DEPARTMENT OF AGRICULTURE, CONSERVATION AND FORESTRY

Maine Geological Survey

Robert G. Marvinney, State Geologist

OPEN-FILE NO. 20-22

Title: *Bedrock geology of the Springfield 15′ quadrangle, Maine*

Author: *Allan Ludman and John T. Hopeck*

Date: *October 2020*

Contents: 20 p. report and 4 color maps

Recommended Citation: Ludman, Allan, and Hopeck, John T., 2020, Bedrock Geology of the Springfield 15′ quadrangle, Maine: Maine Geological Survey, Open-File Report 20-22, 20 p. report and 4 color maps, scale 1:24,000.

TABLE OF CONTENTS

Introduction 1
Topography 1
Access and Bedrock Exposure 1
Geologic and Tectonic Settings 2
Previous Work 3
Stratigraphy 3
Miramichi Terrane 3
Baskahegan Lake Formation (O€bl) 4
Thickness 5
Age 5
Bowers Mountain Formation (Obm) 5
Thickness 5
Age 5
Stetson Mountain Formation (Osm) 6
Thickness 7
Comparison with the Miramichi Terrane Greenfield Segment 7
Age 7
Central Maine/Aroostook-Matapedia Belt 8
Facies Relationships 8
Proximal Facies 8
Daggett Ridge Formation (SOd) 8
Thickness 9
Age 9
Mill Priveledge Brook Formation (SOmp) 9
Thickness 10
Age 10
Intermediate Facies 10
Sam Rowe Ridge Formation (Ssr) 10
Thickness 10
Age 10
Ellen Wood Ridge Formation (Sew) 11
Thickness 12
Age 12
Distal facies 12
Carys Mills Formation (SOcm) 12
Thickness 12
Age 12
Smyrna Mills Formation (Ssm) 12
Thickness 14
Age 14
Bottle Lake Complex 14
Age 14
Deformation 15
D_1 Recumbent Folding 15
D_2 Thrusting 16
D_3 Upright Folding 16
Age 17

D_4: Sinistral/reverse Oblique Slip Faulting 17
Age 17
Late-stage deformations 17
References Cited 19

Bedrock Geology of the Springfield 15' Quadrangle, Maine

Allan Ludman[1] and John T. Hopeck[2]
[1]School of Earth and Environmental Sciences, Queens College (CUNY), 65-30 Kissena Boulevard, Flushing, NY 11367; [2]Maine Department of Environmental Protection, 17 State House Station, Augusta, ME 04333

INTRODUCTION

This report describes the geology of the Springfield 15′ quadrangle that today comprises the Springfield (Plate 1), Bowers Mountain (Plate 2), Bottle Lake (Plate 3), and Weir Pond (Plate 4) 7½′ quadrangles (Figure 1). The area of approximately 205 square miles is located almost entirely in eastern Penobscot County, with a small sliver of Washington County in the northeastern corner. It is sparsely populated, with fewer than 1,000 permanent residents, most concentrated in the Springfield and Bowers Mountain quadrangles in Springfield (409) and Prentiss (214) townships and Carroll Plantation (144).

Topography

The northern Springfield and Bowers Mountain quadrangles are characterized by lower relief than the Weir Pond and Bottle lake quadrangles to the south. The northern part of the area is underlain largely by weakly metamorphosed Late Ordovician to Late Silurian sedimentary rocks of the eastern Central Maine/ Aroostook-Matapedia (CMAM) basin and Cambro-Ordovician sedimentary and volcanic rocks of the Miramichi terrane (Figure 1) blanketed by glacial deposits. The resulting topography consists of broad rolling hills that rise 300 to 500 feet above adjacent lowlands and streams with only a few small ponds. Economic activity consists mostly of forestry and farming. Most local farms had historically raised potatoes, but some have switched recently to corn and hay.

The southern half of the area is underlain mostly by granitic rocks of the Bottle Lake Complex (Figure 1) and exhibits a very different topography with numerous large lakes, swamps, and bogs, the largest of which is, appropriately, named 1,000 Acre Heath. The contact aureole and northern margin of the complex support rugged topography with greater relief than the northern half of the area, including the three highest elevations – Bowers (1195′), Almanac (1070′+), and Getchell (1020′ +) mountains – and several unnamed rounded hills over 800′ high.

Access and Bedrock Exposure

Maine Route 6 traverses the central part of the area east-west, and Routes 169 and 170 provide north-south access in the northern part. In addition, an extensive network of paved and unpaved county, town, farm, recreational, and lumber roads extends throughout the

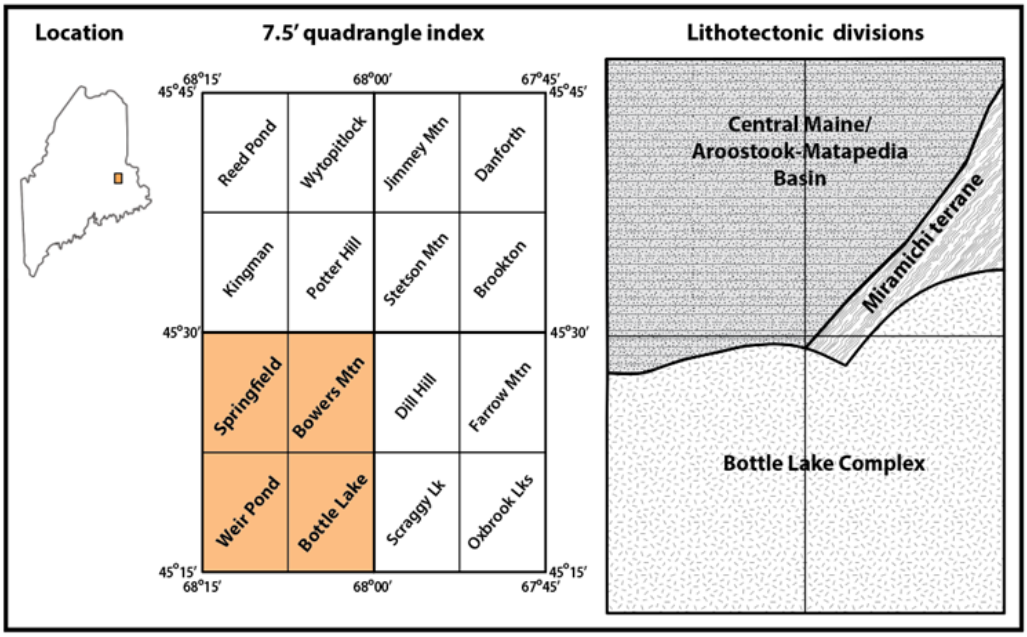


Figure 1. Location and lithotectonic setting.

study area. In an area with less than 1% outcrop, these roads also provide a large percentage of the bedrock exposures on which this report is based, including a few relatively large three-dimensional outcrops on Route 6, smaller exposures along the secondary roads, and numerous pavement outcrops from which glacial deposits have been scraped.

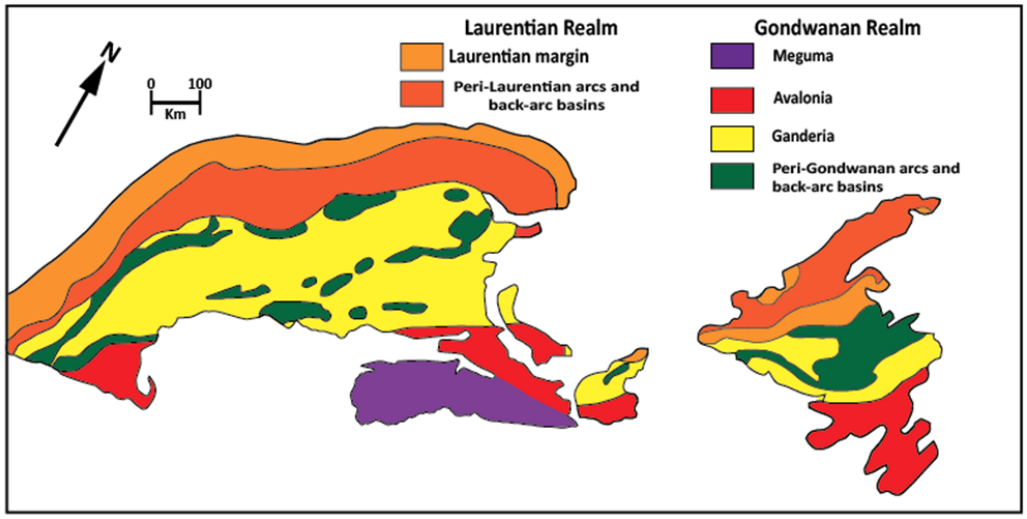
The thickness of glacial cover varies widely. Thick till and outwash deposits in the Bottle Lake and Weir Pond quadrangles result in poor bedrock control in the Bottle Lake Complex, particularly in the southern two thirds of those quadrangles where there are few outcrops, even on the highest hills. Hornfels holds up rugged hills in the contact area, however, so that the pluton/host rock contact can be traced with confidence. In contrast, glacial cover is typically thinner in the Springfield and Bowers Mountain quadrangles where several large farms are located. As a result, their crops commonly reflect the nature of the underlying bedrock with strong correlation of potatoes and corn (and, unfortunately, poison ivy) with limestone and hay with turbiditic sandstone-shale belts.

Geologic and Tectonic Settings

The Paleozoic history of the Northern Appalachians involved the progressive closing of the Iapetus Ocean during accretion of three microplates of the Gondwanan realm (Figure 2A) to ancestral North America, causing the orogenic events outlined in Figure 2B. Maine is underlain largely by remnants of the Ordovician Ganderian microplates separated by Late Ordovician to Early Devonian cover rocks (Figure 3). The older rocks represent the basements and volcanic rocks of Ganderian island arcs deformed during mid-Ordovician accretion to North America ("Taconian" orogeny), and the younger rocks are thick basin sediments eroded from post-Taconian highlands (Ludman et al., 2017).

The Springfield 15′ quadrangle straddles the boundary between the Cambrian-Middle Ordovician Miramichi terrane and adjacent, largely Silurian, cover

A



B

Age	Orogenic Event	Plate Tectonic Explanation
Permian	Alleghanian	Accretion of Gondwana to previously amalgamated plates
Late Devonian	"Neoacadian"	Accretion of Meguma to previously amalgamated plates
Early Devonian	Acadian	Accretion of Avalon to previously amalgamated plates
Late Silurian	Salinic	Closure of remnant back-arc basin and amalgamation of Ganderia with Laurentia
Mid-Ordovician (Caradocian)	"Taconian"	Accretion of leading edge of Ganderian composite plate to Laurentia
Cambro-Ordovician	Penobscot	Amalgamation of Ganderian microplates within the Iapetus Ocean
Latest Neoproterozoic		Rifting of Rodinian supercontinent, opening of Iapetus Ocean
Late Neoproterozoic (~1Ga)	Grenville	Assembly of Rodinian supercontinent

Figure 2. Tectonic setting. (A) Tectonic framework of the Northern Appalachian orogen (after Hibbard et al., 2006). (B) Tectonic evolution of the Northern Appalachians. Shading indicates the time spanned by rocks and structures in the study area.

Figure 3. Lithostratigraphic framework of Maine. Springfield 15′ quadrangle shown in black

rocks of the CMAM belt, and contains important evidence for the sedimentologic and tectonic evolution of their relationships following the Taconian orogeny.

Eastern and northeastern Maine experienced only weak regional metamorphism (chlorite and sub-chlorite) despite its complex, multi-episodic deformation history (Ludman, 2017). As a result, primary sedimentary structures and textures are generally preserved, although they are masked and, in some places, obliterated by transposed layering associated with folding and faulting. More intense metamorphism is recorded only in contact aureoles of granitic and mafic plutons. Extensive magmatism occurred in two pulses following accretionary events. Igneous rocks of the earliest event, associated with Salinic (early Acadian) deformation at around 420 Ma, are not found in the study area. Granitic rocks of the Bottle Lake igneous complex represent the later pulse that followed the main Acadian deformation at around 380 Ma.

