DEPARTMENT OF CONSERVATION
Maine Geological Survey

Robert G. Marvinney, State Geologist

OPEN-FILE NO. 03-93

Title: *Bedrock Geology of the Dill Hill 7.5' Quadrangle, Maine*

Author: *Allan Ludman*

Date: *2003*

Financial Support: Funding for the preparation of this report was provided in part by the U.S. Geological Survey STATEMAP Program, Cooperative Agreement

No. 99HQAG0119.

Contents: 16 p. report and map

Bedrock Geology of the Dill Hill 7.5' Quadrangle, Maine

Allan Ludman
School of Earth and Environmental Sciences
Queens College of the City University of New York
Flushing, New York 11367

INTRODUCTION

Location and purpose

The Dill Hill 7½' quadrangle is in northern Washington County, eastern Maine, midway between Springfield and Topsfield, and about 12 miles south of Danforth (Figure 1). Geologically, it straddles the boundary between the Aroostook-Matapedia and Miramichi terranes (Figure 2). The principal purpose of this STATEMAP project was to define the contacts between the two terranes and deduce the sequence of tectonic events that led to their juxtaposition. Additional goals were to refine the stratigraphy and structure of the Miramichi terrane which occupies most of the quadrangle, trace the contact between the Bottle Lake pluton and its host rocks, and evaluate potential mineral deposits in the area. This last goal was given additional impetus by the discovery of gold mineralization at the Maine-New Brunswick border a few miles along strike to the northeast of the study area.

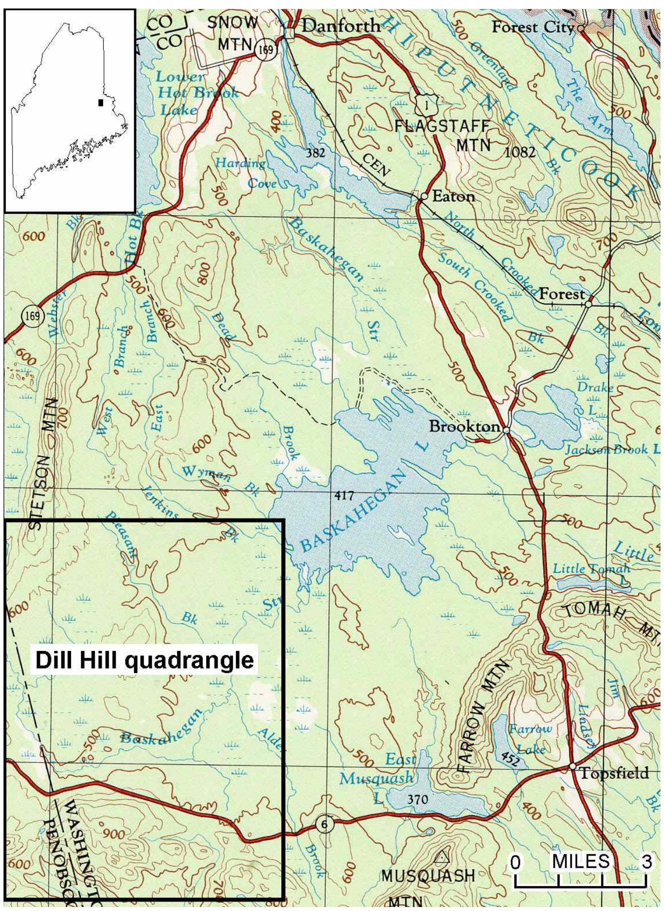


Figure 1. Location of the Dill Hill quadrangle.

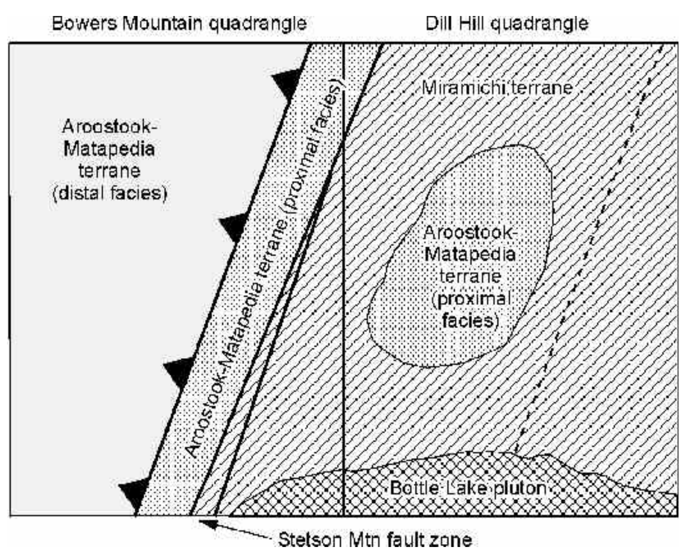


Figure 2. Tectonostratigraphic framework of the Dill Hill and Bowers Mountain quadrangles.

Geologic setting

The southern and eastern parts of the Dill Hill quadrangle are underlain by metasedimentary and metavolcanic rocks that continue northeastward into adjacent New Brunswick as the Cambrian-Ordovician Miramichi terrane (Potter and others, 1979). The Stetson Mountain fault, which separates these rocks from younger clastic rocks of the Aroostook-Matapedia terrane to the west, is exposed in the northwest corner of the quadrangle, and in the Bowers Mountain quadrangle immediately to the west (Figure 2). The younger clastic rocks, and the limestones and slates with which they interfinger to the west, have been traced northward in reconnaissance studies by Hopeck (1991) into the late Ordovician to middle Silurian strata of the Houlton area, defined by Pavlides (1974). The southern part of the quadrangle is occupied by the northern margin of the Bottle Lake pluton, one of the largest granitoid bodies of eastern Maine (Osberg and others, 1985).

Regional metamorphic grade is uniformly very low in eastern Maine, regardless of the age or structural complexity of the rocks. Thus, both polydeformed Cambrian through middle Ordovician Miramichi strata and simply folded late Ordovician through middle Silurian (?) Aroostook-Matapedia strata in the Dill Hill quadrangle experienced only lower greenschist facies (chlorite zone) conditions during deformation. More intense metamorphism occurred in the contact aureole of the Bottle Lake pluton. The innermost part of this aureole is characterized by sillimanite in pelitic rocks, the central part by cordierite and andalusite+cordierite assemblages, and the broad outer zone by biotite-grade hornfels.

Physiography

The study area is blanketed by glacial deposits, with less than 1% exposed bedrock. Although these deposits mask bedrock trends in much of the quadrangle, a varied physiography divisible into six zones reflects the major geologic components (Figure 3). Zone I contains the greatest elevations, with Dill Hill itself (1024') being the highest point in the quadrangle and unnamed hills in the SE corner of Zone I ranging around 1000'. This high ground is underlain by the Bottle Lake pluton (southern part Zone I) and its contact metamorphic aureole (northern part). Zone II is a lowland occupied by the Baskahegan Stream drainage and contains the lowest elevations in the quadrangle (430'-~500'). Bedrock exposures are very sparse in Zone II, but small knobs in the eastern part (II-A) with only 30' of relief provide numerous exposures of chlorite-grade Miramichi strata. Surficial deposits of Zone II obscure the contact between an outlier of proximal Aroostook-Matapedia rocks and the Miramichi terrane.

Zone III contains bedrock-cored hills underlain by proximal Aroostook-Matapedia strata that are covered by glacial deposits of widely varying thickness. Outcrops are abundant near hilltops and in streams in Zone III, but are also surprisingly common on a network of lumber roads in lower areas where only one or two feet of till locally mask bedrock. Unfortunately, the eastern part of Zone III is a thick blanket of sandy till and is nearly devoid of outcrop.

Zone IV is a series of gentle, southeast-facing slopes underlain by sandy and locally clay-rich till and has only a few outcrops of Miramichi volcanic and volcaniclastic rocks. Zone V is dominated by the northeast-trending ridge of Stetson Mountain, with elevations up to 956'. The ridge crest is underlain by highly resistant volcanic rocks of the Miramichi terrane, with glacial deposits occupying most of its southeast flank. Interestingly, similar rocks also underlie lowland portions of Zone IV. Zone VI is the southeastern terminus of an extensive area of lower elevation and lower relief than Zone V, and is underlain by Aroostook-Matapedia strata similar to those in Zone III.

Two distinctive north-northeast-trending topographic lineaments are shown by heavy dashed lines in Figure 3. The lineament at the northwestern corner of the quadrangle coincides with a strand of the Stetson Mountain fault zone that here separates the Miramichi and Aroostook-Matapedia terranes (Figure 2). The significance of the eastern lineament is less obvious, as Miramichi rocks crop out on both sides, yet it can be traced through several quadrangles. Cataclasite is exposed in two places in Baskahegan Stream just west of the lineament, suggesting a north-northeast-trending brittle fault parallel to and perhaps coeval with the Stetson Mountain zone.

Previous Work

Larrabee and others (1965) carried out mapping that included reconnaissance work in the Dill Hill and adjacent Bowers Mountain quadrangles and detailed work in the Danforth 15' quadrangle to the north. They proposed a pre-Silurian age for rocks of the Miramichi terrane. They more-or-less correctly traced the contact to the southeast between the Miramichi rocks and younger rocks of the Fredericton belt, and the contact to the northwest between the Miramichi rocks and the Aroostook-Matapedia terrane. They roughly sketched contacts between large granitic plutons and metasedimentary rocks of the three terranes.

My previous work in eastern Maine (summarized by Ludman, 1991; Ludman and others, 1993) revised Larrabee and others' (1965) stratigraphy, remapped contacts between terranes and between granites and stratified rocks, and recognized polydeformation in Miramichi strata. Rocks of the Miramichi terrane in Maine have been subdivided into three formations, based to a great extent on work in the Dill Hill quadrangle and adjacent Farrow Mountain quadrangle to the east, as shown in the lower half of Figure 4. Clasts of Miramichi units in the proximal facies enabled Hopeck (1991, 1994) to demonstrate post-Caradocian sedimentary linkage between the Miramichi source rocks and their fringing Aroostook-Matapedia debris apron. Hopeck also recognized the westward-fining sequence illustrated in the upper half of Figure 4, in which coarse

