine Mountain fault, however, was prospected by the El Paso Natural Gas Company in 1971. Secondary mineralization in this fault occurred where it cut the pluton on the northwest slope of Pocomoonshine Mountain and resulted in enrichment of chalcopyrite, pyrrhotite,

TABLE 1: REPRESENTATIVE MODAL ANALYSES OF THE POCOMOONSHINE GABBRO-DIORITE*
(Data compiled from Westerman, 1972)

Mineral	1	2	3	4	5	6	7	8
Plagioclase	31-51%	48-71%	17%	0-25%	50-70%	41-53%	38-55%	44-61%
Olivine	33-66	5-17	7	12-25	—-	—-	—-	—-
Orthopx	tr—5	0—4	57	20-48	7-34	0-14	—-	—-
Clinopx	1—8	20-40	15	tr—3	0-39	tr-13	—-	—-
Hornblende	1—3	tr—5	1	12-35	tr-11	17-55	41-59	24-46
Biotite	—-	—-	1	4-20	tr-2.5	0—9	0-tr	2-12
Opaques	1	tr-1	2	tr—1	tr—4	tr—2	tr—4	1—3
Quartz	—-	—-	-	—-	0-0.5	0—9	0-tr	0-14
Apatite	—-	—-	-	—-	0—2	0—1	0—1	tr—2

*Ranges are shown because of wide variability within each rock type.

1. Troctolite (2 analyses)
2. Olivine gabbro (5)
3. Olivine norite (1)
4. Feldspathic mica peridotite (3)
5. Gabbro-norite (9)
6. Pyroxene-bearing hornblende gabbro (5)
7. Hornblende gabbro-diorite (8)
8. Biotite and/or quartz-bearing hornblende diorite (13)

and pentlandite to several times their normal abundances. The rock in the fault zone is a deeply weathered, highly friable limonite- and iron sulfate-stained mafic fault gouge. Westerman (1972, p. 120) suggested that enrichment was caused by hydrothermal fluids that had leached the sulfides from elsewhere in the pluton. This seems to be the most likely explanation, particularly since the sulfides in the mineralized zone are the same as those found throughout the body.

Evolution of the pluton. Westerman (1972, p. 91-118) suggested that crystallization of the visible part of the pluton involved differentiation of an original tholeiitic magma, with solidification following a downward migrating crystallization front. Magma convection and ion diffusion at the front were thought to have controlled the history of the upper part of the body. Later studies of major and trace element fractionation support this model (Westerman, 1981). The peridotite masses are inferred to be of primary magmatic origin rather than mantle xenoliths. They were probably local concentrations of ferromagnesian minerals that eventually sank through the upper part of the body to their final positions.

Westerman (1972, p. 120-126) used gravity data to identify high-density cumulate rocks at depth within the pluton, implying that the body may have cooled symmetrically and that the hornblende-quartz diorites at lake level in the south may represent the most differentiated residual liquid. Coughlin (1981, 1982) suggested precisely this evolution for the much smaller Staples Mountain pluton in the Calais quadrangle, and the presence of other small, strongly differentiated and layered mafic masses in the Calais area suggests that this evolutionary scheme was common in the gabbroic portion of the Bays-of-Maine Igneous Complex.

Studies of the thermal history of the Pocomoonshine pluton, however, suggest a history of multiple magma injections separated by enough time to permit cooling in the aureole (Bromble, 1983; Ludman et al., 1989). This model envisages early intrusion of gabbro, followed by emplacement of a larger mass of diorite. The gabbro may have been injected as a sheet-like body, but the diorite is thought to have been more irregular.

Age. The absolute age of the Pocomoonshine gabbro-diorite is vital in reconstructing regional tectonic history, as well as in setting a minimum age for the unfossiliferous host rock that it intrudes. Unfortunately, the age of the body is not firmly established. Westerman (1972, p. 148; 1973) reported K/Ar ages of biotite from a peridotite lens and hornblende from a hornblende gabbro as 408 14 and 423 24 m.y. respectively—both Silurian ages. As discussed above, these ages are difficult to reconcile with stratigraphic ages based on on-strike continuation of the Flume Ridge Formation into Silurian strata of central Maine, and with the Late Silurian and Siluro-Devonian ages proposed for the Digdeguash and Flume Ridge Formations by Ruitenberg (1967).

Neither the radiometric nor the stratigraphic arguments are totally convincing at this time. Ruitenberg (pers. commun., 1982) has pointed out that K/Ar ages for mafic rocks in New Brunswick have often proved extremely unreliable, and problems of excess argon in mafic rocks are well known. On the other hand, the facies interpretation on which the ages of the Flume Ridge and Digdeguash Formations were first established has been refuted (Fyffe, pers. commun., 1989). Attempts to date related mafic rocks in the Calais quadrangle are now focusing on Nd/Sm and Rb/Sr mineral pair techniques, but are not yet completed. Microfloral remains reported earlier indicate that the Flume Ridge Formation is probably of Silurian or Siluro-Devonian age, suggesting an Early Devonian age for the pluton.

Love Lake Quartz Diorite

Mesocratic rocks of quartz dioritic composition are exposed on the dirt road east of Love Lake in the southeast corner of the Big Lake quadrangle, where they intrude high grade hornfelses of the Woodland Formation. The area is one of thick glacial cover so that the contacts of this body are difficult to define, but Westerman (1972) indicated that the diorite occupies the entire lowland filled by Love Lake. Only the northernmost part of this pluton lies in the Big Lake quadrangle; the largest portion is in the northern part of the adjacent Wesley quadrangle.