Previous Work

The first modern geologic map that included the study area was a 1:250,000 compilation based on USGS reconnaissance mapping between 1956 and 1962 (Larrabee et al., 1965). That study distinguished the two stratigraphic suites here called the Miramichi and CMAM basin strata and postulated a fault contact between them; correlated the Miramichi terrane with Cambro-Ordovician belts in northern Maine; and delineated the contact between the Bottle Lake complex and its host rocks far more accurately than the previous Maine bedrock map (Keith, 1933).

Ayuso (1984) conducted comprehensive field, petrographic, and geochemical studies of the Bottle Lake complex, interpreted its emplacement and petrologic evolution, and constrained its age to around 380 Ma (Ayuso et al., 1984) The complex was evaluated by the Maine Geological Survey in the 1980s as a possible national repository for high-level nuclear waste. Structural analyses based on our mapping, gravity modeling (Doll and Potts, 1990), and a seismic reflection transect (Doll et al., 1996; Costain et al., 1996) revealed that the complex is lens-shaped, shallow, and locally highly fractured, ruling it out its use as a repository.

Our work in the Springfield 15′ quadrangle spans more than 30 years, beginning in the early 1980s with Ludman's reconnaissance mapping for the Maine bedrock map (Ludman, 1985; Osberg et al., 1985) and Hopeck's initial studies in the Springfield and Wytopitlock 15′ quadrangles (reported in Hopeck, 1998). Improvements in understanding stratigraphy and structure have been reported in several Maine Geological Survey open file reports (Hopeck, 1990; Ludman, 1985) and guidebooks of the New England Intercollegiate Geological Conference (Ludman, 1991, 2003, 2013; Hopeck, 1991, 1994, 2013). Local Miramichi stratigraphy was established in the adjacent Dill Hill 7½′ (Ludman, 2003) and Calais 1:100,000 quadrangles (Ludman and Berry, 2003). These studies set the stratigraphic and structural framework for the Springfield 15′ and adjacent quadrangles and played a major role in recent interpretations of post-Middle Ordovician lithofacies relationships and reconstructions of post-Taconian, pre-Acadian paleogeography and sediment-source relationships (Ludman et al., 2017).

STRATIGRAPHY

Rocks of the Miramichi and CMAM belts record two different segments of Early Paleozoic time (Figure 4). No fossils have been found in the Springfield study area but graptolites and trace fossils in neighboring quadrangles and New Brunswick indicate a Cambrian through Middle Ordovician range for the Miramichi section. U-Pb ages of detrital and volcanic zircons discussed below confirm the ages of the three Miramichi units (Ludman et al., 2018). Ages of the CMAM rocks are based on correlation with similar but fossiliferous rocks of the Meduxnekeag Group near Houlton (Pavlides, 1974). A single brachiopod valve yielded a "Silurian" age for the Daggett Ridge Formation in the proximal facies of the CMAM belt (Larrabee et al., 1965).

Miramichi Terrane

The Miramichi terrane is a prominent component of Ganderia, generally interpreted as the sedimentary foundation and volcanic carapace of Ordovician island arcs and back-arc basins (Fyffe et al., 2011). It extends

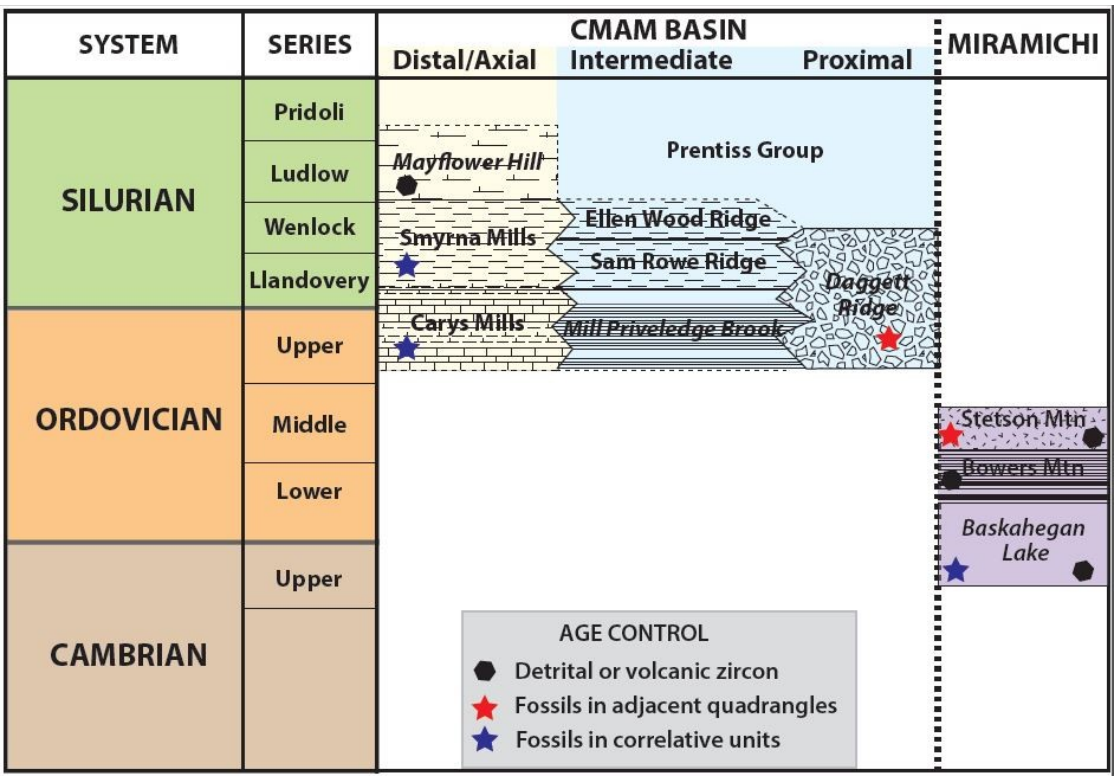


Figure 4. Stratigraphic framework for the Springfield 15′ quadrangle. Italics indicate units not present in the quadrangle but included for completeness.

more than 300 kilometers (km) from northern New Brunswick into Maine, where the Bottle Lake complex separates it into the Danforth segment north of the complex (including rocks of the study area) and the smaller Greenfield segment to the south. The belt in the Danforth segment appears to be continuous, with conformable contacts between formations.

Baskahegan Lake Formation (O€bl)

The Baskahegan Lake Formation is the dominant unit in the Danforth segment and is named for extensive outcrops on the east and south shores of that lake in the Brookton 7½′ quadrangle. It crops out in a broad band that narrows to the southwest through the Dill Hill quadrangle and crops out in the study area only on Almanac Mountain in the Bottle Lake quadrangle.

The Baskahegan Lake Formation consists mostly of thick bedded quartzose and quartzofeldspathic arenites and wackes (~70%) intercalated with abundant but subordinate (30%) slates and mudstones. Feldspathic wackes and arenites typically develop a pale gray to white clay-rich weathering rind as much as 2 centimeters (cm) thick, whereas the quartzose rocks have a thin (millimeters) gray outer weathered rind. Several bedding styles are observed, including massive sandstone beds more than 2 meters thick, nearly complete Bouma sequences of similar thickness, and 5–7.5 cm horizons of rhythmically interlayered sandstone and mudstone/slate. Graded bedding, load casts, ball-and-pillow, and flame structures are common. A distinctive close-spaced "bread-slicer" anastomosing solution cleavage recognizable at chlorite through andalusite metamorphic grades is characteristic of most thick-bedded arenites and wackes.

The Baskahegan Lake Formation is divided into upper (green or gray) and lower (maroon to pale pink) members, whose relative ages are indicated by graded beds at gradational contacts in three places in the Farrow Mountain quadrangle. Both members have similar bedding styles, lithic proportions, and varied clast/matrix proportions; the difference is a greater proportion of hematite in the lower member and of chlorite in the upper.

Outcrops at Almanac Mountain are close to the contact with the Passadumkeag River pluton and are unusually rusty weathering, probably because of sulfide introduced by hydrothermal fluids from the pluton. The rocks are thermally metamorphosed to biotite-cordierite grade. Wackes are converted to dense biotite-rich hornfels containing large spherical cordierite porphyroblasts, arenites to massive quartzofeldspathic hornfels, and pelitic rocks to biotite and cordierite-rich hornfels. Lacking the color differences characteristic of low-grade outcrops, these outcrops are assigned the upper member because of their proximity to the overlying Bowers Mountain Formation.

Thickness

The thickness of the Baskahegan Lake Formation cannot be determined, partly because its base is nowhere exposed in Maine or New Brunswick, and partly because it has been folded at least twice. The width of its outcrop belt and regional continuity suggest a minimum thickness on the order of 1–2 kilometers.

Age

The presence of the trace fossil *Oldhamia* in the lower member of the Baskahegan Lake Formation in New Brunswick indicates a Late Cambrian to earliest Ordovician (Tremadocian) age for that part of the formation (Pickerill and Fyffe, 1999). Its maximum age is constrained, albeit not tightly, by the earliest Cambrian to late Neoproterozoic ages of its youngest detrital zircons: 532 Ma in the lower member, 555 Ma in the upper member (Ludman et al., 2018).

Bowers Mountain Formation (Obm)

The Bowers Mountain Formation is named for extensive outcrops on that eponymous elongate ridge in the Bowers Mountain and Dill Hill quadrangles. Its conformable contact with the Stetson Mountain Formation can be traced through tight folds from the northwest slope of Bowers Mountain in the southeast corner of the Bowers Mountain quadrangle northward to Getchell Brook, Brown Hill and the unnamed adjacent hill to the north, and then north-northeastward across Route 6 to where it is truncated by the Stetson Mountain fault zone in the northeast corner of the quadrangle. A (brittle) fault contact with the Sam Rowe Ridge Formation is exposed in the northern part of the Bottle Lake quadrangle, south of South Springfield.

The Bowers Mountain Formation is a distinctive, dominantly pelitic unit containing rusty- and sooty-weathering sulfidic black shales and non-sulfidic to sparsely sulfidic gray weathering shales, with subordinate shale-siltstone couplets and sulfidic quartz arenites. Zones of euxinic and non-euxinic pelite tens of meters thick are typically homogeneous (Figure 5A), with bedding revealed only by beds and laminae of quartzose siltstone a few millimeters (mm) to 2 cm thick. Massive beds of quartz arenite 15–40 cm thick occur throughout the formation but appear to be more abundant in the lower part, close to the contact with the Baskahegan Lake Formation (Figure 5B).

Lithologic variations from the base to the top of the Bowers Mountain Formation record a transition from highly euxinic to more oxidizing conditions. Sooty black pyritiferous shales occur throughout the formation but are most abundant near its base, decrease upward, and are rare near the top where they are nearly completely replaced by zones of gray shales and thinly intercalated shale and siltstone with little or no pyrite.

Thickness

The Bowers Mountain Formation is sandwiched between the older Baskahegan Lake and younger Stetson Mountain formations and is the only Miramichi unit in Maine for which both upper and lower contacts are preserved. Nevertheless, multiple generations of folding combined with local (?) shearing in black shales and larger offsets in the Stetson Mountain and related faults preclude precise thickness estimates. Outcrop width and inferred deformation style in the type locality suggest a tentative thickness of approximately 200–350 meters.