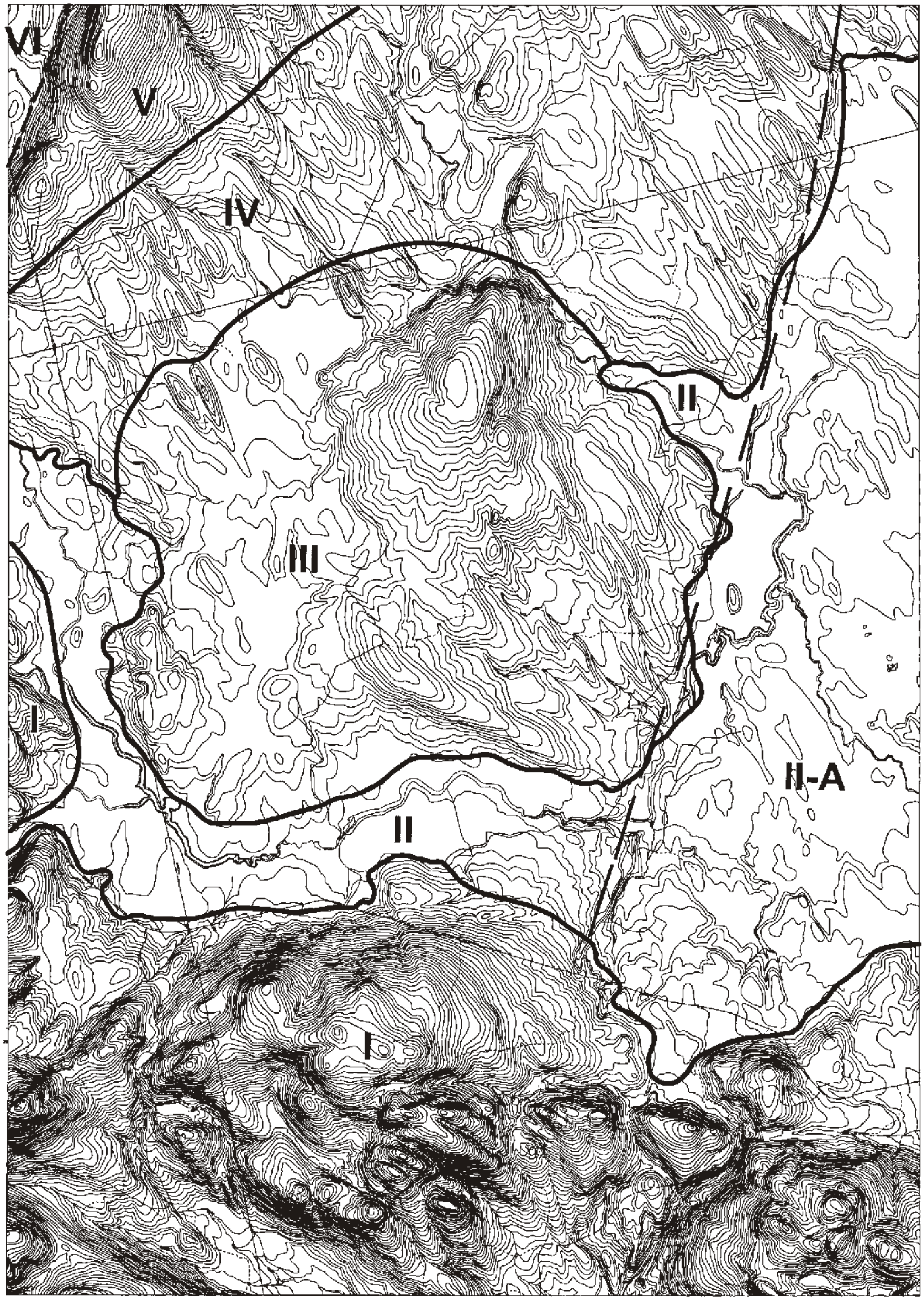


Figure 3. Physiographic subdivisions of the Dill Hill quadrangle described in the text. Dashed lines are topographic lineaments interpreted to be faults.

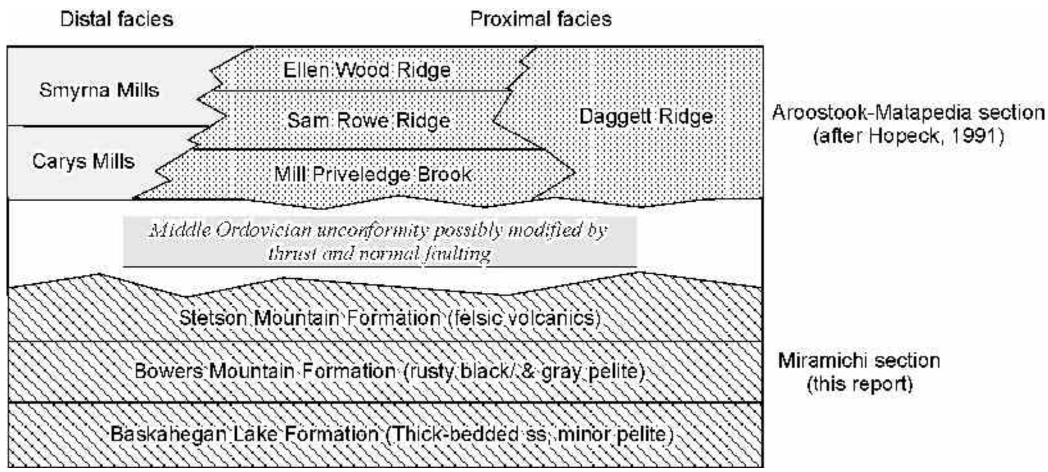


Figure 4. Schematic stratigraphic relationships of the Aroostook-Matapedia and Miramichi terranes in eastern Maine.

conglomerates (Daggett Ridge Formation) interfinger with progressively finger grained rocks and eventually pass westward into limestones and pelites correlated with the Carys Mills and Smyrna Mills formations, respectively, of the Houlton area (Pavlides, 1974).

Evidence for a post-Middle Ordovician unconformity is convincing northwest of the study area, but the absence of the Daggett Ridge and Mill Priveledge Brook Formations at the Miramichi contact in the Dill Hill quadrangle is problematic. A complex evolution is suggested for the present contact involving deformational as well as stratigraphic factors, and unraveling this evolution is one of the major purposes of this study.

Mangini (1982) attempted to model Miramichi polydeformation in volcanic and adjacent units in the Danforth 15' quadrangle. Sayres (1986) used a marker unit to delineate mappable early folds, and to separate effects of Caradocian folding from younger deformation. Sayres (1986) and Sayres and Ludman (1985) used major and trace element geochemistry to show that the Miramichi volcanic suite in Maine was related to Caradocian subduction.

Two large granitic batholiths, the Pokiok and the Bottle Lake plutons, seal the contact between the Miramichi terrane and the Fredericton belt east of the study area. The Pokiok pluton is northeast of the Dill Hill quadrangle, but the northern margin of the Bottle Lake pluton occupies most of the southern part of the map area. Ayuso (1984) mapped lithic variations within the Bottle Lake complex, developed a model for its petrogenesis, and documented its Middle Devonian age (Ayuso and others, 1984).

STRATIGRAPHY

Recent studies have revised or discarded many of the stratigraphic concepts proposed by Larrabee and others (1965). Most of the formation names shown in Figure 4 and on the geologic map have been used in eastern Maine for almost a decade, but are still informal because they have not been submitted to the Committee on Stratigraphic Nomenclature.

Miramichi terrane

Rocks of the Miramichi terrane in eastern Maine are divided into the Baskahegan Lake, Bowers Mountain, and Stetson Mountain Formations (Figure 4). Normal stratigraphic contacts between these units are not exposed – although some sheared contacts are visible – so that the age of the sequence described here is based on fossil localities adjacent to the present study area and on correlation with dated rocks in New Brunswick and other pre-Silurian tracts in northeastern Maine. The three formations are described first, followed by a discussion of their ages and of regional correlations.

Baskahegan Lake Formation (O€bl): The Baskahegan Lake Formation is the dominant stratigraphic unit in the Miramichi terrane in Maine. The formation was named from extensive exposures along the east and south shores of Baskahegan Lake in the Brookton 7.5' quadrangle, adjacent to the Dill Hill quadrangle on the northeast (Ludman, 1991). It consists for the most part of thick-bedded quartzose and quartzo-feldspathic wacke and arenite interbedded with subordinate siltstone and slate. Variations in color, bed thickness, grain size, and lithic proportions have been used in attempts to subdivide the broad outcrop belt of the formation. Color is the only discriminant that works systematically, but only in chlorite zone outcrops because contact metamorphism to higher grade destroys the mineralogic differences responsible for the color variation.

The formation is divided into lower (red-maroon) and upper (dominantly green with significant amounts of gray) members whose bedding, lithic proportions, clast and matrix contents are identical, except for greater amounts of matrix hematite in the lower member and of chlorite in the upper member. (Hematite and chlorite are present in both.) Facing evidence across three exposed contacts between these members shows that the green rocks overlie the red. A narrow (30-50 m) transitional zone contains interbedded green and red lithologies. In two of the contact transects, green or gray sandstones just above the transitional rocks contain numerous hematite and limonite spots.

Bedding in both members is typically thick, but ranges from massive sandstone or granule conglomerate beds more than 2 m thick to pinstriped (2-5 cm), well-graded layers of siltstone and mudstone. Both massive and graded beds are abundant. Massive beds with uniform grain size and lacking laminations are common, but bedding planes are obscured in many outcrops by a regularly spaced (2-4 cm) penetrative pressure-solution cleavage. This cleavage is the most prominent feature in many exposures and, along with associated transposition, obliterates bedding in some. Thick psammite beds are also commonly characterized by graded bedding. In some, granules or coarse sand pass upward into medium sand and siltstone; in others, the relatively homogeneous sandy base of the bed grades over a short interval into a siltstone or mudstone top. Partial and a few nearly complete Bouma sequences are present in some of the graded beds, indicating their turbidite origin. Bottom features such as load casts, flame, and ball and pillow structures are particularly common in these horizons. Contact metamorphism highlights compositional grading, as cordierite and andalusite appear sparsely in the transition between sandy and pelitic parts of a given bed and become abundant at the top.

Sandstone is by far the dominant rock type in the Baskahegan Lake Formation, representing about 75-80% of its outcrop belt. Quartz arenites can be readily distinguished from quartzofeldspathic wackes by their distinctive colors on fresh and weathered surfaces. Quartz arenites are typically the same bluish gray color on both fresh and weathered surfaces, whereas feldspar-rich wackes weather chalky white and are either grayish green or pale red when fresh. The two are mixed randomly throughout the formation, and both occur in massive or well graded beds. Pelitic layers occur as either the tops of graded sets or as individual beds in sharp contact with sandstones at both top and bottom. They are much less abundant volumetrically than the sandstones, generally comprising less than 25% of the thicker graded beds. Thinner, interlaminated couplets commonly contain equal amounts of pelite and psammite, and some mudstone or slate beds associated with thick-bedded sandstones are as thick as 1 m. The pelites may be gray, grayish-green, olive green, or deep maroon, and many associated with the quartzofeldspathic psammites also weather chalky white.

Contact metamorphism converts these rocks to tough hornfelses, and both sandstones and pelites exhibit rusty weathering near the granite contacts due to (introduced) sulfide minerals. The quartz arenites recrystallize with little mineralogic change, but biotite and sparse cordierite develop in the wackes. Pelitic hornfelses in the outer part of contact aureoles are fine-grained and characterized by the grayish-purple color indicative of fine-grained, disseminated red-brown biotite. Grain size increases toward the granites, the purplish color deepens, and cordierite appears – first as tiny dark spots near the cordierite isograd and then as round, equant grains up to 5 mm in diameter adjacent to the granite. Small subhedral andalusite crystals are found within a few hundred meters of the contact with the intrusive rock and prismatic sillimanite occurs within 50 meters of the granite.

Contact relationships and thickness. The base of the Baskahegan Lake Formation is not exposed in eastern Maine or New Brunswick. The upper contact with the Bowers Mountain Formation is typically at least slightly sheared, probably because of the competence contrast between the Baskahegan Lake sandstones and Bowers Mountain pelites. The shearing has, unfortunately, destroyed most evidence concerning the nature of the contact. An apparently undeformed contact on and east of Bowers Mountain in the southwest corner of the study area suggests a gradational contact with the overlying Bowers Mountain Formation. There, thinly laminated black, rusty-weathering carbonaceous pelite and siltstone appear uniquely in the Baskahegan Lake Formation and become more abundant upward at the expense of the typical thick-bedded psammites. Graded bedding below this transition zone suggests that the Bowers Mountain Formation lies above the Baskahegan Lake Formation.