Thin sections of quartz diorite from the Love Lake pluton are very similar to those from the southeastern margin of the Pocomoonshine gabbro-diorite near Cedar Ridge, but the two are mapped as separate bodies (at least on the surface) for the reasons presented above.

Other than by possible connection with the Pocomoonshine pluton, there is little evidence for the age of the Love Lake quartz diorite. It appears to cut D_2 and D_3 folds, and an Early Devonian age is considered most likely.

Granitic Rocks

Small bodies of granite crop out in the southwestern part of the map area, intruding the Digdeguash Formation and hornblende diorites of the Pocomoonshine pluton. In addition, a portion of the Lead Mountain pluton is exposed in the northwest corner of the quadrangle on Amazon Mountain. Larrabee (1964) and Larrabee et al. (1965) mapped two granitic plugs in the southwest corner of the quadrangle. One of these, Larrabee's "Love Ridge Quartz Monzonite," is much smaller than he mapped it, and the other does not seem to exist at all.

Love Ridge Quartz Monzonite. Larrabee (1964) mapped most of Love Ridge and lowlands to the northeast and southwest as being underlain by granite, but showed little outcrop control for this body's size and shape. I have found small granite outcrops on the road leading west onto Love Ridge and a few others nearby, but chlorite grade rocks of the Flume Ridge and Digdeguash Formations crop out within the area designated as either pluton or contact aureole by Larrabee (1964). Accordingly, a much smaller body is shown on the accompanying geologic map. A small apophysis of the Love Ridge quartz

monzonite was shown by Larrabee (1964) extending northeastward from Hosea Pug Lake. I was unable to find granitic bedrock in the designated area, although the Digdeguash Formation there has been heated to andalusite grade. Large granite float blocks are very abundant between Love Ridge and Hosea Pug Lake, but these appear to have come from the Lead Mountain pluton, located in an up-glacial direction from the area, rather than from a pluton exposed locally at the surface. The apophysis is thus not shown on the geologic map. There is possibly a granitic body that comes close to the surface in the area, but it is not exposed.

The Love Ridge pluton, considerably reduced in size, is nonetheless there and is composed of medium grained (0.5-2.5 cm) gray biotite quartz monzonite. The few exposures on the east slope of Love Ridge are of hypidiomorphic granular to subporphyritic rocks lacking primary or secondary foliation. Small shears cut one of the outcrops, but do not result in extensive cataclasis.

Granitic Rocks Cutting the Pocomoonshine Gabbro-Diorite. Two small bodies of biotite granite have been mapped within the Pocomoonshine gabbro-diorite. These are composed of chalky weathering, light gray, medium to coarse-grained granite that locally shows strong foliation. Quartz (37-44%), microcline (32-35%), and albite (15-18%) are the principal constituents, with smaller amounts of biotite. Garnet and zircon are the most abundant accessory minerals.

Foliation defined by parallelism and concentration of biotite flakes is most obvious near the contacts of these small bodies, but can be observed within them as well. In all instances, foliation parallels D_5 fault traces. Pegmatite and aplite veins associated with the granites cut the adjacent mafic and intermediate rocks. Contact reaction between granite and diorite has produced a thin (2 cm) rim of hybrid rock around the southern granite body.

The Pocomoonshine pluton has intensely metamorphosed the Digdeguash Formation near these bodies, and locally caused partial melting (see below). Small in situ pods of anatectic melt similar to the rocks of these two bodies are common in the migmatized Digdeguash Formation, and the small plugs may represent the largest masses of mobilizate in the quadrangle.

Lead Mountain Pluton. Nearly all of Amazon Mountain is underlain by granitic rocks mapped by Larrabee et al. (1965) as part of the Wabassus Lake quartz monzonite. In a more recent study, Loiselle and Ayuso (1979) incorporated these rocks into their Lead Mountain pluton, a large intrusion with an area of approximately 1400 km^2. They indicated that this pluton is distinctly different from the Bottle Lake Complex to the north, and is separated from it by the Norumbega fault zone.

The rocks on Amazon Mountain are medium grained, pinkish-gray granites composed of quartz, pink microcline, and white albite/oligoclase, with very minor amounts of biotite and hornblende. Grain size is somewhat finer than that reported by Larrabee et al. (1965, p. 21) for the Wabassus Lake pluton, and the Amazon Mountain exposures probably represent a slightly chilled border facies. Although the rocks on Amazon Mountain are thought to be cut by two branches of the Norumbega fault zone, they show only slight evidence of cataclasis, and nothing like the mineralized fault gouge observed in the Pocomoonshine gabbro-diorite.

Ages of the Granitic Rocks. Radiometric ages have not been determined for any of the granitic rocks discussed here. These rocks cut D_2 isoclinal folds in the Digdeguash and Flume Ridge Formations as well as intrusive rocks of the Pocomoonshine gabbro-diorite and must be younger than these features. At least one of the bodies, the Lead Mountain pluton, is cut by D_5 faults, although the small granite plugs within the Pocomoonshine pluton show a foliation suggestive of emplacement during D_5.

The structural positions of these rocks are comparable to those of similar granitoids in adjacent areas: the Bottle Lake pluton in the Scraggly Lake, Springfield, Winn, and Wabassus Lake quadrangles; the Pokiok pluton in the Danforth, Amity, and Forest quadrangles; and the Baring, Charlotte, and Meddybemps granites in the adjacent Calais quadrangle. All of these bodies have been dated radiometrically as Early to early Middle Devonian (Faul et al., 1963; Spooner and Fairbairn, 1970; Ayuso and Arth, 1983), although Jurinski has reported a preliminary Silurian age for the Baring granite (see Ludman and Hill, 1990). An Early Devonian age is proposed for the granites of the Big Lake quadrangle, although temporal relationships among the different bodies are unknown.