Age

Detrital zircons were collected from the sandstones shown in Figure 5B in an attempt to constrain the maximum age of the Bowers Mountain Formation. The 485 Ma age of the youngest zircons (the Cambrian-Ordovician boundary) is consistent with the formation's position conformably above the Late Cambrian to Tremadocian Baskahegan Lake Formation and conformably below the Stetson Mountain Formation

Figure 5. Bowers Mountain Formation (A) Strongly cleaved pyritiferous black shales; (B) sulfidic quartz arenite interbedded with biotite-grade black shales (Dill Hill quadrangle).

(Middle Ordovician; see below). In view of the eruptive age of the overlying volcanic rocks, the Bowers Mountain Formation is assigned a late Early to early Middle Ordovician age (Floian to Dapingian).

Stetson Mountain Formation (Osm)

The Stetson Mountain Formation is named for extensive outcrops of volcanic and volcaniclastic rock on the prominent NNE-trending ridge of that name in the Stetson Mountain and Dill Hill quadrangles. It can be traced continuously from the type locality into the northeastern corner of the Bowers Mountain quadrangle, and thence to the south and southwest where it occupies the keel of a large synform that underlies the southeastern part of the quadrangle and closes in the Bottle Lake quadrangle to the south. A second narrow outcrop band crops out east of Sheepskin Ridge, where it is separated by the Stetson Mountain fault from the Sam Rowe Ridge Formation. Although the volcanic rocks locally support steep ridges and hills, they also underlie areas of low relief, such as the lowland occupied by Lindsey and Barker brooks.

The Stetson Mountain Formation contains a variety of volcanic and volcaniclastic rocks ranging chemically from rhyolites and rhyodacites to dacites and andesites (Sayres, 1986) with very subordinate black shale, manganiferous mudstone, and thinly interbedded siltstone and gray shale. Phenocrysts and microphenocrysts are typically subhedral to euhedral feldspars or anhedral quartz that exhibit resorption relationships with a surrounding cryptocrystalline matrix. Original ferromagnesian phenocrysts are rare and, when present are nearly completely chloritized, as are large parts of the matrix in the andesitic rocks. Mafic volcanic rocks near the eastern margin of the Miramichi terrane in the Farrow Mountain quadrangle are not exposed in the study area. Chemical analyses reported by Sayres (1986) and Ludman (2003) indicate that the Stetson Mountain rocks are calc-alkaline with volcanic arc affinities, consistent with the interpretation that the Miramichi terrane represents one or more Ordovician island arcs (Wilson et al., 2016; Fyffe et al., 2011).

A wide variety of eruptive rock types is present in the Stetson Mountain Formation (Figure 6). Cryptocrystalline to very fine grained ashfall tuffs are abundant and typically weather pale gray to chalky white (Figure 6A). Some occur in thin (2–8 cm) beds with homogeneous grain sizes, others in massive layers 1–3 meters (m) thick, and some in thick layers ranging from cryptocrystalline, almost glassy, to fine grained with 0.5 to 5 mm microphenocrysts. Most of these tuffs have devitrified completely but a few well-preserved shards have been recognized in thin section.

Slightly coarser porphyritic and microporphyritic ashflow tuffs are also common, some displaying a weak flow foliation (Figure 6B). Coarse crystal, lithic, and crystal-lithic ashflow tuffs (Figure 6C) are also abundant, in flow units ranging from 10 cm to well over 3 m thick. Lithic fragments 1 cm to 1 m long appear to be intraformational, including several types of ashfall and ashflow tuffs and sedimentary rocks similar to those interbedded with the volcanic rocks (Figure 6D) as described below. The crystals are quartz and feldspars and, as in the finer grained rocks, are commonly partly resorbed by a cryptocrystalline matrix. Lapilli tuffs and tuffs containing flattened pumice fragments are relatively rare.

Sedimentary rocks constitute less than 10% of the Stetson Mountain Formation. The most abundant are thinly interbedded pale gray weathering siltstone and medium gray mudstone, probably eroded from eruptive centers, and interlayered with the volcanic rocks (Figure 6E). Black, carbonaceous shales form discontinuous

Figure 6. Stetson Mountain Formation volcanic rocks. See text for explanation.

Figure 6 (continued). Stetson Mountain Formation volcanic rocks. See text for explanation.

layers and lenses up to several meters thick but unmappable at 1:24,000. Unique manganiferous mudstone and siltstone layers present on Stetson Mountain are intercalated in some instances with siltstone-shale couplets and in others with fine- to medium-grained tuffs (Figure 6F). These have not been observed in the Springfield study area.

Thickness

Challenges to estimating thickness of the Stetson Mountain formation include the lack of an overlying unit, complex mid-Ordovician and Acadian folding and faulting, and post-Acadian deformation associated with emplacement of the Bottle Lake complex. The formation is estimated to be on the order of a few thousand meters thick.

Comparison with the Miramichi Terrane Greenfield Segment

The upper parts of the Danforth and Greenfield segments have similar stratigraphies (Ludman, 2020), with a thick, young volcanic pile underlain by an at least partly euxinic sedimentary section. The range of chemical compositions of volcanic rocks is nearly identical from the two segments, with sparse basalts and more abundant andesites, dacites, and rhyolites (Ludman, 2020). The most significant difference is the absence of the basal Baskahegan Lake Formation from the Greenfield section.

Modern island arc settings like that interpreted for the Stetson Mountain Formation typically comprise subaerial volcanic centers spaced 75–100 km apart, each spewing ash and lava into shallow and deep marine waters at the same time that erosion adds a fringing apron of sedimentary and volcaniclastic debris to the eruptive piles. There are several significant differences between the Greenfield and Danforth segments (Ludman, 2020), suggesting that simple "layer cake" stratigraphy should not be expected.

Age

"Middle Ordovician" graptolites (*Climacograptus sp.* and *Orthograptus sp.*) were reported from a carbonaceous shale horizon in the Danforth quadrangle now mapped as part of the Stetson Mountain Formation (Larrabee et al., 1965), suggesting a Middle Ordovician age for the formation. Attempts were made to recollect at this site, but the outcrop has deteriorated and no additional fossils were found. A 469.3 ±4.6 Ma U-Pb age for zircon from the correlative Olamon Stream volcanic rocks in the Miramichi Greenfield segment is

consistent with the fossil data, suggesting a possible latest Early Ordovician to earliest Middle Ordovician range (Ludman et al., 2018).

Central Maine/Aroostook-Matapedia (CMAM) Belt

Larrabee et al. (1965) recognized the difference between the Miramichi and CMAM suites but assigned some units incorrectly to both. Ludman (1985) suggested the name Prentiss Group for rocks eroded from the Miramichi terrane and distinguished these from limestone and pelites to the west (now the Carys Mills and Smyrna Mills formations of the Meduxnekeag Group). Hopeck (1998) confirmed the Miramichi provenance for the Prentiss Group, demonstrated proximal through intermediate facies relationships within the Prentiss Group, and showed that the Carys Mills and Smyrna Mills formations represent a more distal facies of the same basin. Today, rocks in the study area west of the Miramichi terrane are interpreted as proximal, intermediate, and distal facies deposited in the eastern part of a single broad depocenter (Figure 4; Ludman et al., 2017). This basin contains what had previously been described as separate Central Maine and Aroostook-Matapedia belts and extends from western Maine through the study area into southwestern New Brunswick.

Facies Relationships

Relationships among the four formations of the Prentiss Group appear to be conformable and, in many cases, gradational, both vertically and laterally. Coarse boulder, cobble, and pebble conglomerates of the Daggett Ridge and Mill Priveledge Brook formations crop out near the contact with the Miramichi terrane and pass westward into finer grained and thinner bedded turbidites of the Sam Rowe Ridge and Ellen Wood Ridge formations that contain large amounts of mudstone and slate. Intraformational conglomerates in the Sam Rowe Ridge and Ellen Wood Ridge are finer grained versions of those in the Daggett Ridge and in many instances contain the same lithic clasts, indicating the same Miramichi source.

The Mill Priveledge Brook, Sam Rowe Ridge, and Ellen Wood Ridge formations define a continuous upright sequence but their relationship to the Daggett Ridge Formation is less certain. The Mill Priveledge Brook may locally interfinger with and in some places lie beneath the Daggett Ridge and it is possible that Daggett Ridge deposition was coeval with at least some of the other formations. To the west and south, the Mill Priveledge Brook and Carys Mills formations appear to interfinger with one another and it is difficult to distinguish them in this transition zone. The Carys Mills passes gradually upward into the Smyrna Mills Formation, a thick pile of pelite-rich turbidites very similar to those of the Sam Rowe Ridge and Ellen Wood Ridge formations.

Proximal Facies

Daggett Ridge Formation (SOd)

The Daggett Ridge Formation was named by Larrabee et al., (1965) for massive conglomerates on that ridge and on Jimmey Mountain in the Jimmey Mountain quadrangle (Figure 1). It extends southward to the Stetson Mountain and westward into the Potter Hill quadrangle but is not exposed in the study area. The formation consists mostly of massively bedded coarse polymictic conglomerates (Figure 7) with rare interbedded grits and pelite.

Clasts are angular to sub-rounded, equidimensional to strongly elongated, and typically range in size from cobbles to pebbles but boulders up to two to three meters across are found in several localities. Local clast imbrication and field relationships suggest deposition as a series of debris flows. Most clasts are lithic fragments and the most common are fine- to medium-grained quartzofeldspathic sandstones whose texture, mineralo-

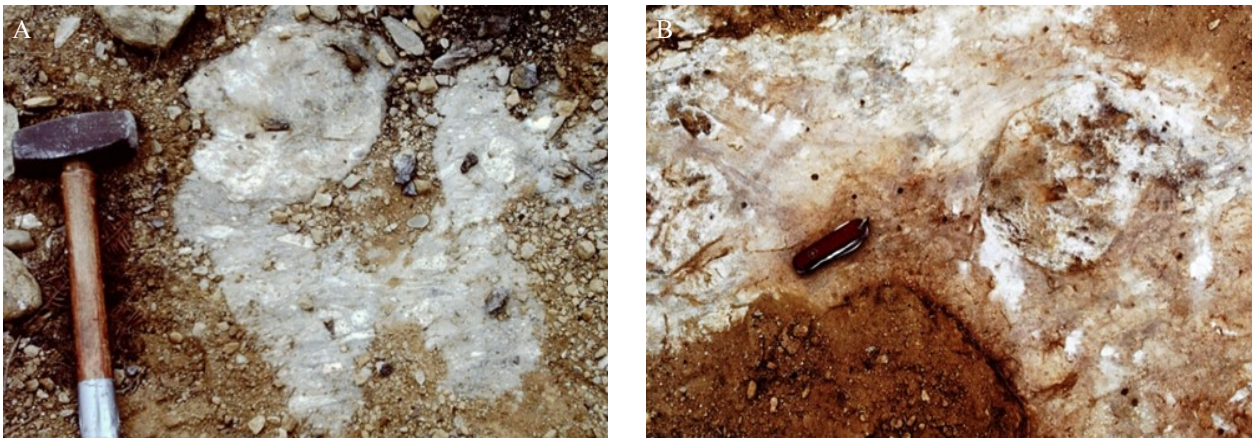


Figure 7. Daggett Ridge Formation conglomerates. (A) Polymict matrix-supported conglomerate with quartz-feldspar sandstone and volcanic clasts. (B) Large rounded tuffaceous clasts.

gy, and bedding features suggest derivation from the Baskahegan Lake Formation. All volcanic components of the Stetson Mountain Formation are also present as clasts, including the unique manganiferous iron formation, as well as pyritiferous black shale possibly derived from the Bowers Mountain Formation.

The conglomerate matrix is poorly sorted and ranges from granule to sand-sized lithic fragments, identical to those of the larger clasts, to silt-sized quartz and feldspar, to fine grained mudstone. The matrix is typically calcareous and locally contains abundant fragments of shallow- water fossils including crinoid columnar segments, brachiopods, and corals, but similar fossils also occur in cobble-sized clasts, suggesting that these were not living in the area at the time that the conglomerates were deposited.