Multiple folding, intraformational and interformational shearing, and the lack of an exposed base make it impossible to estimate the thickness of the Baskahegan Lake Formation accurately. The width of its outcrop belt suggests a thickness on the order of at least a few kilometers, even considering the repetitions due to late stage upright folds. Earlier recumbent folding is recognized but not yet fully unraveled (see below). Most upright folds appear to be right-side up, but a few are definitely inverted, suggesting that both upper and lower limbs of regional-scale recumbent structures are present in the quadrangle. Low topographic relief and poor exposure preclude reconstruction of the early structures, so that the value of "a few kilometers" cited above is the best approximation possible at this time.

Bowers Mountain Formation (Obm): The Bowers Mountain Formation is named here for extensive outcrops on and near Bowers Mountain, particularly on hills around Dipper Pond and on the northern and northwestern slopes of Dill Hill. Outcrops of the Bowers Mountain Formation in the southern part of the study area lie within the contact aureole of the Bottle Lake complex and typically contain cordierite, andalusite, or sillimanite. Chlorite-zone rocks characterize exposures in the northwestern part of the Dill Hill quadrangle and in the Stetson Mountain and Danforth quadrangles to the north and northeast.

As discussed earlier, an apparently gradational contact with the underlying Baskahegan Lake Formation is exposed at Bowers Mountain. This contact can be traced through the contact aureole of the Bottle Lake complex, defining a complex map pattern attributed to superposition of upright folds on early recumbent structures involving both units. Accordingly, an early Ordovician unconformity between the two formations previously suggested by Ludman and others (1993) must be rejected, along with the inferred Penobscot orogeny to which it was attributed.

The Bowers Mountain Formation contains thick sequences of rusty-weathering (sulfidic), carbonaceous pelite and gray-weathering (non-sulfidic), non-carbonaceous to slightly carbonaceous pelitic rocks. Individual beds within these packages are thin, typically only a few centimeters thick. Relatively homogeneous sulfidic and non-sulfidic pelite make up most of the formation with only minor interbedded coarser clastic rocks. Cleavage is well preserved in all exposures except those in the innermost part of the contact aureole surrounding the Bottle Lake pluton, but bedding is less obvious, particularly in homogeneous pelitic horizons in which cleavage is dominant. Thinly interbedded quartzose siltstone layers delineate bedding in many exposures and amount to perhaps as much as 30% of the formation. Siltstone-pelite contacts are sharp and, in contrast with thin-bedded strata of the Baskahegan Lake Formation, rarely display primary features that indicate facing direction.

Thicker (15-50 cm), massive beds of quartz arenite are found throughout the formation, but are more abundant in the sulfidic sequences. They stand in relief above the strongly cleaved pelites and are also distinguished by their lack of contact metamorphic minerals. Original fine to medium sand sized quartz clasts are readily identified in thin section and, in a few instances, in outcrop. Bottom features in these massive sandstones, including load casts and flame structures, do supply valuable facing evidence. Such facing data on Bowers Mountain agree with graded bedding in the adjacent Baskahegan Lake Formation, indicating that the Bowers Mountain Formation lies above the Baskahegan Lake Formation. Pickerill and Fyffe (1999) report a conformable contact between the two formations in southwestern New Brunswick.

Shearing has stymied attempts to elucidate the internal stratigraphy of the Bowers Mountain Formation. Mapping during the summer of 1999 suggests, however, that the pelites in the lower part of the formation are dominantly sulfidic and carbonaceous, and that non-sulfidic rocks are more abundant toward the top of the formation.

Thickness: Multiple folding and shearing make it difficult to determine the thickness of the Bowers Mountain Formation. An estimate of 200-350 m is based on the outcrop width between the Baskahegan Lake and Stetson Mountain Formations near the western edge of the Dill Hill quadrangle and in the adjacent Bowers Mountain quadrangle.

Stetson Mountain Formation (Osm): The Stetson Mountain Formation is a thick sequence of dominantly felsic metavolcanic rocks that had been informally designated as the "rocks of Snow Mountain" in what is now the Danforth 7.5' quadrangle by Larrabee and others (1965). The formation is named for excellent exposures on the eastern and western slopes of Stetson Mountain in the Stetson Mountain quadrangle, and rocks from the type locality are traced continuously into the northern edge of the Dill Hill study area. Stetson Mountain volcanic rocks crop out at the west-central edge of the quadrangle, in the northwest corner, and in lowlands around Route 6 in the southwest corner. The metavolcanic rocks are generally more resistant to erosion than the adjacent metasedimentary units and support prominent ridges throughout their outcrop area.

Detailed mapping in the Danforth (Sayres, 1986) and Stetson Mountain 7.5' quadrangles (Ludman, unpublished data) permitted division of the formation into lower and upper members (the Tolman Hill and Public Lot Ridge members, respectively, of Ludman, 1991) separated by a distinctive horizon composed of manganiferous chert and very fine grained manganiferous felsic tuff. The Tolman Hill member contains very fine-grained to cryptocrystalline felsic ashfall tuffs with only minor ashfall layers in which crystals or rock fragments can be observed. In contrast, the Public Lot Ridge member contains large amounts of coarse ashflow tuff in addition to the ashfall deposits, and abundant volcaniclastic horizons. All Stetson Mountain rocks in the study area are assigned to the lower, Tolman Hill member.

The Tolman Hill member in the Dill Hill quadrangle is a sequence of chalky white weathering, greenish gray to gray cryptocrystalline volcanic rocks that are extremely hard and commonly display conchoidal fracture. Bedding is only rarely identifiable. It is typically revealed by subtle changes in grain color, flattened pumice fragments and lapilli; more rarely, thick eruptive sequences containing cryptocrystalline and coarsely fragmental material clearly delineate primary layering, as do very sparse metasedimentary beds. Metasedimentary rocks, almost entirely thin sequences of black, pyritiferous shale, are extremely rare (< 5% of the member)

Petrographic examination reveals the rocks to be an interlocking mosaic of very fine to cryptocrystalline quartz and feldspar grains, but shard outlines preserved in a few thin sections suggest that these were originally welded ashfall tuffs. The coarsest lithologies in the lower member are fine-grained ashflow tuffs containing endogenous volcanic fragments up to 2.5 cm long. A few crystal tuffs have been observed, mostly in the Jimmey Mountain and Stetson Mountain quadrangles to the north of the study area, and in the Bowers Mountain quadrangle to the west. These contain microphenocrysts of euhedral quartz and feldspar up to 1.5 mm long, some of which are partially resorbed by the cryptocrystalline matrix. No primary ferromagnesian minerals have been identified, but some of the greener varieties contain significant amounts of chlorite. Small accretionary lapilli and flattened pumice fragments occur in the coarser tuffs.

Manganiferous chert and mudstone occur discontinuously throughout the Miramichi terrane of eastern Maine near what appears to be the contact between the lower and upper members, but exposures are not good enough to allow its use as a marker within the Dill Hill quadrangle. Sayres (1986) had more success just to the north, and was able to trace complex early folds outlined by this horizon.

The Public Lot Ridge member, exposed mostly on Public Lot Ridge in the adjacent Stetson Mountain 7.5’ quadrangle, contains a more varied lithologic assemblage including large volumes of volcanogenic metasedimentary rock. Volcanic rock types in the upper member include cryptocrystalline to fine-grained devitrified ashfall tuffs that are identical to those in the Tolman Hill member. These are intercalated with somewhat coarser-grained microporphyries (clasts up to 4 mm), volcanic agglomerates with felsic volcanic fragments set in a tuffaceous matrix, clast-supported conglomerates similar to the agglomerates but with a clastic matrix, and lenses of carbonaceous pelite.

Small volumes of mafic volcanic rock are also present in the Public Lot Ridge member. Fine-grained basaltic flows have been mapped at two localities on Public Lot Ridge, and thick basalt flows and basaltic crystal tuffs crop out at the appropriate stratigraphic level in the eastern part of the Miramichi terrane in the Tomah Mountain quadrangle.

Volcanic chemistry: Chemical analyses (Sayres, 1986) show that most of the Stetson Mountain volcanic rocks are rhyolites and rhyodacites (Table 1) with some basalts and one basaltic andesite (Table 2). These data may not be completely unbiased, since highly fragmental (altered) rocks, rocks rich in chlorite, and those containing ferroan carbonates were not sampled for fear of contamination. Preliminary analyses of trace and rare earth elements suggests an island arc origin for the Stetson Mountain rocks.

Thickness: If the eruptive environment of the Stetson Mountain Formation was like that of modern island arcs, with subaerial volcanic edifices separated by shallow seas and the gaps filled by volcaniclastic debris, ash deposits, and euxinic strata, layer cake stratigraphy would not be expected and thickness would be very difficult to determine. The formation is multiply folded and, in addition, the lower contact is disrupted by shearing against the Bowers Mountain Formation and the upper contact is removed at the faulted or unconformable contact with the overlying Sam Rowe Ridge Formation. Thus, although the areal extent and steeply dipping attitude of the Stetson Mountain Formation suggest a significant thickness, the best estimate at this time is a few thousand meters.

Age and Correlation of units in the Miramichi terrane. The Miramichi terrane continues from Maine into southwestern New Brunswick, where Pickerill and Fyffe (1999) divide it into a lower metasedimentary component (the Woodstock Group) overlain conformably by a dominantly volcanic component (the Meductic Group; Table 3). Unit-for-unit correlation appears straightforward, and Pickerill and Fyffe have adopted the Maine name "Baskahegan Lake Formation" for their oldest metasedimentary rocks, but the age of the Stetson Mountain Formation presents some problems.

Hopeck (1994) showed that all units of the Miramichi terrane in Maine supplied detritus to a late Ordovician through middle Silurian clastic wedge that prograded westward into the Aroostook-Matapedia basin. Therefore, deposition (and deformation) of the Miramichi rocks must have been completed by late Caradocian-Ashgillian times. No fossils have been found in the Baskahegan Lake or Bowers Mountain Formations in Maine, but their correlatives in New Brunswick have been more productive. Pickerill and Fyffe (1999) reported that ichnofossils in southwestern New Brunswick imply a Tremadocian age for the upper, green member of the Baskahegan Lake Formation, and that the the lower member is probably Late Cambrian through Early Tremadocian. Arenigian graptolites in the overlying Bright Eye Brook Formation in New Brunswick (see Table 3) provide an age for the correlative Bowers Mountain Formation and a minimum age for the Baskahegan Lake Formation.

There is some discrepancy between ages reported for the volcanic part of the Miramichi terrane in Maine and southwestern New Brunswick. Graptolites from black sulfidic shales in Maine, reportedly from a horizon within what is now called the Stetson Mountain Formation, yielded a "Caradocian age" (Larrabee and others, 1965). Pickerill and Fyffe infer that lithologically and chemically similar volcanic rocks in New Brunswick must be older than the Early Caradocian Belle Lake Formation, and therefore presumably Llanvirnian-Llandeillian. This problem is complicated further by the fact that interbedded grits and black shales of the Belle Lake Formation in the New Brunswick Miramichi sequence (Venugopal, personal communication) are identical to the Mill Priveledge Brook Formation in the Potter Hill 7.5' quadrangle NW of Dill Hill that Hopeck (1994) showed contains clasts of the Stetson Mountain, Bowers Mountain, and Baskahegan Lake Formations and was thus considered to lie unconformably above the Stetson Mountain Formation.

Although these details remain to be resolved, there is little doubt that the Miramichi terrane represents a Cambrian(?)-earliest Ordovician siliciclastic turbidite and euxinic slate environment followed by early through middle Ordovician volcanic arc eruptive rocks.