METAMORPHISM

Metamorphism of the stratified rocks in the Big Lake quadrangle, indeed of most of the rocks in southeastern Maine, was thermal, controlled by emplacement of mafic and felsic plutons following D_3 deformation. Regional metamorphism is observable only in areas far from pluton contacts, where it is indicated by a weak foliation of muscovite and chlorite flakes in pelitic rocks and by formation of these minerals in sandstones of appropriate composition.

Regional Metamorphism

Regional metamorphic intensity was uniformly very low in eastern Maine, corresponding to conditions of the lower greenschist facies (chlorite zone) regardless of the age or structural complexity of the rocks. Thus, the Cookson Group has undergone only chlorite grade regional metamorphism despite having been intensely folded before deposition of the Fredericton trough strata, and twice afterward. Neither pre-Silurian (D_1) nor Acadian ($D_{2,3}$) deformation in the Big Lake quadrangle were accompanied by metamorphism more intense than chlorite grade. Similar low grades were recorded by pre-Silurian rocks of the Miramichi anticlinorium to the north (Ludman, 1981, 1983) and the Siluro-Devonian volcanic rocks to the south (Gates, 1977). The rocks of eastern and southeastern Maine thus

preserve only the shallowest crustal history of these Paleozoic orogenic events.

Mineral assemblages of the metasedimentary rocks in the chlorite zone include: muscovite-quartz-plagioclase (arenites of the Kendall Mountain Formation); muscovite-chlorite-quartz-plagioclase-carbon-pyrite (Kendall Mountain Formation and Pocomoonshine Lake pelites); chlorite-muscovite-quartz-plagioclase (pelites of the Digdeguash Formation and non-calcareous rocks of the Flume Ridge Formation); and chlorite-muscovite-quartz-plagioclase-calcite ankerite (calcareous rocks of the Flume Ridge Formation). Rock fragments are also present in the coarse clastic rocks of the Kendall Mountain and Digdeguash Formations. Neither the Woodland nor Calais Formations are exposed in chlorite grade outcrops.

Contact Metamorphism

Well developed thermal aureoles surround the plutons of eastern Maine, particularly mafic bodies such as the Pocomoonshine gabbro-diorite. Contact effects range from a slight increase in grain size of muscovite and the appearance of biotite, to partial melting of the Digdeguash Formation at the contact with the gabbro. Intermediate conditions are indicated by the appearance of cordierite, andalusite, garnet, staurolite, and sillimanite in pelitic rocks; clinozoisite, actinolite, diopside, garnet, and wollastonite in calcareous rocks; and chlorite and actinolite in mafic metavolcanic rocks. The aureoles are mostly raised to conditions of the albite-epidote hornfels and hornblende hornfels facies, but the innermost zones of the mafic aureoles and xenoliths in the gabbros contain assemblages of the pyroxene hornfels facies.

Most of the thermally metamorphosed rocks display either an equidimensional granoblastic texture or a porphyroblastic texture where one or more of the index minerals have formed. A strong schistosity, however, is found in pelites of the Woodland and Digdeguash Formations at high grade, where mimetic crystallization of muscovite has preserved and heightened original S_2 regional metamorphic foliation.

Each of the formations can be traced through a distinctive series of textures and mineral assemblages with increasing metamorphic grade. This permits them to be readily identified at any grade, and also requires that these changes be detailed here.

Cookson Group. Pelites in all formations of the Cookson Group change markedly with increases in grade. Carbonaceous pelites are converted from sooty, strongly cleaved slates to black, somewhat sooty dense hornfelses with only limited fissility. Small porphyroblasts of cordierite and andalusite form in medium grade carbonaceous pelites, and both poikiloblastically enclose carbon, quartz, and mica grains. Cyclic radial twinning is commonly present in the cordierite, and inclusions in that mineral may also preserve S_2 and S_1 foliations. The rusty weathering of low grade exposures is in many cases enhanced in the higher grade rocks. Typical assemblages, all including carbon and sulfide are: muscovite-quartz-plagioclase-cordierite; muscovite-plagioclase-quartz-cordierite-andalusite. Sillimanite appears in place of andalusite near gabbro contacts, and sillimanite-potassic feldspar assemblages are common near the migmatite zones.

Psammites of the Cookson Group vary in their response to metamorphism. Arenites and wackes of the Kendall Mountain Formation change little mineralogically, but recrystallize to denser textures with sutured grain contacts. Wackes of the Woodland Formation become purplish at the biotite isograd and a dense granofels is produced. Interbedded pelites increase in grain size and 0.5 to 1.5 mm muscovite flakes appear in both carbonaceous and non-carbonaceous types. Higher grades are marked by the appearance first of small equant porphyroblasts of cordierite and then by andalusite crystals the size and shape of grains of rice. These minerals form in both sandstone and pelite of the Woodland Formation, but are largest and most abundant in the pelites. On weathered surfaces, cordierite is removed to form small pits whereas andalusite stands up slightly in relief. Most primary sedimentary features survive until the sillimanite isograd, but even bedding disappears in the innermost migmatite zones of the contact aureoles. Sillimanite first appears as white fibrolite needles in pelites, but occurs as greenish or gray prisms a few millimeters long near the gabbro contacts in both pelite and sandstone.