Thickness

The unconformable nature of its contact with the Miramichi terrane and the lack of an overlying unit would make it difficult under the best conditions to estimate the minimum thickness of the Daggett Ridge Formation. The conditions are, however, far from optimal. It is impossible to estimate the degree to which the formation has been affected by folding because of difficulty in recognizing bedding, the absence of facing indicators, and the lack of mappable horizons or members. The formation's lateral extent and the nature of folding in the rest of the Prentiss Group suggest a thickness of at least several hundred meters.

Age

The Daggett Ridge Formation contains fragments of the three formations described above and is therefore younger than the entire Miramichi section, i.e. post Floian-Dapingian. In addition, the large lithic clasts contain cleavages, randomly oriented quartz veins, and strain fabrics not observed in the matrix, indicating that the Miramichi source rocks were deformed prior to erosion and deposition of the conglomerate. Coral and crinoidal debris are not age-diagnostic, but a single brachiopod valve was described by Boucot as "Silurian" (in Larrabee et al., 1965). The Daggett Ridge Formation is assigned a late Middle Ordovician through Middle Silurian range based on the age of the (unconformably) underlying Stetson Mountain Formation and inferred ages of the intermediate and Prentiss Group distal facies.

Mill Priveledge Brook Formation (SOmp)

The Mill Priveledge Brook Formation was named after extensive exposures in and near that brook in the north-central part of the Potter Hill and south-central part of the Wytopitlock quadrangle (Hopeck, 1998). It consists mostly (80%) of nearly equal amounts of rusty-weathering dark gray to black shale and quartzofeldspathic siltstone in typically well graded beds (Figures 8A, B), granule to pebble conglomerate and sooty black shale in graded beds 2.5 to 5.0 cm thick, with subordinate (10%) cobble conglomerate in thicker horizons (30 cm–1 m), calcareous wackes and pelites, and felsic tuffs.

All lithologies are sulfidic to some extent, with pyrite cubes as large as 0.5 cm in some pelites. The calcareous wackes also contain smaller grains (1–2 mm) of ankerite that resemble more widespread similar lithologies in the overlying Sam Rowe Ridge Formation. Pelites interbedded with the calcareous wackes become progressively more calcareous near the transition to the micritic limestones of the Carys Mills Formation, making it difficult to distinguish the two formations.

Coarse conglomerates contain clasts up to 25 cm across similar to those in the Daggett Ridge Formation. Most appear to have been derived from the Baskahegan Lake Formation, with significant contributions from the Stetson Mountain volcanics. In contrast to the Daggett

Figure 8. Mill Priveledge Brook Formation. (A) Interbedded black shale and subordinate sulfidic sandstone and siltstone. (B) Closeup showing thin siltstone layers in dominant rusty weathering sulfidic black shale (Wytopitlock quadrangle)

Ridge, however, most clasts in the Mill Priveledge Brook are well rounded, suggesting greater transport.

Thickness

The Mill Priveledge Brook Formation is estimated to be several hundred to 1,000 meters thick.

Age

Derivation of lithic clasts in the Mill Priveledge Brook Formation from the Miramichi suite requires the formation to be younger than Middle Caradocian, and its interfingering with the Carys Mills Formation suggests an Ashgillian to Llandoverian range. It is older than the (structurally) overlying Sam Rowe Ridge Formation, for which there is neither fossil nor detrital zircon age control.

Intermediate Facies

Sam Rowe Ridge Formation (Ssr)

The Sam Rowe Ridge Formation underlies a large part of the Bowers Mountain quadrangle, with numerous exposures on Sam Rowe, Tar, and Sheepskin ridges, Weatherbee Hill, and unnamed hills east of Thompson's Corner. It also crops out in Bog Brook and adjacent hills in the southeast corner of the Springfield quadrangle, and west of South Springfield in the northwest corner of the Weir Pond quadrangle where it is in fault contact with the Bowers Mountain Formation. Many outcrops have bedding styles reminiscent of the Mill Priveledge Brook Formation, but Sam Rowe Ridge rocks are lighter colored, finer grained, thinner bedded, and contain less pyrite and carbon than the more euxinic Mill Priveledge Brook.

The formation consists mostly of non-sulfidic, non-carbonaceous thin- to medium-bedded (2.5–12 cm), well graded sand-silt and sand-silt-mud turbidites (Figure 9). Bases of the graded sets are fine- to medium-grained quartzofeldspathic wackes that weather pale gray to white and pass upward into medium gray weathering siltstone and darker mudstone (Figure 9A). Rhythmic and continuous bedding is characteristic of many exposures (Figure 9A) but many show a greater variety of thickness and/or wacke beds that pinch out (Figure 9B). Equal proportions of wacke and mudstone are most common but can vary from 1:4 to 4:1 in a single large outcrop. Diagenetic 1–2 mm ankerite rhombs and pyrite cubes are abundant in wackes and mudstones (Figure 9B) and weather to a pale orange-brown color characteristic of deeply weathered Sam Rowe Ridge exposures.

Conglomerates with a sandy matrix make up perhaps as much as 5% of the Sam Rowe Ridge Formation. Most clasts are similar to those in the Mill Priveledge Brook (i.e. derived from the Miramichi terrane) but in some areas intraformational clasts are also observed. Gray argillaceous micrite is associated with calcareous wacke at a few outcrops in the northeastern corner of the Bowers Mountain quadrangle, notably in Tar Ridge Road east of North Road, and in Baskahegan Stream. Fine-grained felsic ashfall tuff horizons have also been observed as well as a single coarser grained mafic crystal tuff. These subordinate rock types appear to be distributed randomly in the formation.

Thickness

The Sam Rowe Ridge Formation is in fault contact with underlying units so that its base is not exposed, making it impossible to estimate its thickness accurately. Based on its areal extent and deformation, a minimum thickness of 1,000 m is suggested.

Age

Fossils have not been found in the Sam Rowe Ridge Formation, but several lines of evidence suggest an Early to Middle Silurian age: (1) Baskahegan Lake and Stetson Mountain Formation clasts in Sam Rowe Ridge conglomerates indicate that the Sam Rowe Ridge

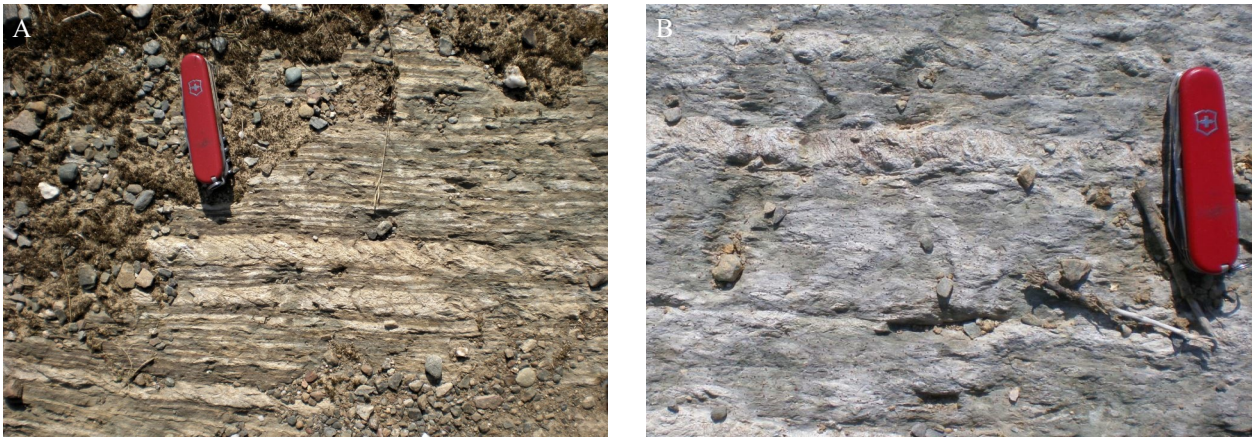


Figure 9. Sam Rowe Ridge bedding styles. (A) Millimeter and centimeter scale graded beds of siltstone and slate. (B) Slate dominant section with weathered ankerite crystals (dark spots) in siltstone.

is younger than its Miramichi source rocks. (2) The Sam Rowe Ridge apparently lacks the mid-Ordovician folding that affected the Miramichi terrane (see below) and is therefore post-Caradocian. (3) The Sam Rowe Ridge appears to interfinger to the west with the lower part of the mid-Llandovery through Wenlock Smyrna Mills Formation; (4) In the Lincoln area, the Smyrna Mills grades upward into sandstones correlated with the Mayflower Hill Formation of central Maine, indicating correlation with the Waterville Formation in central Maine which has been dated as Llandovery (Orr and Pickerill, 1995) and Wenlock (Ruedemann, in Perkins and Smith, 1925) .

Ellen Wood Ridge Formation (Sew)

The Ellen Wood Ridge Formation lies conformably and gradationally above the Sam Rowe Ridge Formation, with which it shares very similar lithology and bedding styles. It consists mostly of thin to medium bedded (a few millimeters to several centimeters) fine-grained sandstone, siltstone, and pelite, usually in well graded beds (Figure 10). Conglomerate lenses occur throughout the formation and felsic volcanic rocks are common in the upper part of the formation. Flute casts and flame structures are locally well developed (Figure 10C)

The Ellen Wood Ridge is distinguished from the Sam Rowe Ridge by the (mostly) green and greenish gray color of its wackes and pelites, sparse ankerite and pyrite, and a greater abundance of volcanic and volcaniclastic rocks, particularly in the upper part of the formation. Typical Sam Rowe Ridge wacke and pelite are gray on both weathered and fresh surfaces, but the uppermost horizons weather greenish-gray even though the fresh surface remains gray. These pass upward into the Ellen Wood Ridge Formation, the contact drawn where green-weathering wacke and pelite are also green on fresh surfaces. The distinctive light green color is caused by abundant small chlorite flakes but varies locally to grayish maroon as in Figure 10C.

Most of the Ellen Wood Ridge volcanic component crops out north of the Springfield 15′ quadrangle. It consists of massive felsic rhyolitic breccias, ash flows and tuffs locally interbedded with feldspathic wackes and pelite. Clasts in the breccias include angular and subangular cobbles and pebbles of greenish pelites and