Farther northeastward in the Canadian Miramichi terrane, the Miramichi Group of central and northeastern New Brunswick corresponds to the Baskahegan Lake and Bowers Mountain Formations. The overlying Tetagouche Group volcanic rocks in those areas are slightly younger than the Meductic Group, and reflect a back-arc setting rather than the arc itself. To the northwest in Maine, similar stratigraphic sequences were described in the Weeksboro-Lunksoos Lake anticlinorium (Neuman, 1967), the nearest pre-Silurian tract to the northwest, and in the Munsungun-Winterville anticlinorium in northern Maine (Hall, 1970).

Aroostook-Matapedia terrane

Aroostook-Matapedia strata in the central and north-central parts of the Dill Hill quadrangle are assigned to the Sam Rowe Ridge Formation, one of four clastic units that comprise the Prentiss Group of Hopeck (1994). He interpreted the Prentiss Group as representing a proximal facies eroded from the adjacent Miramichi terrane (see Figure 4). The other three units (Mill Priveledge Brook, Daggett Ridge, and Ellen Wood Ridge Formations) crop out extensively in the Bowers Mountain and

Table 1 : Chemical analyses of Stetson Mountain Formation felsic volcanic rocks, from Dill Hill, Jimmey Mountain, and Bowers Mountain 7.5' quadrangles (from Sayres, 1986).

Wt. %	1	2	3	4	5	6	7	8	9	10
SiO_2	58.5	62.1	62.2	32.6	34.5	66.0	68.6	69.9	70.1	70.1
TiO_2	0.52	0.65	0.73	0.76	0.58	0.52	0.46	0.41	0.41	0.40
Al_2O_3	15.0	16.2	14.0	15.1	15.8	13.5	14.0	14.0	13.6	14.0
$Fe_2O_3^*$	9.78	6.42	7.36	6.49	5.31	5.09	4.49	4.68	3.12	4.63
MnO	0.24	0.09	0.19	0.35	0.07	0.24	0.22	0.13	0.15	0.13
MgO	4.33	2.31	3.70	2.19	1.80	3.36	1.72	1.00	0.74	0.97
CaO	1.91	1.42	2.33	2.77	1.49	4.38	0.84	0.60	2.44	0.58
Na_2O	5.26	2.51	2.50	2.20	3.75	1.18	2.25	2.25	3.13	2.29
K_2O	0.12	3.87	2.20	3.34	3.08	1.35	4.95	4.44	2.11	4.44
P_2O_5	0.11	0.13	0.25	0.27	0.12	0.22	0.15	0.09	0.07	0.08
LOI	4.16	3.62	4.39	3.47	3.16	3.85	1.93	1.93	3.93	2.16
Total	100.1	100.0	100.2	99.8	100.4	100.3	100.0	100.1	100.1	100.4
ppm										
Cr	90	60	30	20	50	20	10	20	10	20
Rb	20	140	80	90	110	50	90	130	70	130
Sr	250	140	1190	390	280	370	520	170	330	180
Y	<10	10	30	30	20	30	20	30	20	50
Zr	60	120	130	70	150	120	110	160	50	150
Nb	10	20	20	10	10	20	20	20	10	20
Ba	170	5690	1180	1510	6150	5170	2930	5700	2530	5560
Wt.%	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
SiO_2	70.3	71.0	72.6	73.2	73.3	74.6	76.4	76.6	77.0	77.0
TiO_2	0.53	0.36	0.38	0.20	0.36	0.35	0.19	0.32	0.18	0.23
Al_2O_3	14.9	13.5	12.9	11.1	14.4	12.3	11.8	11.6	11.6	11.6
$Fe_2O_3^*$	4.26	4.98	3.17	1.68	2.73	3.73	1.87	1.66	1.78	1.55
MnO	0.12	0.07	0.08	0.13	0.05	0.04	0.07	0.08	0.06	0.09
MgO	1.11	1.01	1.40	0.51	0.88	0.85	0.67	0.46	0.67	0.66
CaO	0.76	0.57	1.45	3.85	0.17	0.07	0.47	1.60	0.48	1.40
Na_2O	1.49	2.93	1.46	1.70	2.80	3.78	5.60	3.25	5.56	1.46
K_2O	3.78	3.00	3.53	2.55	2.85	2.44	1.18	1.77	1.10	3.08
P_2O_5	0.13	0.10	0.09	0.04	0.07	0.07	0.04	0.05	0.04	0.04
LOI	2.62	2.31	2.77	5.08	2.16	1.77	1.77	2.47	1.62	2.85
Total	100.2	100.3	100.1	100.3	100.1	100.3	100.3	100.1	100.3	100.2
ppm										
Cr	10	20	20	10	20	30	20	20	20	10
Rb	130	110	90	100	110	70	60	70	50	120
Sr	350	130	440	350	50	90	720	200	730	160
Y	30	40	20	50	30	20	20	10	20	30
Zr	140	110	90	130	60	140	100	100	80	100
Nb	20	<10	30	10	20	20	10	10	20	10
B a	127 0	364 0	156 0	119 0	276 0	210 0	109 0	148 0	102 0	205 0

* Total iron expressed as ferric iron (Fe_2O_3).

Jimmey Mountain quadrangles to the west and north, where they were defined by Hopeck (1991, 1994). See Hopeck (1994) for detailed descriptions of the Prentiss Group and its relationship to the distal Carys Mills and Smyrna Mills Formations with which it interfingers to the west. Strata west of the Stetson Mountain fault contain interbedded feldspathic sandstone and pelite with minor argillaceous micritic limestone, and are also assigned to the Sam Rowe Ridge Formation. Similar rocks are also found in the eastern parts of the Smyrna Mills and Carys Mills outcrop belts; the rocks west of Stetson Mountain may represent a facies

Table 2 : Composition of mafic volcanic rocks from the eastern flank of the Miramichi Terrane (from Sayres, 1986).

Wt. %	1	2	3	4	5	6
SiO_2	52.0	52.8	53.0	53.9	55.9	57.2
TiO_2	1.41	1.35	1.38	1.05	0.97	1.06
Al_2O_3	17.5	18.2	17.3	19.4	13.0	13.8
$Fe_2O_3^*$	11.2	10.1	11.0	9.75	11.7	9.89
MnO	0.12	0.12	0.12	0.11	0.18	0.14
MgO	4.44	4.21	4.36	3.22	5.61	6.03
CaO	6.84	5.03	6.83	4.36	9.87	7.58
Na_2O	4.66	4.65	4.59	6.51	1.38	2.12
K_2O	0.62	0.83	0.55	0.55	0.42	0.21
P_2O_5	0.32	0.25	0.33	0.24	0.16	0.27
LOI	0.85	2.70	0.62	1.23	0.93	1.77
Total	100.1	100.4	100.2	100.4	100.2	100.2
ppm						
Cr	40	40	40	30	150	180
Rb	20	30	40	20	20	<10
Sr	280	360	290	260	380	240
Y	27	30	40	24	20	29
Zr	150	170	140	130	70	100
Nb	20	30	20	30	30	40
Ba	240	410	240	380	200	190
ppm						
La	24.7			13.8		20.1
Ce	49.3			30.2		39.4
Pr	6.30			4.12		5.10
Nd	27.1			17.4		21.8
Sm	5.60			3.90		4.20
Eu	1.45			1.05		1.22
Gd	5.80			4.20		4.80
Tb	0.80			0.60		0.70
Dy	5.40			4.20		5.00
Ho	1.10			1.00		1.10
Er	3.10			2.80		3.40
Tm	0.30			0.30		0.40
Yb	2.90			2.60		3.00
Lu	0.64			0.62		0.63

* Total iron expressed as ferric iron (Fe_2O_3).

transitional between the proximal to intermediate (Sam Rowe Ridge) and distal (Smyrna Mills and Carys Mills) facies.

Sam Rowe Ridge Formation (Ssr)

Mapped contacts and F_1 hinge surfaces in rocks of the Miramichi terrane are truncated east of Stetson Mountain and in the central part of the quadrangle by an extensive area of regularly interbedded fine to medium-grained clastic rocks. These are separated by only the narrow band of volcanic rocks on Stetson Mountain from identical rocks mapped by Hopeck (1991) in the adjacent Potter Hill quadrangle as the type locality of the Sam Rowe Ridge Formation. They are therefore interpreted to be an outlier of the Sam Rowe Ridge Formation. Chlorite grade exposures dominate in all but the southernmost part of the outlier, where biotite is evident in the outer part of the contact aureole surrounding the Bottle Lake pluton.

The Sam Rowe Ridge Formation in the Dill Hill quadrangle consists mostly of regularly and thinly bedded, gray to chalky white weathering, fine- to medium-grained sandstones intercalated with medium gray weathering non-pyritiferous pelites. Beds range in thickness from 2 cm to almost a meter, al-

Table 3: Correlation of Miramichi units in Maine and southwestern New Brunswick (Pickerill and Fyffe, 1999). Asterisks indicate fossil age control.

Age	Maine (this paper)	SW New Brunswick	
Early Caradoc		Meductic Group	* Belle Lake Formation
?	* Stetson Mountain Formation		Oak Mountain Formation
			Eel River Formation
			Porten Road Formation
Early Arenig	Bowers Mountain Formation	Woodstock Group	* Bright Eye Brook Formation
Early Tremadoc Cambrian	Baskahegan Lake Formation		* Baskahegan Lake Formation

though most are in the range of 5-15 cm. Sandstone to pelite ratios are generally 1:1, particularly in the thinner beds, but horizons dominated by sandstone or pelite are also common, apparently distributed randomly throughout the section. Graded bedding is nearly ubiquitous and is commonly accompanied by small load casts and flame structures. A few burrows and burrow networks are parallel to bedding in fine-grained sandstones and siltstones, and were interpreted as feeding tracks by Ron Pickerill (personal communication, 1984).

The sandstones are argillaceous wackes that range in composition from quartzo-feldspathic (gray weathering) to highly feldspathic (chalky weathering). Lithic fragments are rare, probably because of the small clast size. Most sandstones in the outlier east of Stetson Mountain are non-calcareous, but some just west of the quadrangle have enough carbonate cement to effervesce slightly. Small (1-2 mm) orange-brown weathering rhombs altered from primary ankerite or siderite are present in sandstones and pelites. Pelitic parts of graded sets are commonly medium to dark gray on their weathered surfaces. A few dark gray to black, rusty-weathering pelitic beds were found in lumber road exposures on the western slope of the unnamed hill that dominates the outlier in the north-central part of the quadrangle. These are uniquely rich in manganese oxides and hydroxides, and some have developed a manganiferous crust as thick as 2.5 cm since being exposed by road construction.

A few distinctive rock types are interspersed irregularly throughout the outlier and main body of the Sam Rowe Ridge Formation, including limestone, conglomerate, and volcanic rocks. Most occur in single beds or horizons too thin to be mapped at quadrangle scale, but a few are extensive enough to be shown. Attempts to use these horizons as markers have been frustrated by poor outcrop control.

Conglomerate, volcaniclastic conglomerate or agglomerate, and volcanic rocks are extensive enough to be mappable in the Dill Hill outlier. These coarse-grained rocks occur in massive beds up to 2 m thick, locally intercalated with chalky weathering pelite. Rounded clasts ranging from pebbles to small cobbles are set in a sand or silt matrix. Conglomerates weather chalky white to a pale orange-tinted buff, reflecting their varied feldspar and volcanic clast contents. Many of the clasts are of felsic volcanic rock, others of quartzose sandstone; Hopeck (1994) showed that these were eroded from the adjacent Stetson Mountain and Baskahegan Lake Formations in the Jimmey Mountain and Potter Mountain 7.5' quadrangles north and northwest of Dill Hill. Clast proportions vary markedly within the narrow outcrop band of these conglomerates. Some conglomerate matrix has a greenish gray, highly calcareous component, and two brachiopod valves were discovered in one of these rocks in the north-central part of the quadrangle. Hopeck (1994) reported other conglomerates in the main body of the formation that are dominated by intraformational clasts, many of which were not completely consolidated during their deposition. These have not been observed in the Dill Hill outlier.