Characteristic assemblages in the Woodland Formation include: muscovite-biotite-quartz-cordierite-plagioclase; muscovite-biotite-quartz-plagioclase-cordierite-andalusite; muscovite-biotite-quartz-plagioclase-sillimanite; and muscovite- biotite-quartz-plagioclase-sillimanite-microcline. Small flakes of muscovite and chlorite partially replace cordierite, and sericite commonly replaces andalusite, probably as a retrograde product associated with emplacement of granitoids following higher-grade metamorphism associated with the gabbros.

Anatectic migmatite zones surround mafic rock bodies intruded into the Woodland Formation and exhibit distinctive textures and mineralogy. Chalky white-weathering quartzofeldspathic leucosome with small sulfide-rich knots occurs as massive outcrops engulfing discontinuous, swirling rafts of melanosome composed of sillimanite, biotite, quartz, microcline, plagioclase, and sometimes muscovite. Green spinel is present in a few localities as well. Andalusite and cordierite porphyroblasts survive metastably in some of the melanosomes. Gneissic rocks composed of alternating leucosome and melanosome bands 1-2 mm thick are common. In situ mobilizate pods and lenses ranging from a few centimeters to about a meter in length characterize migmatites in the southwest part of the Calais quadrangle, but have not been observed in adjacent parts of the Big Lake area because of poor outcrop control. Pyrite is present in all assemblages and as a result the rusty weathering characteristic of the entire Cookson Group is always present.

Digdeguash Formation. Progressive thermal metamorphism of the Digdeguash Formation is well illustrated by exten-

sive exposures between Third Chain Lake and Seavey Ridge, and many of the details of this metamorphism have been discussed elsewhere (Bromble, 1983; DeMartinis, 1985; Ludman et al., 1989). Only general aspects of these rocks will be summarized here.

It is difficult to establish what minerals form first after chlorite in Digdeguash Formation pelites in the contact aureole of the Pocomoonshine gabbro-diorite because of sparse exposures in the outer part of the aureole. Biotite and andalusite seem to appear at nearly the same distance from the gabbro contact. Within the andalusite zone, increasing metamorphic intensity is shown by a gradual increase in the size of gray chiastolitic crystals to a maximum of 20 cm long, development of a phyllitic sheen due to growth of muscovite and biotite flakes parallel to S_2, and a darkened color caused by an increase in biotite content. Slender chiastolite crystals are abundant and comprise as much as 35% of pelitic horizons on Seavey Ridge. Andalusite zone assemblages, all containing muscovite and quartz, include: chlorite-biotite-plagioclase; biotite-plagioclase; biotite-plagioclase-andalusite; biotite-garnet-plagioclase. Garnet is not common and seems to be restricted to a few sulfide-rich layers. It is largely made up of the almandine component (76.8%) with lesser amounts of pyrope (6.8%), spessartine (14.2%), grossularite (2.2%), and shows weak zoning with cores slightly enriched in spessartine (Bromble, 1983; Ludman et al., 1989). Very pale yellow staurolite has been identified in two thin sections from andalusite grade rocks, but is rare.

Sillimanite first appears as needles, then mats of fibrolite intergrown with biotite, so that sillimanite zone biotite flakes typically have a silky appearance recognizable in the field. Fibrolite also rims and replaces andalusite crystals. Prismatic sillimanite first appears near the sillimanite-K-feldspar isograd and increases in size until the gabbro contact. Partial melting occurred close to the contact, and migmatized Digdeguash Formation hornfels is well exposed along lumber roads on Seavey Ridge (Ludman, 1978; DeMartinis, 1985). Dark sillimanite-rich melanosome rafts are engulfed in quartzofeldspathic leucosome, as is the case with the migmatites of the Woodland Formation, but neither rusty weathering nor relict cordierites are found in the Digdeguash Formation. Pink andalusites are found in quartz-andalusite pods in the higher grade parts of the contact aureole, and complex textural relationships suggest a multiple metamorphism (and hence multiple magmatic injection) history for the Pocomoonshine pluton (Ludman et al., 1989). Temperatures of 710°-805° have been estimated for migmatite melanosomes by two-feldspar geothermometry (Bromble, 1983), but slightly lower temperatures are indicated by iron-magnesium partitioning in biotite-garnet pairs (Bromble, 1983; Ludman et al., 1989). Maximum pressure during emplacement of the Pocomoonshine gabbro-diorite is estimated at 2.5-2.75 Kbars.

Flume Ridge Formation. Changes in the appearance of the Flume Ridge Formation with increasing metamorphic grade have already been outlined above. The most drastic change is from the light gray fresh color and orange-brown weathered surface of chlorite grade exposures to the buff weathering and purple fresh color in biotite grade outcrops. With the appearance of biotite, most Flume Ridge Formation rocks become massive, dense granofelses. Rocks with thin calcite-rich layers become "zebra-striped" with purplish biotite-quartz-plagioclase granofels alternating with blue-green calc-silicate granofels. Typical assemblages in the more calcareous rocks are: biotite-quartz-plagioclase-calcite, biotite-actinolite-quartz-plagioclase, and biotite-chlorite-quartz-plagioclase-calcite. Diopside appears near the contact with the Pocomoonshine gabbro-diorite, and wollastonite has been identified in Flume Ridge Formation xenoliths near the base of Pocomoonshine Mountain. There is no sign of anatexis of the Flume Ridge Formation, and no sillimanite has been observed in its more argillaceous horizons.