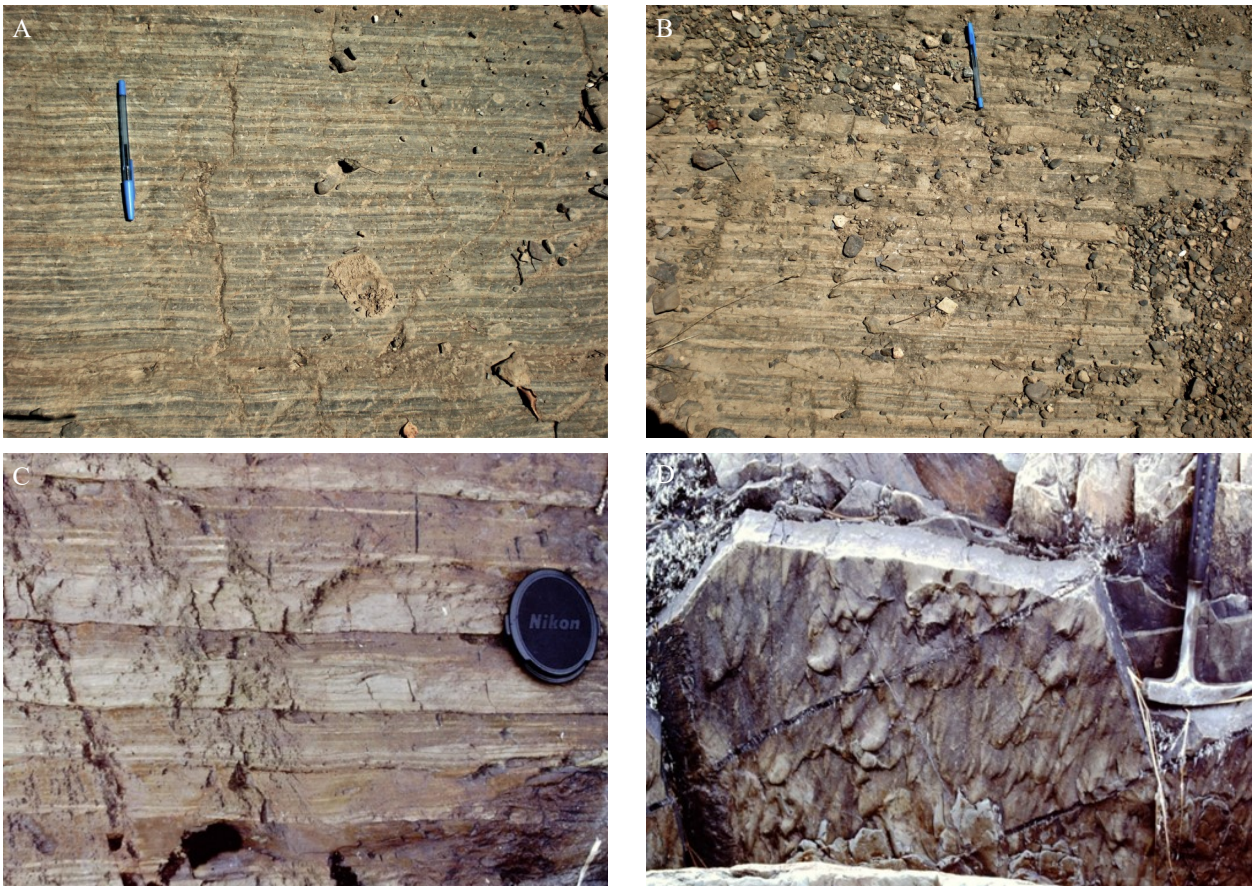


Figure 10. Ellen Wood Ridge Formation bedding. (A) Millimeter to centimeter scale graded silt (light) and siltstone/mudstone (dark). (B) Centimeter scale silt-mud turbidite bedding. (C) Thick-bedded maroon silt-mud turbidites showing well-developed graded beds . (D) Flute casts.

wackes interpreted as intraformational, fine-grained felsic tuffs, with cobbles and pebbles of pumiceous debris. Clasts definitely attributable to the Baskahegan Lake Formation are rare but are present. Feldspathic wackes interbedded with these volcanic rocks are white on weathered surfaces but deep forest-green when fresh.

Thickness

As with the Sam Rowe Ridge, a complete section through the Ellen Wood Ridge Formation is not exposed. The base can be located in several places, but nowhere has a contact with an overlying unit been observed. A minimum thickness of 800–1,000 m is suggested.

Age

The age of the Ellen Wood Formation is most probably Middle Silurian. It is clearly younger than the Sam Rowe Ridge and appears to be equivalent to the upper part of the Smyrna Mills Formation, suggesting a Late Wenlock to Early Ludlow age.

Distal Facies

The distal facies of the CMAM belt underlies part of the Weir Pond quadrangle, most of the Springfield, East Winn, and Lee 7½′ quadrangles to the west and the Potter Hill quadrangle to the north. It consists of broad outcrop bands of a dominantly carbonate unit (micritic limestone and dolomicrite) and a dominantly pelitic unit (mudstone thinly interbedded with subordinate siltstone). These have been correlated with the Carys Mills and Smyrna Mills formations, respectively, near Houlton (Pavlides, 1974) and those names have been adopted in the Lincoln—Springfield area (Ludman et al., 2017). A thick-bedded, variably calcareous, quartzofeldspathic sandstone caps the Carys Mills-Smyrna Mills belt just west of the Springfield 15′ quadrangle and in several places south of Houlton in the Danforth 1:100,000 quadrangle (Ludman et al., 2017).

Carys Mills Formation (SOcm)

The Carys Mills Formation in the Springfield 15′ quadrangle consists mostly of medium to dark gray micrite and dolomicrite interlayered with argillaceous micrite and calcareous slates and phyllites, calcareous wackes, and very subordinate non-calcareous slate and phyllite. Weathering in unmetamorphosed outcrops produces a ribbed appearance in which thin (1–2 mm) knife-sharp pelitic laminae stand above the dominant carbonates. Dark gray weathering of the micrite and slightly rusty weathering of dolomicrite reveal bedding (Figure 11A), but only at a few rare places. One or more generations of transposed layering obscure or completely obliterate bedding at most outcrops (Figures 11B, C), making it difficult to interpret both stratigraphy and the style, number, and sequence of deformation events.

Metamorphism in the Bottle Lake complex contact aureole brings about a profound change, coarsening the Carys Mills and producing distinctive layers of white to greenish-white marble/calc-silicate granofels and dark purplish-gray biotite-rich hornfelsed pelite that further mask original bedding (Figure 11C, D).

Thickness

The base of the Carys Mills Formation is not exposed in the Springfield area so that only a portion of the formation is visible. Multiple folding events (see below) coupled with difficulties distinguishing bedding from secondary layering further obstruct thickness estimates. Broad outcrop bands in the Springfield 15′ and quadrangles adjacent to the west and north suggest that thickness is on the order of several hundred to thousands of meters.

Age

Fossils in the Houlton area indicate that the Carys Mills Formation ranges from latest Ordovician (Ashgillian) to earliest Silurian (Llandoverian; Pavlides, 1974). Relationships with adjacent units suggest that

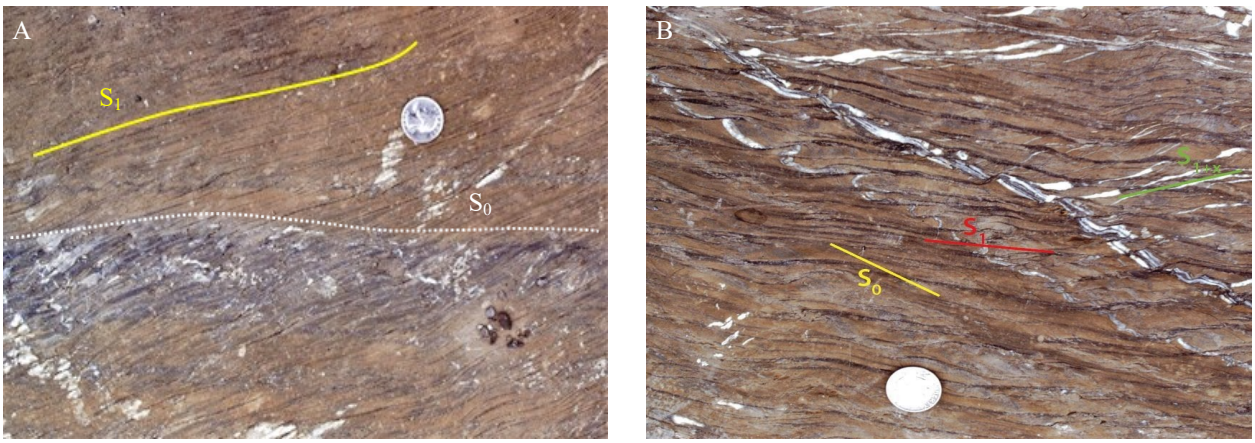


Figure 11. Bedding (S_0) and transposed layering (S_1) in the Carys Mills Formation. (A) S_0 cut by S_1 but still visible. (B) Bedding (S_0) obscured by two generations of secondary layering: S_1 transposed layering parallel to cleavage; S_{1+x} younger carbonate veins.

Figure 11 (continued). Thinly (C) and thickly (D) banded Carys Mills calc-silicate. Dark = biotite-rich granofels; White=calcite ± actinolite.

this range is also appropriate in the Springfield area.

Smyrna Mills Formation (Ssm)

The Smyrna Mills Formation consists almost entirely of thinly interbedded medium to dark gray slates and lighter gray siltstones (Figure 12), with some fine sandstone and color variations related to stratigraphic position. As with the Carys Mills Formation, primary layering is often obscured by a transposed structural fabric (described in detail below). There appear to be gradational contacts with the underlying Carys Mills Formation (similar to that reported in the Houlton area by Pavlides, 1974), and with the overlying Mayflower Hill Formation west of the study area.

Smyrna Mills slate-siltstone couplets are typically around 5 cm thick, with slate:siltstone proportions averaging 60:40. Graded beds are not uncommon but many siltstone beds have sharp upper and lower contacts with adjacent slate. The siltstones lack internal lamination seen in the Sam Rowe Ridge and Ellen Wood Ridge formations, and locally show pinch-and-swell structures. Some exposures contain minor amounts of ankerite, but pyrite is very rare.

The lower part of the Smyrna Mills Formation consists of pale gray, locally calcareous siltstone and medium gray pelite that can be difficult to distinguish from deeply weathered Carys Mills outcrops. Lenses of blue-gray calcareous siltstone and dark gray argillaceous limestone 8–10 m thick are similar to the upper horizons of the Carys Mills Formation and are found only in the lower part of the Smyrna Mills. Bedding above the transition zone is similar but the limestones disappear, and siltstone and slate are chalky weathering rather than gray, indicating increased feldspar (ash?) content, and many outcrops have a pale greenish tinge. Gray and greenish-gray slate and pale gray siltstone make up the bulk of the formation, but one of two dramatic changes characterize the transition to the overlying Mayflower Hill Formation north and west of the Springfield 15′ quadrangle. In some instances, the uppermost horizons are alternating green and pale grayish-red to deep maroon slates with white-weathering, pale gray siltstones. In others, the pelites are pyritiferous, sooty, highly carbonaceous slates with few siltstone interbeds.

Contact metamorphism near the Passadumkeag River pluton accentuates primary and transposed compositional layering (Figure 12). Gray siltstone layers recrystallize to tough, dense quartzofeldspathic granofels with abundant red-brown biotite. Lower grade

Figure 12. Cordierite-grade Smyrna Mills Formation hornfels. Pale gray layers are metamorphosed siltstone, darker layers pelite. Small circular pits in both layers are weathered cordierite crystals.

pelitic hornfelses are biotite-muscovite rich and at higher grade develop equant 1–4 mm cordierite porphyroblasts. These tend to weather more rapidly than the matrix, producing a characteristic pitted appearance.

Thickness

Difficulties distinguishing bedding from transposed layering and the lack of marker horizons hinder structural interpretation for the Smyrna Mills Formation and estimates of its thickness. Its broad outcrop bands in the Springfield, Lee, and East Winn quadrangles suggest a thickness on the order of at least two kilometers.

Age

Interfingering relationships with the Ellen Wood Ridge and Sam Rowe Ridge formations to the east indicate that Smyrna Mills deposition spanned those of those units. Fossils have not been found in the Smyrna Mills in the study area, although as this is written specimens are being processed for microfossils. A mid-Silurian age is inferred, based on fossils reported by Pavlides (1971) in the Houlton area.

BOTTLE LAKE COMPLEX

The Bottle Lake complex occupies approximately 1,100 km^2 in east-central and eastern Maine and was divided by Ayuso (1984) into the Passadumkeag River and Whitney Cove granitic plutons (Figure 13). The Passadumkeag River pluton underlies ~75% of the Weir Pond and 85% of the Bottle Lake quadrangle but is well exposed only near its northern margin. (Plates 1–4). Ayuso's (1984) map projects the Whitney Cove pluton into the southeastern corner of the Bottle Lake quadrangle, but in an area lacking outcrop. Although his map shows both rim and core facies in the southern half of the Springfield map area, most exposures are from the rim facies. Both plutons are reversely zoned, with more mafic core and felsic rim facies.