Fine-grained ashfall tuffs and coarser crystal and lithic tuffs of felsic composition occur in the main body of the Sam Rowe Ridge Formation, along with a few chloritic (mafic) tuffs. Lenses and a horizon of grayish green ashfall tuff have been mapped near the western margin of the Dill Hill outlier in an area of extremely poor exposure. It is very similar to tuffs in the Stetson Mountain Formation, but in the absence of conclusive evidence to the contrary, the simplest structural interpretation has been applied and these rocks are assigned to the Sam Rowe Ridge Formation.

Gray, argillaceous micritic limestone crops out in several places in the main body of the formation. It has not been identified within the Dill Hill outlier, although some is exposed in the main east-west access road in the northeastern corner of the Bowers Mountain quadrangle just west of Stetson Mountain.

Thickness: Neither upper nor lower contact of the Sam Rowe Ridge Formation has been observed in the study area, although it is clear that the lower contact truncates structural features of the underlying Miramichi strata. A complete section is mappable, however, in the adjacent Potter Hill and Jimmey Mountain 7.5' quadrangles, suggesting a thickness of approximately 2,000 m.

Age and correlation: Hopeck (1994) demonstrated that the Prentiss Group is a thick clastic wedge eroded from the Miramichi terrane and spread westward into the Aroostook-Matapedia basin. Clasts from units of the Miramichi terrane are found throughout the wedge. This, coupled with its simpler structural history, indicates that the Sam Rowe Ridge Formation was deposited after folding and erosion of the Miramichi terrane – no earlier than in middle Caradocian times.

Neither the brachiopods nor ichnofossils mentioned above yielded specific ages for the formation. The burrows were attributed to a deep water environment, but occur throughout the lower Paleozoic (R. Pickerill, personal communication). In the absence of fossil control, the age of the Sam Rowe Ridge Formation is based on its relationship with well-dated rocks on strike to the north. Hopeck traced the formation westward through a transitional facies into limestones and slates that he was able to trace northward into the Houlton area where Pavlides (1974) first named the Carys Mills and Smyrna Mills Formations. The Carys Mills Formation is generally viewed as Ashgillian through Llandoverian, the Smyrna Mills Formation as Wenlockian (see Osberg and others, 1985), so that a late Ordovician through early Silurian age is inferred for the Prentiss Group.

STRUCTURAL GEOLOGY

A complex deformation history is interpreted for rocks of the Dill Hill quadrangle, including two episodes of folding followed by brittle faulting (Figure 5). Outcrops in the southern part of the quadrangle are abundant enough to demonstrate that rocks of the Miramichi terrane experienced both episodes of folding, but are not sufficient to reconstruct even the large-scale early structures. These early reclined to recumbent folds (F_1) have been folded by upright, open, NNE-trending structures (F_2) throughout the Miramichi terrane in Maine.

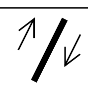
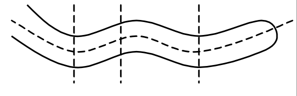
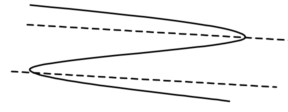
Post-Early Devonian	Reverse faulting	
Mid-Silurian-Early Early Devonian (Acadian orogeny)	F_2 upright folding	
Middle Ordovician (Caradocian)	F_1 recumbent folding	

Figure 5. Deformation history of the Dill Hill 7½' quadrangle

In contrast, the Sam Rowe Ridge Formation records only the F_2 structures. The NNE-trending Stetson Mountain fault zone separates the Aroostook-Matapedia and Miramichi terranes in the northwest corner of the study area, clearly truncating contacts and both generations of folds. The fault contact is mappable along strike to where it is apparently intruded by the Pokiok pluton to the north and the Bottle Lake pluton to the south. A major topographic lineament in the north-central and central parts of the quadrangle corresponds with another series of truncations – in this instance of F_1 hinge surfaces – and is interpreted as a related fault. These relationships are shown in the structural cross-sections on the accompanying geologic map.

F_1 folding

The existence of large-scale F_1 folds within the Miramichi terrane has been inferred from several lines of evidence. Traces of F_1 hinge surfaces can be identified by reversals in graded bedding, but have been modified by the F_2 upright folding. For example, the roughly east-trending F_1 hinge surface of one major early fold can be traced across most of the southern part of the quadrangle, its limbs outlined by the contact between the Baskahegan Lake and Bowers Mountain Formations. Reversals in facing in the Baskahegan Lake Formation also indicate mesoscopic folds whose hinge surfaces are warped around F_2 axes. Graded bedding indicates that some of the outcrop-scale F_1 folds are inverted and others right-side up (Figure 6); in a tantalizing few places, this allows an early hinge surface to be mapped for as much as a kilometer.

The distinctive closely and regularly spaced pressure-solution cleavage characteristic of Baskahegan Lake Formation sandstones is axial planar to outcrop-scale F_1 folds throughout the Miramichi terrane in eastern Maine, and is itself folded by F_2 folds in the Dill Hill quadrangle. These folds exhibit a range of attitudes, from near-vertical to sub-horizontal plunges, NE to E-W trends, upright to nearly recumbent hinge surfaces. NNE-trending F_2 cleavage cuts F_1 cleavage and both limbs of F_1 folds. Mappable folds within the study area (Figure 7) and regional scale features mapped in adjacent quadrangles suggest the presence of large-scale folds in Miramichi strata that were originally reclined to recumbent.

Facing evidence and outcrop pattern demonstrate the effects of F_1 folding on the Baskahegan Lake and Bowers Mountain Formations, but data from the Dill Hill quadrangle alone are not enough to prove that the Stetson Mountain Formation was also involved. Conclusive evidence is found in the Baker Ridge area near Danforth where typical Stetson Mountain ashfall tuffs reveal both episodes of folding (Sayres, 1986).

F_2 folding

Rocks of the Prentiss Group record a much simpler deformational history than those of the Miramichi terrane. Upright,

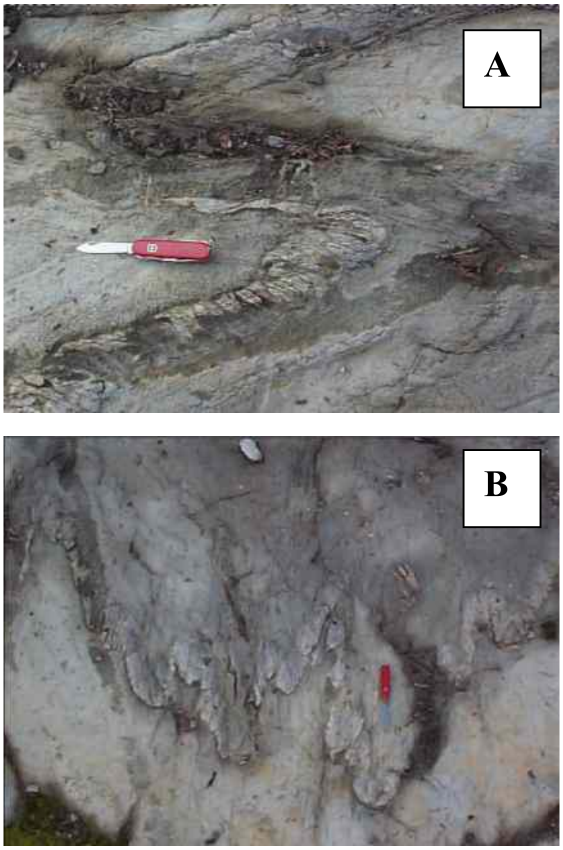


Figure 6. Upright (A) and inverted (B) F_1 synclines in the Baskahegan Lake Formation. Knife blade in (A) indicates both plunge and facing direction in interbedded coarse and fine-grained sandstones. Knife blade in (B) points in direction of steep fold plunge; the sandstone bed on which it is lying faces in the opposite direction.

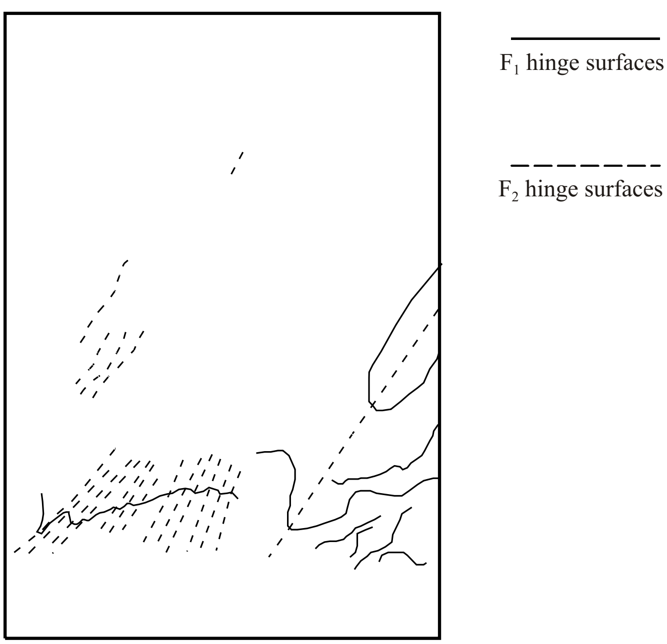


Figure 7. Mappable F_1 and F_2 hinge surfaces in the Dill Hill 7.5' quadrangle.

typically open F_2 folds found in the Sam Rowe Ridge outlier can be traced southwestward into the Baskahegan Lake Formation, where they deform the earlier F_1 hinge surfaces. Hinge surfaces of these F_2 folds trend 010-020 throughout the Dill Hill quadrangle, in rocks of both the Miramichi terrane and the Prentiss Group. Minor F_2 folds plunge gently to both northeast and southwest, and in the Sam Rowe Ridge Formation are characterized by a very strongly penetrative axial plane cleavage. This cleavage is the dominant planar feature in homogeneous pelitic parts of the Sam Rowe Ridge Formation, obliterating bedding in most exposures. Bedding is better preserved in interbedded slate and sandstone sequences, enhanced by differential weathering, and bedding-cleavage intersections are abundant.

Outcrop-scale folds are uncommon, but the geometry of F_2 folds is best illustrated by excellent exposures of the Sam Rowe Ridge Formation on the unnamed hill near the north-central edge of the quadrangle. Reversals of facing direction suggest that the wavelength of F_2 folds in the Sam Rowe Ridge Formation is on the order of a few hundred meters (see Figure 7 and the geologic map).

Faulting

Effects of shearing have been observed throughout much of the outcrop belt of the Baskahegan Lake Formation and locally at the Baskahegan Lake–Bowers Mountain and Bowers Mountain–Stetson Mountain contacts. Most of these appear to have resulted from competence contrasts rather than significant tectonic activity, and none can be mapped in outcrop at 1:24,000 scale. However, the two prominent NNE-trending lineaments shown in Figure 3 coincide with truncations of both F_1 and F_2 structures, contain abundant cataclasite and breccia, and are interpreted as late-stage brittle faults. Fault-related features include fine- to very fine-grained cataclasite derived mostly from the Stetson Mountain volcanics and massive Baskahegan Lake wackes; phyllonite derived from Sam Rowe Ridge pelitic horizons, especially on the western flank of Stetson Mountain; a penetrative foliation shown in the northwest corner of the quadrangle; and zones of brecciation and quartz veining.