SUMMARY OF GEOLOGIC HISTORY

It is difficult under the best of circumstances to reconstruct geologic history for an area which contains less than 1% bedrock exposure. Where the ages of the stratified rocks and of the plutons that intrude them are open to question, the problems are even more severe. Some tentative conclusions concerning the sequence and timing of events have been reached, however, and these are summarized in Figure 4.

The earliest event recognized in the Big Lake area was deposition of the Calais Formation in an anoxic basin during earliest Ordovician times. Crustal instability, perhaps related to continued subsidence of the western margin of the Avalonian platform, led to the influx of voluminous turbidites of the Woodland Formation. Arenites, quartzites, and shales of the Kendall Mountain Formation followed, and the increased maturity of the sediments may reflect a cessation of tectonism along the western margin of Avalon. The span of time represented by deposition of the Cookson Group probably records the final stages in the foundering of the margin of Avalon during opening of the Iapetus Ocean.

Several timing schemes are possible for post-Cookson events, depending on what ages are assigned to the Fredericton trough strata and the Pocomoonshine Formation gabbro-diorite. The possible age ranges of events are shown in dashed lines in Figure 4, with my preferences shown in solid lines. The discussion that follows is based on these prejudices.

(Whatever scheme is chosen, however, direct evidence for the original relationships between the Fredericton trough and St. Croix belt is lacking because their contact is everywhere tectonic in nature. Based on Ruitenberg's (1967) age assignments for the Digdeguash and Flume Ridge Formations, the absence of F_1 from the Fredericton trough, and the lack of compelling arguments for the South Princeton-Crawford fault zone to be a major Acadian or post-Acadian suture, the Pocomoonshine Lake and perhaps Digdeguash Formations are thought to have originally rested with angular unconformity upon exposed units of the Cookson Group.)

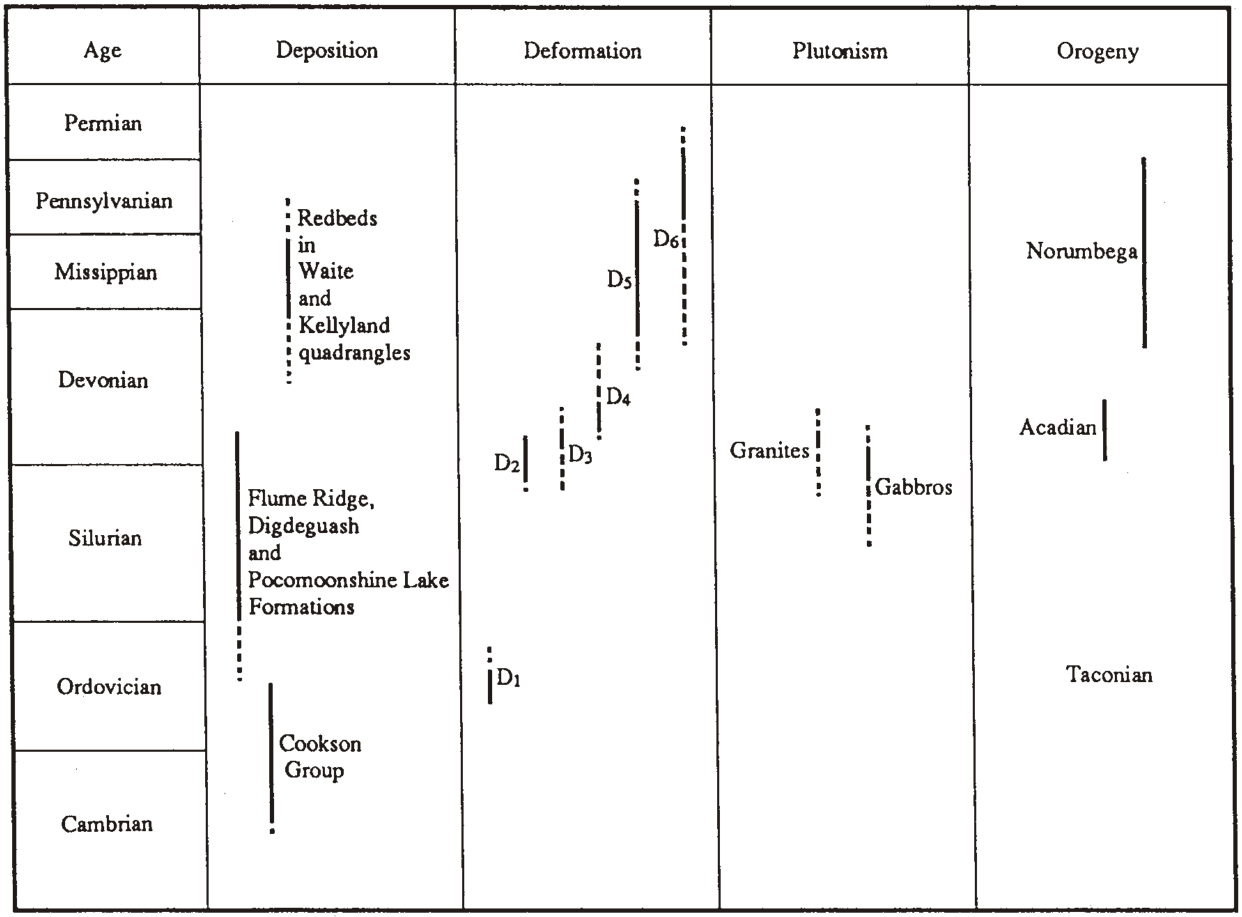

Figure 4. Summary of geologic history. Dashed lines = possible ranges; solid lines = suggested ages.