The mineralogy, textures, and chemistry of the Passadumkeag River pluton were described in great

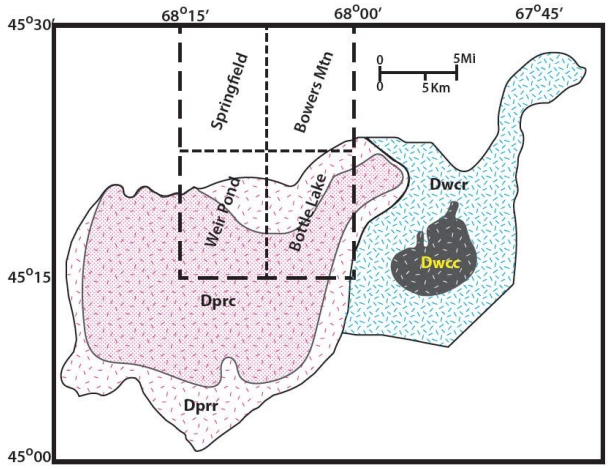


Figure 13. Extent and zonation of the Bottle Lake complex (after Ayuso, 1984). Dpr = Passadumkeag River pluton; Dwc=Whitney Cove pluton. [c=core; r-rim facies]

detail by Ayuso (1984) and will be summarized only briefly here. Most of the pluton is leucocratic, generally containing less than 5% biotite ± hornblende; Figure 14A, B), although these ferromagnesian minerals are more abundant locally (Figure 14C). Biotite and hornblende are typically finer grained and interstitial within a framework of coarser quartz and feldspar crystals. Most of the pluton is quartz monzonite with potassic feldspar more abundant than plagioclase, and quartz making up less than 20% of the volume. A few outcrops have more quartz and less plagioclase and approach granitic composition.

Most of the rocks are coarse grained, with quartz and feldspar crystals 5 mm to 2.5 cm long (Figure 14A), but porphyritic varieties are abundant in which euhedral gray, white, or pink potassic feldspar phenocrysts up to 7.5 cm long are set in a finer grained (5 mm – 1 cm) groundmass (Figure 14B). Rapakivi textures are rare and foliation has only been observed in a few places.

Figure 14. Variation within the Passadumkeag River pluton.

Figure 14 (continued). Variation within the Passadumkeag River pluton.

Age

The Passadumkeag River pluton must be younger than the youngest rocks that it intrudes, in this case the Late Silurian Mayflower Hill Formation west of the study area at Rollins Mountain in the Lee and East Winn quadrangles. It also truncates Acadian folds and the Stetson Mountain fault, helping to determine the timing of the ductile and brittle events that produced those structures.

The pluton was dated directly as Middle to Upper Devonian (Givetian-Frasnian) by Ayuso et al. (1984), based on nearly identical 381 ±4 Ma whole-rock Rb-Sr isochron and 381 ±3 Ma U-Pb zircon Concordia intercept ages. The cooling history of the pluton was reported in a $^{40}Ar/^{39}Ar$ study that tracked the times of cooling through the closure temperatures of amphibole, biotite, and potassic feldspar (Ghanem, 2015). Results indicate rapid cooling at shallow crustal depths, consistent with the low regional metamorphic grade and the emplacement age from Ayuso et al., (1984).

DEFORMATION

A complex deformation history involving episodes of folding, thrusting, and high-angle faulting is recorded in the study area despite the low intensity of regional metamorphism (Figure 15). The timing of events is based on known and inferred ages of the affected rocks, radiometric dating of plutons that intrude or are affected by deformation, and by structural relationships among the Springfield area formations in nearby quadrangles. Insofar as most stratigraphic age assignments are not precisely defined by faunal or radiometric means, the timeline should be considered tentative at this time. Temporal boundaries between series and stages in the following discussion are from the 2017 International Chronostratigraphic Chart, v. 2017/02 (Cohen et al., 2013, modified in 2020).

D_1 Recumbent Folding

The earliest tectonic event (D_1) was an episode of large-scale recumbent folding observed only in the

Orogeny/Pluton	Deformation Event	Timing (Ma)*
	D_6: Sinistral WNW trending minor folds	?
	D_5: Rand Hill fault	<381
Bottle Lake pluton[1]	◄- - - -

Miramichi terrane. No small-scale recumbent folds have been observed in the study area, but the Bowers Mountain Formation lies structurally above younger Stetson Mountain volcanic rocks southeast of Gates Hill (Bowers Mountain quadrangle), indicating that these lie on the inverted limb of large D_1 fold. Several smaller-scale inverted anticlines and synclines in have been observed in the Dill Hill and Stetson Mountain quadrangles involving all three formations of the Miramichi belt.

Based on the stratigraphic ages discussed above, D_1 occurred between the inferred 469 Ma age of the Stetson Mountain Formation and the Late Ordovician to Early Silurian (~453–438 Ma) age of the Carys Mills Formation, the oldest rocks not affected by those events. Support for this timing comes from a well-developed early cleavage (S_1) found in large Miramichi clasts in the Daggett Ridge and Mill Priveledge Brook formations but not in those formations themselves where the dominant structural fabric is related to D_3. Mid-Ordovician deformation in Maine and New Brunswick is attributed to the accretion of Ganderia to ancestral North America and is commonly referred to as the Taconian orogeny. In this report, that event will be described as "Taconian" in view of the distance of the study area from the classic Taconian orogen in New York and Massachusetts – without disputing the plate tectonic cause of this orogeny.

D_2 Thrusting

A tectonically quiet interval followed D_1, during which the Prentiss Group and Meduxnekeag Group were deposited unconformably on the folded Miramichi belt (Figure 16A). Deformation of these cover rocks began with eastward thrusting of intermediate facies rocks of the Prentiss Group over their Miramichi source area (Figure 16B). A klippe in the Dill Hill quadrangle was isolated from the thrust sheet during subsequent evolution of the Stetson Mountain fault (Figures 16C, D, E).

The timing of D_2 thrusting is bracketed in the study area between deposition and lithification of the Wenlockian (~433–427 Ma) Sam Rowe Ridge Formation and its displacement by the Stetson Mountain fault which is intruded by the 381 Ma Passadumkeag River pluton in the Weir Pond quadrangle. In the Danforth quadrangle, the thrust is deformed by D_3 folding and cut by D_5 faulting, both of which are older than the Early Devonian Pokiok plutonic complex (402–415 Ma).

D_3 Upright Folding

D_3 folding affected all stratified rocks in the study area and is expressed as numerous outcrop- and smaller-scale, northeast to north-northeast-trending upright folds that typically plunge gently to either the northeast or southwest. Large-scale folds are hard to identify

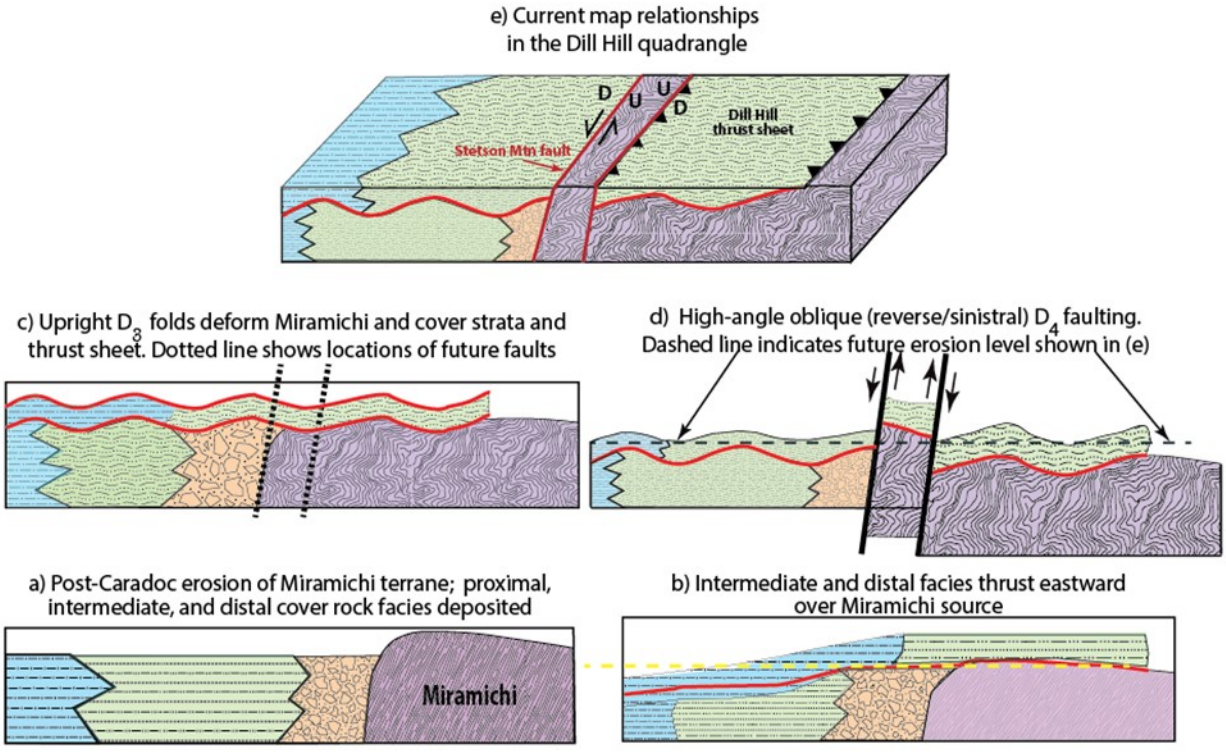


Figure 16. Evolution of the Stetson Mountain fault zone .

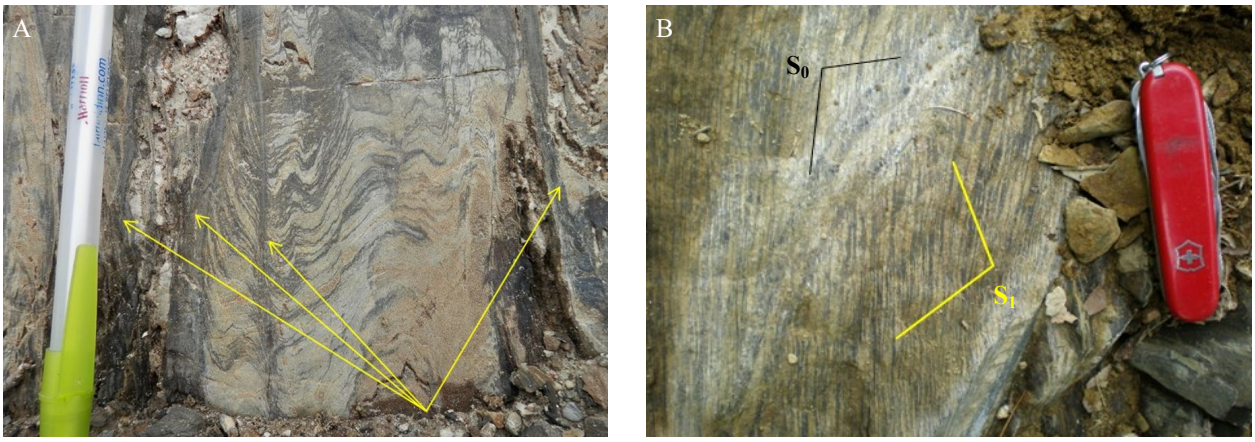


Figure 17. Small-scale D_3 upright folds in (A) Carys Mills limestone and (B) Smyrna Mills silt/mud turbidites. Yellow arrows point to transposed layering axial planar to D_3 hinge surfaces.

because of a lack of marker horizons within the broad outcrop bands shown in Plates 1–4. Fold style varies depending on lithology, generally broadest in thick-bedded Baskahegan Lake and Stetson Mountain formations, but tight to isoclinal in thinner bedded Smyrna Mills, Carys Mills, Sam Rowe Ridge, and Ellen Wood formations (Figure 17).