The fault on the western flank of Stetson Mountain in the northwestern corner of the quadrangle has been named the Stetson Mountain fault (Ludman, 1991). This structure can be mapped continuously from the Bowers Mountain quadrangle, west of the study area, into the northwest corner of the Dill Hill quadrangle, and farther northward through most of the Stetson Mountain and Jimmey Mountain quadrangles. Fault-produced foliation and bands of cataclasite dip steeply to the northwest. The Stetson Mountain fault delineates the easternmost limit of the Aroostook-Matapedia terrane, with the exception of the Sam Rowe Ridge outlier in the north-central part of the study area (see below). A normal, west side-down sense of motion is suggested for the fault, based on the interpretation that the outlier was originally connected with the type locality of the Sam Rowe Ridge Formation.

The other, unnamed, fault in the north-central part of the quadrangle terminates southward at the contact with the Bottle Lake pluton and passes northward into an area of very poor exposure (even for the Dill Hill quadrangle). Fine-grained cataclasite and abundant quartz veins in Baskahegan Stream confirm the presence of a brittle fault with a steep northwest dip and help explain the apparent truncation of F_1 structures by the topographic lineament. Normal west-side-down movement is inferred for this fault because of its similar orientation and deformation mechanics, but the map pattern is not so conclusive as it is for the Stetson Mountain fault.

Two other faults, parallel to and probably related to the first two mentioned, are inferred from truncation of formation-rank contacts west of Dipper Pond in the southwestern part of the quadrangle. These faults do not have so well-defined a topographic expression, although they are mapped through a series of aligned stream valleys. Other brittle faults with similar orientation have been mapped in the Bowers Mountain and Springfield quadrangles (Hopeck, 1994).

Timing of deformation events

F_1 is constrained to be younger than the middle Caradocian age of the youngest rocks affected by the deformation (Stetson Mountain Formation), but older than the inferred Ashgillian age of the first rocks deposited after that event (basal Daggett Ridge and Mill Priveledge Brook Formations). A late Caradocian age is indicated. F_2 must be younger than the Wenlockian age of the Smyrna Mills Formation, but older than the Early Devonian emplacement of the Pokiok pluton that truncates F_2 structures. A late Silurian through early Devonian scenario is possible. The Stetson Mountain fault is younger than F_2, but apparently older than the ca. 380 Ma emplacement age of the Bottle Lake pluton, i.e., also late Silurian through early Devonian.

Contact relationships between the Miramichi and Aroostook-Matapedia terranes

Hopeck (1991, 1994) demonstrated a sedimentary linkage between these two terranes, based on the identification of Miramichi clasts in the Prentiss Group and the interfingering of the Prentiss Group with limestones and pelites of the Aroostook-Matapedia terrane. North and west of the Dill Hill quadrangle, coarse proximal conglomerates of the Daggett Ridge Formation pass westward into Sam Rowe Ridge sandstone/pelite interbeds, supporting his facies interpretation. The Sam Rowe Ridge rocks in the north-central part of the Dill Hill quadrangle are problematic because they rest directly on their Miramichi source rocks without the intervening Daggett Ridge or Mill Priveledge Brook Formations that crop out extensively immediately to the north of the study area.

The southern contact of the Sam Rowe Ridge Formation clearly truncates formation contacts within the Miramichi terrane in the Dill Hill quadrangle. This relationship could have resulted from either an angular unconformity in an area where the Mill Priveledge Brook Formation was not deposited or from a thrust fault that transported Sam Rowe Ridge rocks eastward and onto elevated Miramichi source rocks and was subsequently modified by uplift on the eastern side of the Stetson Mountain fault zone. Seismic reflection data reveal at least one east-directed thrust involving Aroostook-Matapedia rocks just west of the Dill Hill area (Doll and others, 1989, 1996) and a late, gently west-dipping cleavage in Carys Mills limestones near their contact with pelites in the Springfield quadrangle (Ludman, unpublished data) is tentatively attributed to a second thrust.

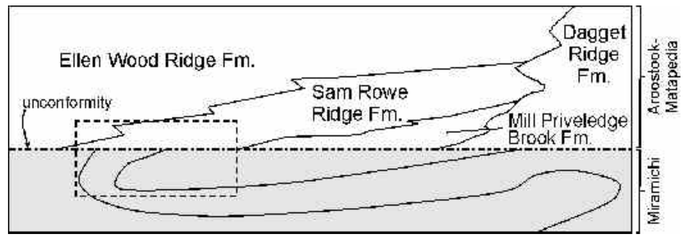


Figure 8. Inferred relationships between Aroostook-Matapedia and Miramichi terranes according to an unconformity model. Relationships in the Dill Hill quadrangle are indicated by the dashed rectangle.

Unfortunately, the contact between the terranes is not exposed in the study area, leaving the problem unresolved. There is no direct evidence of a fault – neither the late west-dipping cleavage cited above nor cataclastic fabric – suggesting that the unconformity model is more appropriate. If correct, this implies a modification of facies relationships in the Prentiss Group (Figure 8).

INTRUSIVE IGNEOUS ROCKS

Hills along the southern edge of the Dill Hill quadrangle are underlain by granite assigned by Ayuso (1984) to the Bottle Lake plutonic complex, one of the largest intrusive bodies in eastern Maine (Osberg and others, 1985). Ayuso divided the complex into two major phases, the Whitney Cove pluton to the east and the slightly younger Passadumkeag River pluton to the west, with distinctions made by higher ferromagnesian mineral content and abundant hornblende in the latter. Most granite in the Dill Hill quadrangle, and almost all exposures in the Washington County portion of the area, was designated by Ayuso as belonging to a rim facies of the Whitney Cove pluton. Outcrops in the southwestern corner of the quadrangle, on the south slope of Bowers Mountain and the north-facing slope of hills to the south were attributed to a rim facies of the Passadumkeag River body.

Three texturally and mineralogically different granite varieties were identified during this study, two of which correspond to Ayuso's (1984) categories. The third, a unique porphyritic type, is thought to be a border phase of the Passadumkeag River pluton (see accompanying geologic map). The Whitney Cove pluton intrudes and/or thermally metamorphoses the Baskahegan Lake and Bowers Mountain Formations in the study area and thermally metamorphoses the Sam Rowe Ridge Formation although it is not in contact with it at the surface. The Passadumkeag River pluton intrudes the Bowers Mountain and Stetson Mountain Formations within the study area and was interpreted by Ayuso (1984) as also truncating the Whitney Cove pluton. West of the Stetson Mountain fault in the Bowers Mountain and Springfield 7.5' quadrangles, the Passadumkeag River pluton cross-cuts the Sam Rowe Ridge, Smyrna Mills, and Carys Mills Formations as well, so that it seals the contact between the Aroostook-Matapedia and Miramichi terranes.

Whitney Cove pluton (Dbwc). The rim facies of the Whitney Cove granite is homogeneous in the study area, a coarse-grained (2-4 cm), pale gray to white weathering hornblende-biotite granite containing pink microcline. Albite is common, somewhat more so than in the Deblois pluton to the south, but is rarely found as euhedral crystals. Instead, the plagioclase typically occurs as subhedral to anhedral grains that, along with quartz, are interstitial among the more abundant euhedral microcline crystals. The ferromagnesian mineral content is low, ranging from 10-15% of the rock. Biotite flakes up to 1.5 cm in diameter are by far the most abundant. Although Ayuso (1984) states that the Whitney Cove pluton contains no hornblende, trace amounts of that amphibole have been observed throughout the body in the Dill Hill quadrangle. Apatite and zircon are the most common accessory minerals, with some pyrite locally. No late-stage aplite or pegmatite dikes have been observed at the contact with the host rock.

Passadumkeag River pluton (Dbpr). The rim facies of the Passadumkeag River pluton in the study area differs texturally from the Whitney Cove pluton in being coarser grained, typically 4-6 cm, and containing euhedral plagioclase crystals. Mineralogically it has a higher ferromagnesian mineral content in which hornblende is more abundant than biotite, and alkali feldspar and plagioclase are present in nearly equal amounts. Although its color index is higher, gray to white microcline locally weathers chalky white, giving the rock a lighter appearance than many outcrops of the Whitney Cove pluton in which the microcline weathers brick-red. The only significant lithologic variation observed in the Passadumkeag River pluton in the study area is a porphyritic variety (Dbprp) exposed near the Miramichi contact on the south side of Bowers Mountain and on unnamed hills southeast of Dipper Pond. Light gray potassic feldspar phenocrysts 1-1.5 cm long are set in a white, unusually fine-grained groundmass in which round quartz grains stand out prominently and abundant biotite and hornblende create a salt-and-pepper appearance. This rock is interpreted as a chilled border phase of the pluton.

Age. Ayuso and others (1984) used U-Pb zircon and Rb-Sr whole-rock ages to demonstrate that the Whitney Cove pluton was emplaced at 380 ± 5 Ma. Essentially identical results were obtained for the Passadumkeag River pluton. This also sets the minimum age for the Stetson Mountain fault as the pluton is not sheared along the trace of that structure and is therefore interpreted to have intruded it.

METAMORPHISM

A sharply defined thermal metamorphic aureole surrounds the Whitney Cove pluton in the Dill Hill quadrangle, extending 2.25 to approximately 3.25 km northward from the mapped contact with the metasedimentary rocks of the Miramichi and Aroostook-Matapedia terranes. The aureole was superimposed on a region that had experienced nothing more intense than chlorite grade metamorphism, despite the multiple deformation history recorded in the Baskahegan Lake, Bowers Mountain, and Stetson Mountain Formations.

Outside the aureole, the observed metamorphic effects are highlighted by crystallization of abundant small light green chlorite flakes in sandstones and pelites of the Baskahegan Lake Formation. Chlorite has also been observed in argillaceous wackes and siltstones of the Sam Rowe Ridge Formation, but has not been identified in the Bowers Mountain Formation. Chlorite and white mica flakes are weakly aligned parallel to S_1 cleavage in the Baskahegan Lake Formation psammites and more strongly aligned in pelitic interbeds in that formation. These phyllosilicates are kinked and locally broken in S_2 cleavage in the Baskahegan Lake Formation, but there does not seem to have been a second generation of chlorite growth during F_2, even though some chlorite has been identified in Sam Rowe Ridge Formation pelites. The low grade of regional metamorphism indicates that both Ordovician and Silurian deformations took place at epizonal crustal levels.

The outermost thermal effects associated with emplacement of the Whitney Cove pluton are highlighted by the appearance of red-brown biotite in argillaceous wackes and pelites in most units, and by the presence of a slightly paler red-brown biotite in Stetson Mountain volcanic rocks. The pronounced color change from gray or greenish gray to deep "maroon" color in the metasedimentary rocks permits easy location of the biotite isograd. The granoblastic texture produced by thermal metamorphism obliterates most traces of cleavage in the metasedimentary units, although insoluble residue produced during generation of S_1 pressure solution cleavage is locally identifiable. Wackes typically become dense, massive granofelses in which original clasts can still be readily identified, and fissile pelite is converted to very fine-grained granofels or hornfels. Biotite grain size increases from the biotite isograd toward the pluton and the higher grade rocks are generally darker purple in color.

The remainder of the aureole is divided into two zones, a broad cordierite (+ andalusite) zone indicating moderate contact metamorphism, and a narrow sillimanite zone immediately adjacent to the pluton. Available data do not permit delineation of separate cordierite and andalusite zones, although cordierite appears to form somewhat farther from the pluton than the andalusite. The first appearance of cordierite is typically as small round grains, but these increase to as much as 1.25 cm in diameter in the higher grade part of the zone. Andalusite in the lower grade part of the zone occurs as 5 mm long crystals the shape of rice grains, but the crystals become larger and more elongate with increasing intensity. Thin sillimanite prisms are restricted to a few exposures immediately adjacent to the pluton.