Following deposition of the Cookson Group, an episode of tight to isoclinal folding (F_1) affected the St. Croix belt. This deformation postdated the Middle Caradocian Kendall Mountain Formation, but its minimum age is not tightly constrained. D_1 may be related to the Middle Ordovician Taconian orogeny or may have been synchronous and unrelated. If the former is correct, connection between Avalon, Miramichia, and ancestral North America is implied as early as Caradocian times. In the latter case, D_1 could represent an amalgamation of plates on the west margin of Avalon that corresponds to a larger scale accretion of plates to North America during the Taconian orogeny.

Deposition of the Pocomoonshine Lake, Digdeguash and Flume Ridge Formations followed, during Silurian (possibly Late Ordovician) through Early Devonian (?) times. The change from coarse polymictic grits of the Digdeguash Formation to the finer grained calcareous strata of the Flume Ridge Formation suggests progressive lowering of the (Taconian?) source regions during filling of the Fredericton trough. Volcanic, hypabyssal igneous, schist, and abundant quartz clasts in Digdeguash Formation grits indicate that this source was complex and at least partly continental. Felsic volcanic clasts in the Digdeguash Formation are similar to felsites in the Kendall Mountain Formation, but could also have been derived from either the Precambrian Coldbrook Group to the east or volocanic rocks of the Tetagouche Group to the west. The nature of the Fredericton trough is uncertain. It may have been a remnant oceanic basin separating Avalon from the Miramichi anticlinorium and ancestral North America, or a marginal sea behind a Miramichi or coastal volcanic belt arc.

D_2 upright folding followed deposition of the Fredericton trough sequence, and probably represents the main phase of the Acadian orogeny in this area. Continued compression led to D_3 thrusting and folding in a later Acadian stage. Slight relaxation (transtension?) may have initiated D_4 normal faulting and provided access for magmas of the Pocomoonshine Formation gabbro-diorite and Love Lake Formation quartz diorite. D_4 probably began before and continued throughout emplacement of the mafic plutons. Intrusion of the granitic rocks followed D_4, and the entire region was then subjected to strike-slip faulting (D_5) that produced the Norumbega family of faults.

The Acadian orogeny is thought to mark the final accretion of the Avalonian continental block to North America (Hopeck et

al., 1989). D_4 and D_5 appear to have been post-accretion adjustments made to accommodate different continental shapes and times of collision along the Appalachian orogen.

D_6 faults offset every other structural element in eastern Maine and are clearly the youngest deformational features. There is little evidence for the latest date at which this event could have occurred. The Oak Bay fault is a northwest-trending structure that extends up the St. Croix River from Passamaquoddy Bay to Oak Bay, New Brunswick, parallel to D_6 faults. Foci of low magnitude earthquakes cluster in this fault zone, suggesting either that some D_6 motion is modern, or that D_6 faults are being reactivated today.

There is other evidence of neotectonic activity in the region. Several independent lines of research, including releveling of benchmarks, evaluation of historical records, and submergence of colonial and precolonial structures show that eastern Maine is currently subsiding at rates possibly as high as 9 mm/yr relative to northeastern and central Maine (Anderson and Race, 1980; Smith and Bridges, 1980; Tyler and Ladd, 1980). The highest rates of subsidence appear to be in the Calais-Big Lake area. The deformational history of the region has apparently not yet ended.

ECONOMIC POTENTIAL

At present, the only use being made of geologic materials from the Big Lake quadrangle is the mining of gravel from the glacial cover. The DiCenzo Construction Company of Calais has sporadically operated a road metal quarry in Flume Ridge Formation hornfels just west of the Princeton-South Princeton road, south of the junction with the lumber road that crosses Pocomoonshine Mountain. The most recent blasting was in 1982 and 1984, but the quarry is now abandoned and filled with ground water.

Two potential mineral deposits, both associated with the Pocomoonshine gabbro-diorite, have been explored, but neither proved profitable enough to be developed. The mineralized D_5 Pocomoonshine Mountain fault was prospected by El Paso Natural Gas Company in 1971, and several cores were drilled into the mafic gouge, but no further action was taken.

In 1979, the General Refractories Corporation examined pelitic hornfelses of the Digdeguash Formation along Seavey Ridge to determine the feasibility of operating an andalusite mine for the production of refractory brick. Samples of the hornfels richest in andalusite were collected and analyzed chemically and petrographically. Andalusite was reported to be abundant enough for mining, but the project was abandoned because the Fe_2O_3 content of the andalusite was too high (10%), the crystals were partly to severely retrograded to sericite, and the pelite only comprised 50% of the total hornfels (Glenn Jones, pers. commun., 1983).

There do not appear to be any other significant mineral occurrences in the quadrangle that warrant exploration. D_4 fault zones are extensively silicified in places, but I have not identified any minerals other than quartz and pyrite in these veins. Volcanic rocks of the Kendall Mountain Formation might be a source of sulfide minerals, but none have been identified and the unit is almost certainly too thin to be profitable. It is thus likely that, at least in the near future, sand and gravel will continue to be the most valuable geologic materials in the quadrangle.