A prominent close-spaced cleavage is characteristic of D_3 folding in thin-bedded carbonate and pelitic rocks and is commonly paralleled by transposed layering shown in Figure 17A and B. Although bedding is still recognizable in Figure 17B, in many outcrops it is uncertain whether the dominant layering is primary or tectonic. It is particularly difficult to determine whether layering folded during D_5 shearing is primary or secondary.

Age

The timing of D_3 is bracketed between the ages of the youngest rocks affected and the oldest plutons that intrude its folds. The youngest rock is the Mayflower Hill Formation (Ludlow-Pridoli; see Ludman et al., 2018) in the East Winn and Lincoln Center quadrangles. The Passadumkeag River pluton cuts D_3 folds and metamorphoses transposed layering in the Bottle Lake and Weir Pond quadrangles so that D_3 must be older than ~381 Ma. D_3 folds also appear to be intruded in the Danforth quadrangle by the Skiff Lake component of the Pokiok pluton dated at 409 ±2 Ma (U-Pb zircon; Bevier and Whalen, 1990) and 389 ±20 (Rb-Sr whole-rock; McCutcheon et al., 1981). D_3 is therefore considered to be an early Acadian event.

D4: Sinistral/Reverse Oblique Slip Faulting

The final step in evolution of the Stetson Mountain fault zone that today separates the Miramichi and CMAM belts was an episode of moderate to high angle oblique faulting attributed to D_4 (Figure 16). Figure 16 shows that an area of Sam Rowe Ridge rocks surrounded by Miramichi strata in the Dill Hill and Stetson Mountain quadrangles is now interpreted as a klippe, isolated by late stage movement on later faults.

Cataclasite at the contact between the two belts is visible in two places, demonstrating the brittle nature of faulting. Fine-grained cataclasite derived from Stetson Mountain volcanic and Sam Rowe Ridge sedimentary rocks is exposed on the west side of Stetson Mountain in the Dill Hill quadrangle. Cataclasite at the contact between juxtaposed Bowers Mountain and Sam Rowe Ridge strata is visible on a camp road southwest of South Springfield in the Bottle Lake quadrangle.

Two lines of evidence indicate the strike-slip component of the fault: (1) sinistral shear bands in Sam Rowe Ridge and Bowers Mountain cataclasite juxtaposed at the latter exposure mentioned above (Figure 18A) and (2) steeply plunging minor folds that deform thin layering interpreted as D_3 transposed layering (Figure 18B).

Outcrops of Carys Mills limestone on Route 6 just west of Springfield contain a NNE trending, moderately to steeply west-dipping spaced cleavage parallel to the Stetson Mountain fault zone and observed thus far only near that structure (Figure 19). This cleavage cuts bedding, cleavage and transposed layering associated with D_3 folding and is interpreted as a D_4 fabric.

Age

Fabrics and structures associated with the Stetson Mountain fault zone are intruded and metamorphosed by the Passadumkeag River pluton in the study area and by the Pokiok pluton in the Danforth quadrangle. The last stage of reverse oblique faulting is thus older than 389–409 Ma.

Late-stage Deformations

The Bottle Lake pluton intrudes most, but not all structural features, but is itself sheared locally at Rand Hill (D_5) and hydrothermally altered. Passadumkeag

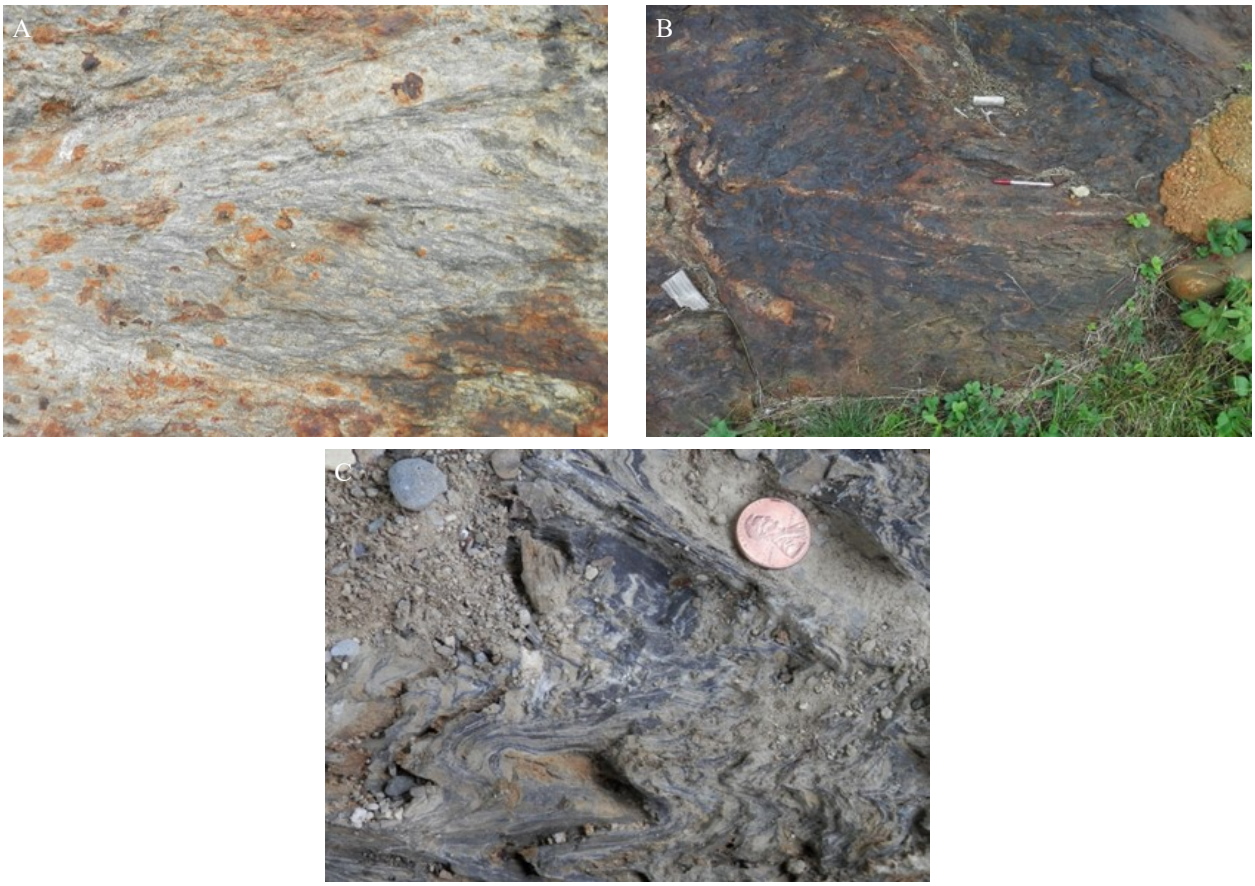


Figure 18. Indicators of sinistral oblique nature in the Stetson Mountain fault zone. Sinistral shear bands in Sam Rowe Ridge (A) and drag folds in Bowers Mountain (B) formations, Bottle Lake quadrangle SW of South Springfield. (C) Steeply plunging folds deforming initially near-vertical D3 transposed layering.

Figure 19. Moderately west-dipping spaced cleavage attributed to D_4 cutting D_3 folds, cleavage, and transposed layering in Carys Mills limestone, Springfield quadrangle.

River pluton coarse granitic rock is brittlely fractured in this shear zone and its feldspars altered to white clay minerals. The brittle nature of deformation suggests some degree of cooling of the pluton, whereas the extensive hydrothermal alteration, not observed elsewhere in the study area, suggests interaction with late-stage hydrothermal fluids from the pluton. An age slightly younger than the ~381 Ma emplacement age is suggested.

Small-scale WNW-trending asymmetric (sinistral) folds with steep plunges are found throughout the study area and much of eastern and central Maine. These are attributed to a late-stage (D_6) event that appears to deform all other structures in the region. D_6 appears to have been caused by a stress field different from those of the older NE-SW trending structures but there is little evidence for its age in the study area.

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Bedrock Geology of the
Springfield Quadrangle, Maine

Bedrock geologic mapping and compilation by
John T. Hopeck and Allan Ludman

Digital cartography by
Susan S. Tolman
Amber T. H. Whittaker

Geologic editing by
Henry N. Berry IV

Cartographic design by
Christian H. Halsted

Robert G. Marvinney
State Geologist

Funding for the field work and preparation of this map was provided by the Maine Geological Survey.

Maine Geological Survey
Address: 93 State House Station, Augusta, Maine 04333
Telephone: 207-287-2801 **E-mail:** mgs@maine.gov
Home page: www.maine.gov/dacf/mgs/

Open-File No. 20-22
2020
Plate 1

This map supersedes a portion of MGS Open File No. 90-25b.

EXPLANATION OF UNITS

STRATIFIED ROCKS

Note about terminology. Stratified rocks in this quadrangle are in the lower greenschist facies of regional metamorphism. Because sedimentary features are widely preserved at such a low metamorphic grade, sedimentary rock names are used in the unit descriptions to emphasize their depositional character with the understanding that all stratified rocks have been metamorphosed.

Aroostook-Matapedia Basin
Distal facies

Meduxnekeag Group

Silurian [S]

Ssm — **Smyrna Mills Formation.** Thinly interbedded (commonly 2–7 centimeters) silt-mud turbidites typically in well-graded couplets. Mudstone/slate makes up about 65% of formation overall but proportions vary within and between outcrops. Mudstones are typically medium to dark gray, siltstones medium gray but weathered siltstone surfaces are pale buff. Bedding is commonly obscured or obliterated by transposed layering parallel to axial planes of upright folds.

Silurian-Ordovician [SO]

SOcm — **Carys Mills Formation.** Interbedded dark gray micrite and lighter gray dolomicrite with subordinate calcareous and non-calcareous phyllite and sparse calcareous wacke. Bedding commonly obscured or obliterated by transposed layering. When visible, beds range from 5 to 15 centimeters; transposed layers are thinner (millimeter to centimeter scale). Well exposed in road cuts on Route 6 west of Springfield near the intersection of Ham Drive.

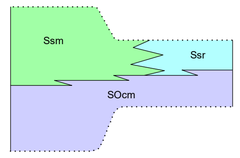
Aroostook-Matapedia Basin
Intermediate facies

Prentiss Group

Silurian [S]

Ssr — **Sam Rowe Ridge Formation.** Thinly bedded to medium-bedded (5–20 centimeters) turbidites with nearly equal proportions of pale gray or chalky buff weathering, variably calcareous siltstone to fine-grained sandstone and dark gray, strongly cleaved non-calcareous mudstone. 1–3 millimeter limonite spots weathered from pyrite and/or ankerite are locally characteristic of both siltstone and mudstone.

INTERPRETIVE STRATIGRAPHIC RELATIONSHIPS



EXPLANATION OF SYMBOLS

Note: Structural symbols are drawn parallel to strike or trend of measured structural feature. Barb or tick indicates direction of dip, if known. Annotation gives dip or plunge angle, if known. For planar features, symbol is centered at observation point. For linear features, tail of symbol is at observation point. Multiple measurements at a site are represented by combined symbols. Symbols on the map are graphical representations of information stored in a bedrock database at the Maine Geological Survey. The database may contain additional information that is not displayed on this map.

- Outcrop of mapped unit.
- Bedding, tops unknown (inclined, vertical).
- Bedding, tops up (inclined).
- Transposed layering (inclined).
- Cleavage (inclined, vertical). c1 = First cleavage, in outcrop with multiple cleavages.
- Intersection lineation (plunging). 0x1 = Intersection of bedding (S0) with first cleavage (S1). 1x2 = Intersection of first cleavage (S1) with second cleavage (S2).
- Axial plane of fold (inclined).
- Fold axis (plunging).
- 19 — Photo location. Numbers refer to figure numbers in the report.