This metamorphic zonation, coupled with the low (chlorite zone) regional grade, indicates a relatively shallow crustal environment for the study area throughout deformation and pluton emplacement. The transition from andalusite to sillimanite in the Whitney Cove contact aureole requires pressures lower than that of the aluminosilicate triple point, and miarolitic cavities in the Pokiok pluton that intrudes the Miramichi suite a few miles to the east suggest pressures on the order of 2 kilobars.

ECONOMIC POTENTIAL

Gold

Freewest Resources Canada, Inc. (1998; Northern Miner, 1998) reported the discovery of gold deposits in volcanic rock of the Miramichi terrane in contact with the Pokiok pluton just northeast of the study area. The mineralization apparently was concentrated in faults that provided access for fluids derived from the magma. A similar geologic setting is found at the northwestern corner of the Dill Hill quadrangle, and on strike to the southwest in the Bowers Mountain quadrangle. There, possibly correlative volcanic rocks of the Stetson Mountain Formation have been sheared in the Stetson Mountain fault zone and later intruded by the Whitney Cove pluton.

Unfortunately, this study did not reveal outcrop or thin-section scale evidence of gold mineralization. Some quartz veining is concentrated in the Stetson Mountain fault zone, but no gold has been identified in these veins. Geophysical or geochemical sampling would be useful in exploring this potential resource more fully, but was beyond the scope of the current project.

Manganese

Some outcrops in the Sam Rowe Ridge Formation outlier develop a thick (up to 3 cm) weathering rind composed largely of somewhat iridescent black manganese oxides and hydroxides. These occurrences are scattered through the formation, without apparent stratigraphic control, and do not appear to be voluminous enough to justify more detailed examination. Similar deposits in the Aroostook-Matapedia terrane farther north were investigated by the U.S. Geological Survey in the 1950's, but were never developed.

Sand and gravel

The most promising resource in the quadrangle is abundant sand and gravel in glaciofluvial deposits that have already been extensively quarried by the Baskahegan and other lumber companies to help build their network of access roads. An esker parallel to the unnamed lineament in the eastern part of the quadrangle has provided large volumes of sand and gravel, as have pits in kame-like deposits in Physiographic Zones III and IV (Figure 3).

REFERENCES CITED

Ayuso, R., 1984, Field relations, crystallization, and petrology of reversely zoned plutons in the Bottle Lake Complex, Maine: U.S. Geological Survey, Professional Paper 1320, 58 p.

Ayuso, R. A., Arth, J. G., Sinha, A. K., Carlson, J., and Wones, D. R., 1984, Comparative geochronology in the reversely zoned plutons of the Bottle Lake complex, Maine: U-Pb on zircons and Rb-Sr on whole rocks: Contributions to Mineralogy and Petrology, v. 88, p. 113-125.

Doll, W. E., Costain, J. K., Domoracki, W. D., Coruh, A., Ludman, A., and Hopeck, J., 1989, Interpretation of seismic reflection lines crossing the Norumbega fault zone and Bottle Lake plutonic complex, eastern Maine: Geological Society of America, Abstracts with Programs, v. 21, p. 320.

Doll, W. E., Costain, J. K., Domoracki, W. D., Coruh, A., Ludman, A., and Hopeck, J., 1996, Implications of a seismic reflection profile across part of the Norumbega fault zone, east-central Maine: Geology, v. 24, no. 3, p. 251-254.

Freewest Resources Canada Inc., 1998, Summary report on the Golden Ridge property in York and Carleton Counties, New Brunswick, town of Amity, Maine, NTS 21G/13: Freewest Resources Canada Inc., Thunder Bay, Ontario, August.

Hall, B. A., 1970, Stratigraphy of the southern end of the Munsungun anticlinorium, Maine: Maine Geological Survey, Bulletin 22, 63 p.

Hopeck, J., 1991, Post-Caradocian stratigraphy of the Aroostook-Matapedia and Miramichi blocks, in Ludman, A. (editor), Geology of the coastal lithotectonic block and neighboring terranes, eastern Maine and southern New Brunswick: New England Intercollegiate Geological Conference, 83rd Annual Meeting, September 27-29, 1991, Princeton, Maine, p. 157-168.

Hopeck, J., 1994, Post-Caradocian strata of the Miramichi anticlinorium and their relation to the Aroostook-Matapedia belt, in Hanson, L. S. (editor), Guidebook to field trips in north-central Maine: New England Intercollegiate Geological Conference, 85th Annual Meeting, September 23-25, 1994, Millinocket, Maine, p. 43-59.

Larrabee, D. M., Spencer, C. W., and Swift, D. J. P., 1965, Bedrock geology of the Grand Lake area, Aroostook, Hancock, Penobscot, and Washington Counties, Maine: U.S.Geological Survey, Bulletin 1202-E, 38 p.

Ludman, A., 1991, Stratigraphy of the Miramichi terrane in eastern Maine, in Ludman, A. (editor), Geology of the coastal lithotectonic block and neighboring terranes, eastern Maine and southern New Brunswick: New England Intercollegiate Geological Conference, 83rd Annual Meeting, September 27-29, 1991, Princeton, Maine, p. 338-357.

Ludman, A., Hopeck, J. T., and Brock, P. C., 1993, Nature of the Acadian orogeny in eastern Maine, in Roy, D. C., and Skehan, J. W. (editors), The Acadian orogeny: Recent studies in New England, maritime Canada, and the autochthonous foreland: Geological Society of America Special Paper 275, p. 67-84.

Mangini, M., 1982, Stratigraphy and structure of the Upper Tetagouche Group in the Miramichi anticlinorium, eastern Maine: M.A. thesis, Queens College, Flushing, New York, 133 p.

Neuman, R. B., 1967, Bedrock geology of the Shin Pond and Stacyville quadrangles, Penobscot County, Maine; U.S. Geological Survey, Professional Paper 524-I, 37 p.

Northern Miner, 1998, Freewest targets gold at Golden Ridge: Northern Miner, v. 84, no. 33, October 12-18, p. 13.

Osberg, P. H., Hussey, A. M., II, and Boone, G. M., 1985, Bedrock geologic map of Maine: Maine Geological Survey, scale 1:500,000.

Pavlides, L., 1974, General bedrock geology of northeastern Maine, in Osberg, P. H. (editor), Guidebook for field trips in east-central and north-central Maine: New England Intercollegiate Geological Conference, 66th Annual Meeting, October 12-13, 1974, Orono, Maine, p. 61-85.

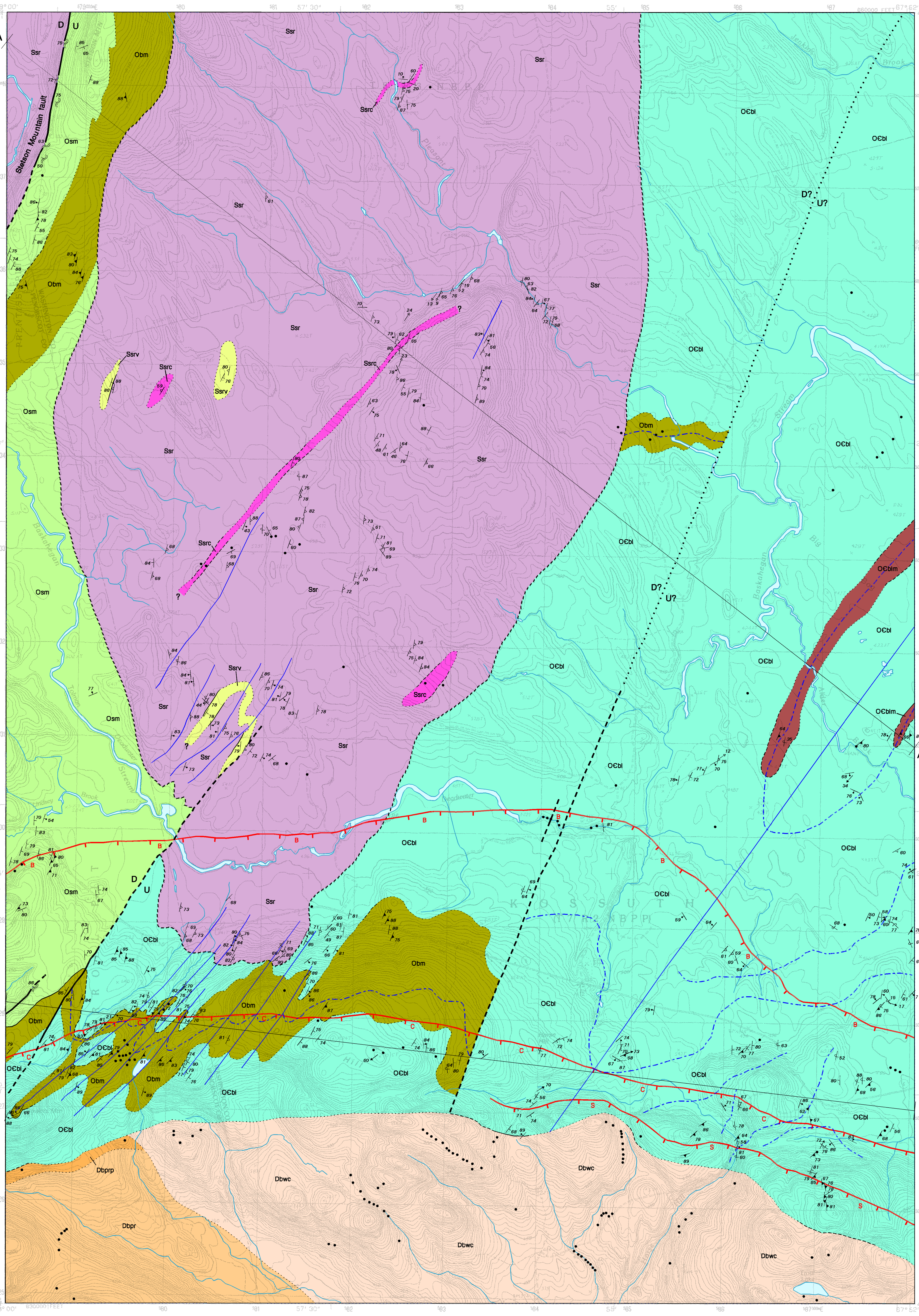
Pickerill, R. K., and Fyffe, L. R., 1999, The stratigraphic significance of trace fossils from the Lower Paleozoic Baskahegan Lake Formation near Woodstock, west-central New Brunswick: Atlantic Geology, v. 35, no 3, p. 215-224.

Potter, R. R., Hamilton, J. B., and Davies, J. L., 1979, Geological map of New Brunswick: New Brunswick Department of Natural Resources, Map NR-1, Fredericton, N.B., Canada, scale 1:500,000.

Sayres, M., 1986, Stratigraphy, polydeformation, and tectonic setting of Ordovician volcanic rocks in the Danforth area, eastern Maine: M.A. thesis, Queens College, Flushing, New York, 135 p.

Sayres, M., and Ludman, A., 1985, Stratigraphy and polydeformation of Tetagouche (Ordovician) volcanic rocks of the Miramichi anticlinorium in the Danforth quadrangle, eastern Maine: Geological Society of America, Abstracts with Programs, v. 17, p. 62.

Bedrock Geology



Dill Hill Quadrangle, Maine

Bedrock geologic mapping by
Allan Ludman

Geologic editing by:
Henry N. Berry IV

Digital cartography by:
Robert A. Johnston

Robert G. Marvinney
State Geologist

Cartographic design and editing by:
Robert D. Tucker

Funding for the preparation of this map was provided in part by the U.S. Geological Survey National Geologic Mapping Program, Cooperative Agreement No. 99HQAG0119.