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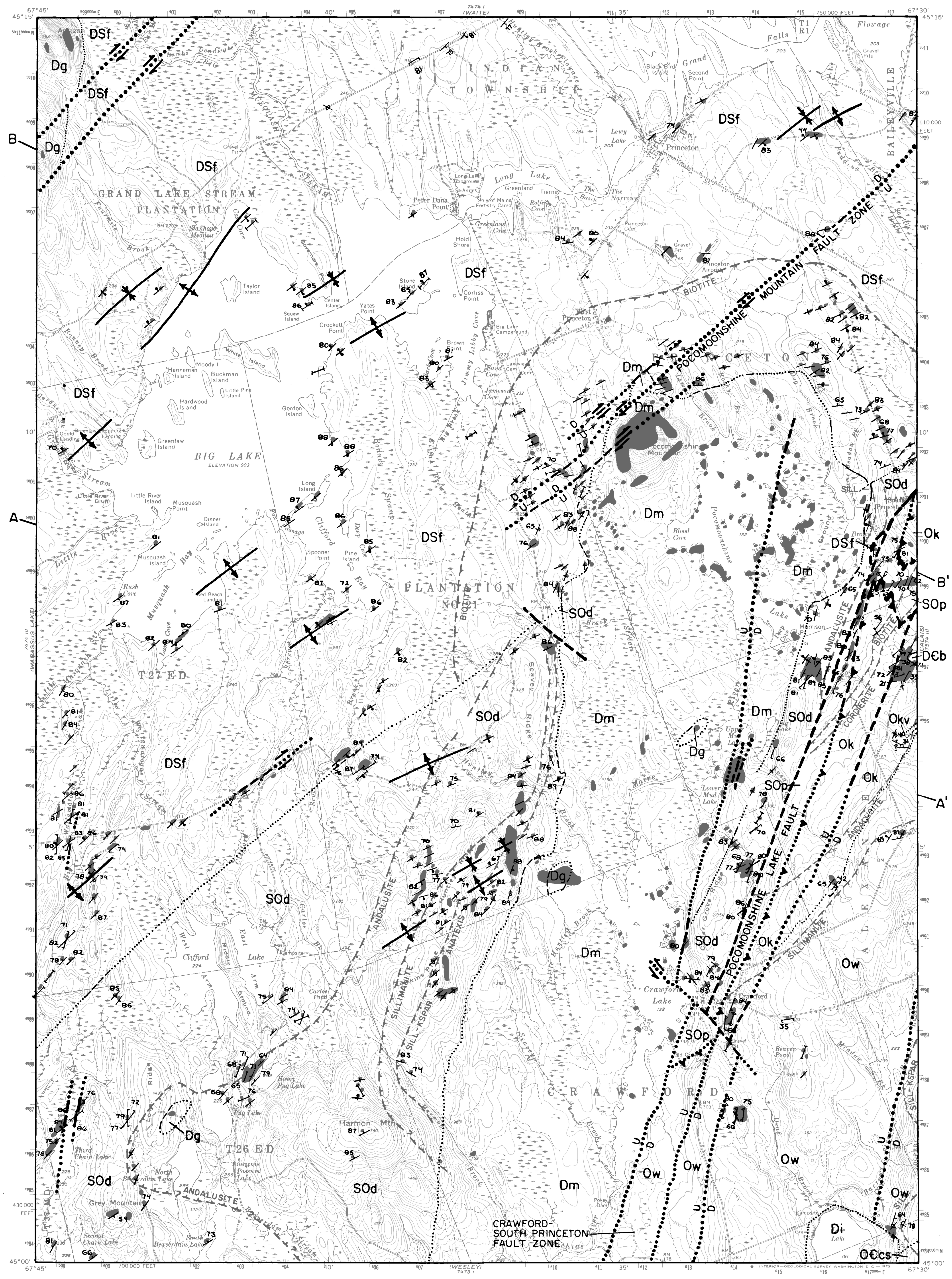


EXPLANATION

INTRUSIVE ROCKS

Dg	Granitic rocks; biotite granite and granodiorite	
Di	Love Lake quartz diorite	
Dm	Pocomoonshine Gabbro-Diorite Complex,	Including: Mica peridotite, troctolite, norite, gabbro, diorite
DЄb	Baileyville Dike	

STRATIFIED ROCKS

DSf	Flume Ridge Formation	Variably calcareous sandstones, siltstones, and slates. Green and ankeritic in chlorite zone, with large detrital muscovite flakes. Purplish in biotite zone, with blue-white calc-silicate layers, stringers, and pods.
SOd	Digdeguash Formation	Well graded, gray, turbiditic grits, sandstones, and slates. Characterized by large andalusite crystals in contact aureoles. At highest metamorphic grade, anatexis produces migmatitic sillimanite gneiss.
SOp	Pocomoonshine Lake Formation	Thinly laminated carbonaceous pelite and siltstone.

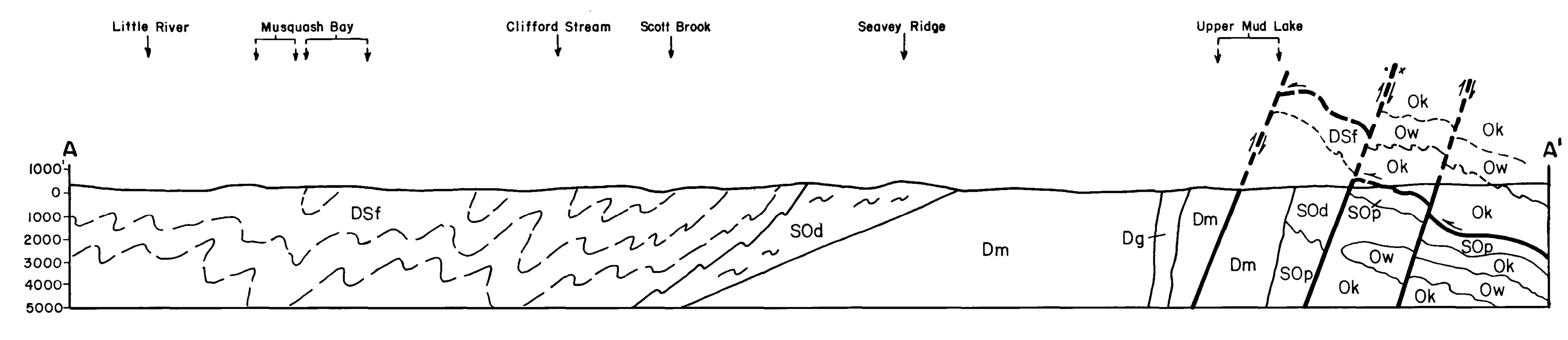
Inferred Unconformity

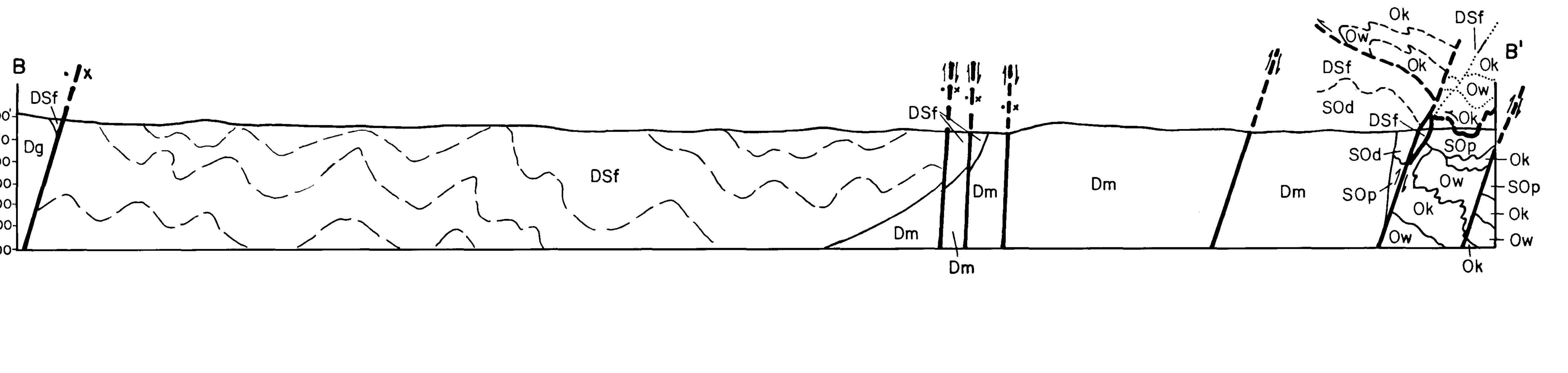
COOKSON GROUP

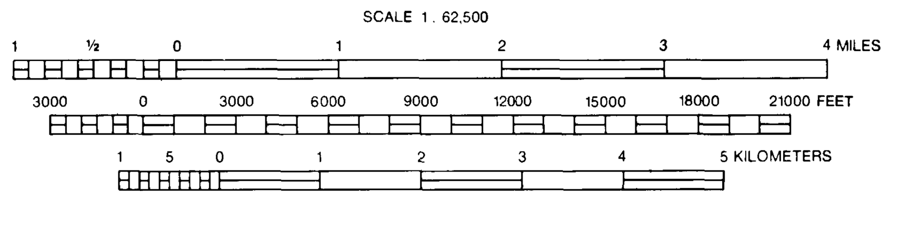
Ok	Kendall Mountain Formation	Quartzofeldspathic arenite interlayered with minor carbonaceous pelite; massive quartzite, quartzofeldspathic and lithic arenite; thin felsic tuffs and basalts.
Ow	Woodland Formation	Interbedded, well graded, quartzofeldspathic wacke and both carbonaceous and non-carbonaceous pelites; minor thick-bedded quartzofeldspathic wacke and calc-silicate granofels.
OЄc	Calais Formation	Interbedded black, highly graphitic, pyritiferous shale; pillowed and massive basalt; garnet-quartz coticule.
OЄcs		Black, highly graphitic, pyritiferous shale

SYMBOLS

- Lithologic contact: observed, covered, inferred
- Fault: observed, covered, inferred; showing offset
- Metamorphic isograd
- Axis of anticline
- Axis of syncline
- Bedding: inclined, showing facing
- Bedding: vertical, showing facing
- Overturned bed
- Trend of Bedding in pavement outcrop
- Cleavage: inclined, vertical
- Metamorphic foliation: inclined vertical
- Mylonitic foliation: inclined vertical
- Outcrop







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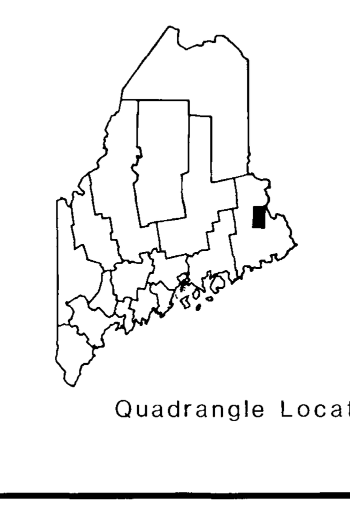

Quadrangle Location

BEDROCK GEOLOGY OF THE BIG LAKE QUADRANGLE, MAINE

BY
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1990

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