Maine Geological Survey

Address: 22 State House Station, Augusta, Maine 04333
Telephone: 207-287-2801 **E-mail:** mgs@maine.gov
Home page: http://www.maine.gov/doc/nrimc/nrimc.htm

Open-File No. 03-93
2003

This map accompanied by a 16 p. report.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Bottle Lake Complex

Devonian

Dbpr / Dbprp — **Passadumkeag River pluton.** Coarse grained biotite-hornblende granite and quartz monzonite with gray microcline. **Dbprp:** porphyritic border phase. Age is 380 ± 5 based on U-Pb zircon and Rb-Sr whole-rock analyses (Ayuso and others, 1984).

Dbwc — **Whitney Cove pluton**. Medium-grained to coarse-grained biotite granite with pink microcline. Ferromagnesian content generally 10-15%. Age is 380 ± 5 Ma based on U-Pb zircon and Rb-Sr whole-rock analyses (Ayuso and others, 1984).

STRATIFIED ROCKS

AROOSTOOK-MATAPEDIA TERRANE

Prentiss Group

Silurian(?)

Ssr — **Sam Rowe Ridge Formation**. Thinly and rhythmically interbedded sandstone and gray pelite in roughly equal proportions. Beds are mostly 5-15 cm thick, but range from 2 cm to almost a meter. Graded beds are ubiquitous. The sandstone is fine-grained to medium-grained argillaceous wacke that ranges in composition from quartzo-feldspathic to highly feldspathic. Pelite is medium-gray to dark-gray. Small amounts of ankerite or siderite are commonly present in both sandstone and pelite, but calcareous rocks are rare.

Ssrc — Polymictic conglomerate. Pebble to small cobble conglomerate with rounded clasts of felsic volcanic rock and quartzose sandstone. The matrix is generally silt or sand, and some is highly calcareous. Many clasts are derived from the Stetson Mountain and Baskahegan Lake Formations (Hopeck, 1994). In addition to the mapped units, minor amounts of conglomerate are scattered through the formation.

Ssrv — Fragmental volcanic and volcaniclastic rocks. Grayish-green ashfall tuff. Similar to rocks of the Steson Mountain Formation.

----- UNCONFORMITY -----

MIRAMICHI TERRANE

Ordovician(?)

Osm — **Stetson Mountain Formation**. Gray or green, fine-grained to cryptocrystalline ashfall tuffs; medium-grained ashflow tuffs; minor volcanic agglomerates, black shale, and manganiferous chert or mudstone. Interpreted to be conformable with the Bowers Mountain Formation.

Obm — **Bowers Mountain Formation**. Thinly bedded pelite with subordinate thin quartz arenite interbeds. Pelite in the lower part of the formation is predominantly rusty-weathering, black, sulfidic and carbonaceous, whereas in the upper part of the formation gray-weathering, non-sulfidic, non-carbonaceous to slightly carbonaceous pelite is more abundant. Internal stratigraphic relationships are obscured by shearing, however, frustrating efforts to define upper and lower members. Massive beds of quartz arenite 15 to 50 cm thick are found throughout the formation. The Bowers Mountain is interpreted to be conformable with the Baskahegan Lake Formation.

Lower Ordovician(?)-Cambrian(?)

OЄbl — **Baskahegan Lake Formation**. Bluish-gray to grayish-green quartzose or quartzo-feldspathic wacke and arenite in thick massive beds, or in Bouma sequences with subordinate gray, green, or maroon pelite. Both massive and graded beds are common. A penetrative pressure-solution cleavage is well developed. Massive beds, including some coarser beds of granule conglomerate, range to greater than 2 meters thick. Thinly interbedded pinstriped siltstone and mudstone occur in graded beds down to 2-5 cm in thickness. All rocks are metamorphosed to hornfels in contact aureole of the Bottle Lake pluton.

OЄblm — Maroon Lower Member. Same rock types as the rest of the formation, except for deep red color in both wacke and pelite, caused by a greater proportion of matrix hematite. This unit is recognized only in chlorite-grade exposures, presumably because the hematite is not preserved at higher metamorphic grade. Primary facing indicators along the contact show that this member is stratigraphically below the green and gray rocks of the rest of the formation. Base of the unit is not exposed.

EXPLANATION OF LINES

Stratigraphic or intrusive contact (well located, approximately located, inferred).

Inferred unconformity, possibly modified by thrust and normal faulting.

High angle fault (well located, approximately located, inferred). Relative motion indicated by letters: U = upthrown block, D = downthrown block.

B — Contact metamorphic isograd related to the Bottle Lake Complex. Index mineral labeled on higher-grade side of line: biotite (B), cordierite (C), sillimanite (S). Some rocks in the cordierite zone also contain andalusite porphyroblasts. Sillimanite isograd has not been delineated in the southwestern part of the map.

Inferred trace of F1 hinge surface. Identified by reversals in facing direction of bedding. Variable in orientation due to F2 deformation. Restricted to units older than the Sam Rowe Ridge Formation.

Inferred trace of F2 hinge surface. Identified by pattern of mapped contacts and by reversals in facing direction of bedding. Generally north to northeast-trending, upright folds.

A — A' Line of cross-section.

EXPLANATION OF SYMBOLS

Outcrop of mapped unit, no structural data given.

20 20 20 — Strike and dip of bedding. Stratigraphic tops determined from relict primary features where indicated (tops unknown, tops upward, overturned).

20 — Strike and dip of first cleavage. Spaced cleavage defined by mineral preferred orientation. Axial plane fabric of first generation folds.

20 — Strike and dip of second cleavage. Predominant planar fabric in homogeneous pelitic rocks, particularly in the Sam Rowe Ridge Formation.

20 — Strike and dip of mylonitic foliation. A penetrative foliation related to the Stetson Mountain fault in the northwest corner of the map area.

20 — Trend and plunge of first generation (F1) minor fold.

20 — Trend and plunge of second generation (F2) minor fold.

20 — Trend and plunge of second generation intersection lineation.

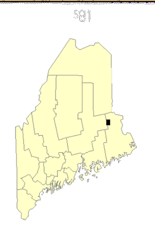
REFERENCES CITED

Ayuso, R. A., Arth, J. G., Sinha, A. K., Carlson, J., and Wones, D. R., 1984, Comparative geochronology in the reversely zoned plutons of the Bottle Lake complex, Maine: U-Pb on zircons and Rb-Sr on whole rocks. Contributions to Mineralogy and Petrology, v. 88, p. 113-125.

Hopeck, J., 1994, Post-Caradocian strata of the Miramichi anticlinorium and their relation to the Aroostook-Matapedia belt. In Hanson, L. S. (editor), Guidebook to field trips in north-central Maine: New England Intercollegiate Geological Conference, 85th annual meeting, Millinocket, Maine, p. 43-59.

SOURCES OF INFORMATION

Bedrock geologic mapping by Allan Ludman completed during the 1999 field season.



Quadrangle Location

SCALE 1 : 24,000

1 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0 1 KILOMETER

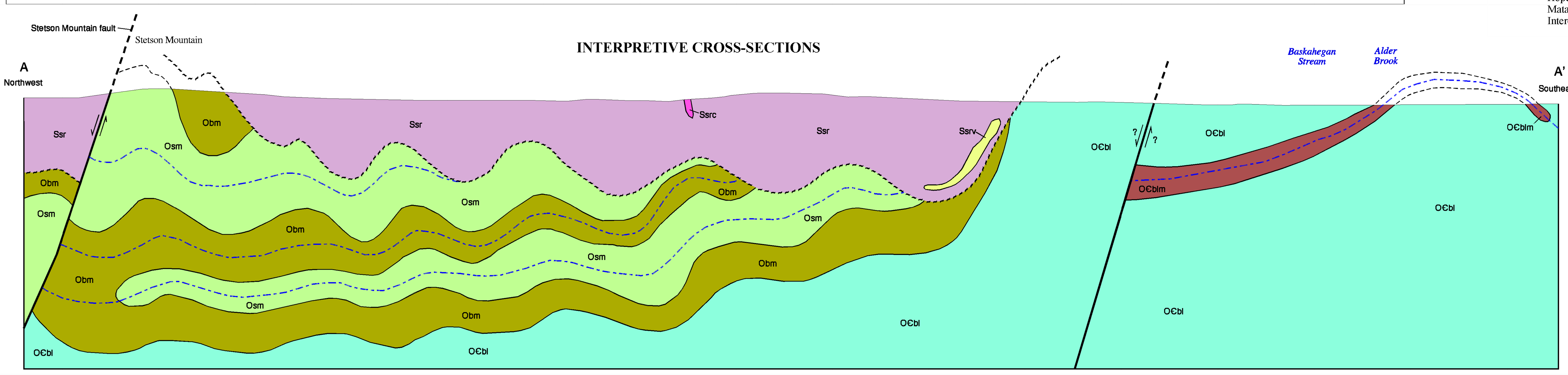
CONTOUR INTERVAL 10 FEET

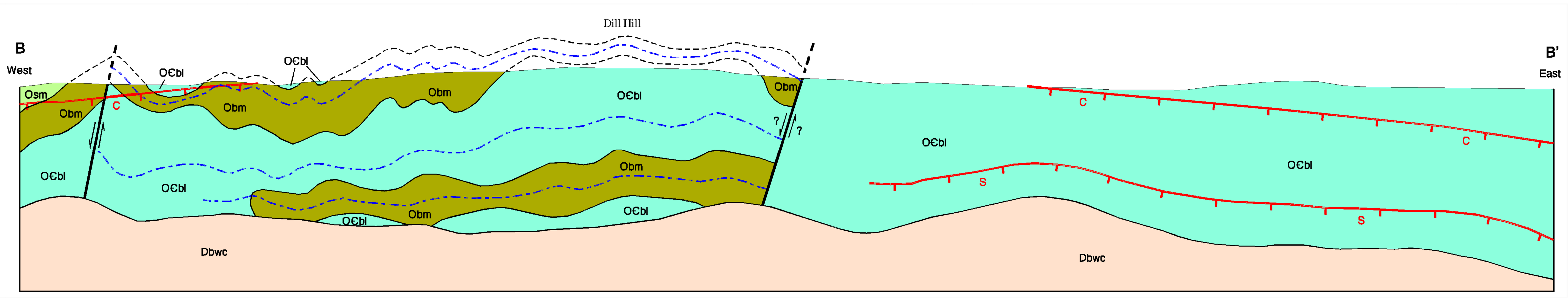
TRUE NORTH

Topographic base from U.S. Geological Survey Dill Hill quadrangle, scale 1:24,000 using standard U.S. Geological Survey topographic map symbols.

The use of industry, firm, or local government names on this map is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

INTERPRETIVE CROSS-SECTIONS





GEOLOGIC TIME SCALE

Geologic Age		Absolute Age*
Cenozoic Era		0-65
Mesozoic Era	Cretaceous Period	65-145
	Jurassic Period	145-200
	Triassic Period	200-253
Paleozoic Era	Permian Period	253-300
	Carboniferous Period	300-360
	Devonian Period	360-418
	Silurian Period	418-443
	Ordovician Period	443-489
	Cambrian Period	489-544
Precambrian time		Older than 544

* In millions of years before present. (Okulitch, A. V., 2002, Échelle des temps géologiques, 2002: Commission géologique du Canada, Dossier Public 3040 (Série nationale des sciences de la Terre, Atlas geologique) - RÉVISION.)