EXPLANATION OF LINES

Contact between rock units, of stratigraphic origin.
Location is constrained by bedrock outcrops indicated by symbols on the map.
The location of some contacts is not well constrained.

High-angle fault (approximately located).
The sense of inferred relative motion is indicated by U = up and D = down.
Arrows indicate sense of strike-slip motion.

GEOLOGIC TIME SCALE

Geologic Age	Absolute Age*
Cenozoic Era (Cz)	0-66
Mesozoic Era (Mz)	
Cretaceous Period (**K**)	66-145
Jurassic Period (**J**)	145-201
Triassic Period (**Tr**)	201-252
Paleozoic Era (Pz)	
Permian Period (**P**)	252-299
Carboniferous Period (**C**)	299-359
Devonian Period (**D**)	359-419
Silurian Period (**S**)	419-444
Ordovician Period (**O**)	444-485
Cambrian Period (**Є**)	485-541
Precambrian time (**pЄ**)	Older than 541

* In millions of years before present. (Walker, J.D., Geissman, J.W., Bowring, S.A., and Babcock, L.E., compilers, 2012 Geologic Time Scale v. 4.0: Geological Society of America, doi: 10.1130/2012.CTS004R3C.)

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Hopeck, John Thomas, 1998, Stratigraphy and structural geology of the Wytopitlock and Springfield fifteen-minute quadrangles, eastern Maine: Ph.D. dissertation, City College (CUNY), New York, 160 p.

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Ludman, Allan, Hopeck, John, and Berry, Henry N., IV, 2017, Provenance and paleogeography of post-Middle Ordovician, pre-Devonian sedimentary basins on the Gander composite terrane, eastern and east-central Maine: implications for Silurian tectonics in the northern Appalachians: Atlantic Geology, v. 53, p. 63-85. doi: 10.4138/atlgeol.2017.003.

SOURCES OF GEOLOGIC INFORMATION

Field work by Allan Ludman, 1981–2017.
Field work by J.T. Hopeck, 1986–1998.

SCALE 1:24,000

1 0.5 0 1 Mile
1000 0 1000 2000 3000 4000 5000 6000 7000 Feet
1 0.5 0 1 Kilometer

CONTOUR INTERVAL 10 FEET

Approximate Mean Declination, 2017 17° W

Base map features from Maine Office of GIS - 1:24,000 USGS contour lines, E911 roads, 1:24,000 National Hydrography Dataset, USGS GNIS placenames and 1:24,000 political boundaries. Map projection Universal Transverse Mercator, North American Datum, 1927.

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.

Bedrock Geology of the
Bowers Mountain Quadrangle, Maine

Bedrock geologic mapping and compilation by
Allan Ludman and John T. Hopeck

Digital cartography by
Susan S. Tolman
Amber T. H. Whittaker

Geologic editing by
Henry N. Berry IV

Cartographic design by
Christian H. Halsted

Robert G. Marvinney
State Geologist

Funding for the field work and preparation of this map was provided by the Maine Geological Survey.

Maine Geological Survey
Address: 93 State House Station, Augusta, Maine 04333
Telephone: 207-287-2801 **E-mail:** mgs@maine.gov
Home page: www.maine.gov/dacf/mgs/

Open-File No. 20-22
2020
Plate 2

This map supersedes a portion of MGS Open File No. 90-25b.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Bottle Lake Complex

Middle Devonian [D]

Passadumkeag River pluton.

Dbpr — **Rim facies.** Coarse-grained hornblende-biotite granite. Somewhat lower color index and higher ratio of biotite to hornblende than rocks in the core facies of the pluton.

STRATIFIED ROCKS

Note about terminology. Stratified rocks in this quadrangle are in the lower greenschist facies of regional metamorphism. Because sedimentary features are widely preserved at such a low metamorphic grade, sedimentary rock names are used in the unit descriptions to emphasize their depositional character with the understanding that all stratified rocks have been metamorphosed.

Aroostook-Matapedia Basin
Distal facies

Meduxnekeag Group

Silurian [S]

Ssm — **Smyrna Mills Formation.** Thinly interbedded (commonly 2–7 centimeters) silt-mud turbidites typically in well-graded couplets. Mudstone/slate makes up about 65% of formation overall but proportions vary within and between outcrops. Mudstones are typically medium to dark gray, siltstones medium gray but weathered siltstone surfaces are pale buff. Bedding is commonly obscured or obliterated by transposed layering parallel to axial planes of upright folds.

Silurian-Ordovician [SO]

SOcm — **Carys Mills Formation.** Interbedded dark gray micrite and lighter gray dolomicrite with subordinate calcareous and non-calcareous phyllite and sparse calcareous wacke. Bedding commonly obscured or obliterated by transposed layering. When visible, beds range from 5 to 15 centimeters; transposed layers are thinner (millimeter to centimeter scale).

Aroostook-Matapedia Basin
Intermediate facies

Prentiss Group

Silurian [S]

Sew — **Ellen Wood Ridge Formation.** Thinly to moderately bedded (5–20 centimeters) silt-mud and fine-grained sand-mud turbidites with nearly equal proportions of mudstone and coarser clastic rocks. Very similar to Sam Rowe Ridge but typically pale green on both fresh and weathered surfaces. Minor tuffaceous horizons. Load and flute casts abundant locally.

Ssr — **Sam Rowe Ridge Formation.** Thinly bedded to medium-bedded (5–20 centimeters) turbidites with nearly equal proportions of pale gray or chalky buff weathering, variably calcareous siltstone to fine-grained sandstone and dark gray, strongly cleaved non-calcareous mudstone. 1–3 millimeter limonite spots weathered from pyrite and/or ankerite are locally characteristic of both siltstone and mudstone.

Silurian-Ordovician [SO]

SOmp — **Mill Priveledge Brook.** Rusty-weathering, black, pyritiferous, highly carbonaceous mudstone and shale interbedded with lithic sandstones, granule conglomerates, and quartzofeldspathic sandstones.

Miramichi terrane

Late Early Ordovician - early Middle Ordovician [O]

Osm — **Stetson Mountain Formation.** Chalky white weathering felsic to intermediate, fine-grained to very fine grained ashfall tuffs and fine-grained to medium-grained crystal and lithic ashflow tuffs. Subordinate discontinuous horizons of thinly interbedded dark gray mudstone, feldspathic siltstone, and manganese-rich mudstone.

Obm — **Bowers Mountain Formation.** Sulfidic, black, carbonaceous shale with subordinate beds 10–30 centimeters thick of quartzose sandstone passes upward in the formation into alternating zones of black (carbonaceous) and dark gray (non-carbonaceous) shale thinly interbedded with quartzose and quartz-feldspar siltstone. In the contact aureole of Passadumkeag River pluton, shales are converted to cordierite-biotite-muscovite hornfels; sandstones to dense quartzose hornfels.

EXPLANATION OF SYMBOLS

Note: Structural symbols are drawn parallel to strike or trend of measured structural feature. Barb or tick indicates direction of dip, if known. Annotation gives dip or plunge angle, if known. For planar features, symbol is centered at observation point. For linear features, tail of symbol is at observation point. Multiple measurements at a site are represented by combined symbols. Symbols on the map are graphical representations of information stored in a bedrock database at the Maine Geological Survey. The database may contain additional information that is not displayed on this map.

- Outcrop of mapped unit.
- Rock chips from drilled well.
- Float presumed to represent underlying bedrock.
- Quartz vein (inclined, strike only).
- Bedding, inclined (tops unknown, tops known, overturned); vertical (tops unknown, tops known).
- Flow fabric in volcanic ash flow (inclined).
- 1 — Photo location. Numbers refer to figure numbers in the report.
- Transposed layering (inclined).
- Cleavage (inclined, vertical). e = early.
- Lineation, unspecified (plunging).
- Fold axial plane (inclined); fold axis, plunging (unknown rotation, sinistral rotation sense).
- Phyllonitic foliation or foliation in brittle shear zone (inclined, strike only).
- Joint or joint set (inclined, vertical).

EXPLANATION OF LINES

Contact between rock units, of stratigraphic or intrusive origin. Location is constrained by bedrock outcrops indicated by symbols on the map. The location of some contacts is not well constrained.

U / D — High-angle fault (well located, approximately located). The sense of inferred relative motion is indicated by U = up and D = down. Arrows indicate sense of strike-slip motion.

GEOLOGIC TIME SCALE

Geologic Age	Absolute Age*
Cenozoic Era (Cz)	0-66
Mesozoic Era (Mz)	
Cretaceous Period (K)	66-145
Jurassic Period (J)	145-201
Triassic Period (Ŧ)	201-252
Paleozoic Era (Pz)	
Permian Period (P)	252-299
Carboniferous Period (C)	299-359
Devonian Period (D)	359-419
Silurian Period (S)	419-444
Ordovician Period (O)	444-485
Cambrian Period (Ꞓ)	485-541
Precambrian time (pꞒ)	Older than 541

* In millions of years before present. (Walker, J.D., Geissman, J.W., Bowring, S.A., and Babcock, L.E., compilers, 2012 Geologic Time Scale v. 4.0: Geological Society of America, doi: 10.1130/2012.CTS004R3C.)

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Ludman, Allan, Hopeck, John, and Berry, Henry N., IV, 2017, Provenance and paleogeography of post-Middle Ordovician, pre-Devonian sedimentary basins on the Gander composite terrane, eastern and east-central Maine: implications for Silurian tectonics in the northern Appalachians: Atlantic Geology, v. 53, p. 63-85. doi: 10.4138/atlgeol.2017.003.

SOURCES OF GEOLOGIC INFORMATION

Field work by Allan Ludman, 1979–2014.
Field work by J.T. Hopeck, 1986–1998.
Published mapping by R.A. Ayuso, 1984.

Maine

Springfield	Kingman	Potter Hill
	Bowers Mountain	Stetson Mountain
Weir Pond	Bottle Lake	Scraggly Lake

SCALE 1:24,000

1 0.5 0 1 Mile
1000 0 1000 2000 3000 4000 5000 6000 7000 Feet
1 0.5 0 1 Kilometer

CONTOUR INTERVAL 20 FEET

Approximate Mean Declination, 2017 17° W

Base map features from Maine Office of GIS - 1:24,000 USGS contour lines, E911 roads, 1:24,000 National Hydrography Dataset, USGS GNIS placenames and 1:24,000 political boundaries. Map projection Universal Transverse Mercator, North American Datum, 1927.

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Bedrock Geology of the
Bottle Lake Quadrangle, Maine

Bedrock geologic mapping and compilation by
Allan Ludman and John T. Hopeck

Digital cartography by
Susan S. Tolman
Amber T. H. Whittaker

Geologic editing by
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Funding for the field work and preparation of this map was provided by the Maine Geological Survey.

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Open-File No. 20-22
2020
Plate 3

This map supersedes a portion of MGS Open File No. 90-25b.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Middle Devonian [D]

Bottle Lake Complex

Dbp **Passadumkeag River pluton.** Coarse-grained biotite-hornblende granodiorite. Locally porphyritic with larger alkali feldspar phenocrysts up to 5 centimeters in a coarse-grained matrix. Mafic enclaves (xenoliths of Ayuso, 1984) are common.

Dbpr **Rim facies.** Coarse-grained hornblende-biotite granite. Somewhat lower color index and higher ratio of biotite to hornblende than rocks in the core facies of the pluton. Patterned area near the margin of the pluton north of Duck Lake contains abundant leucocratic dikes.

Dbw **Whitney Cove pluton.** Medium-grained to coarse-grained biotite granite. Mapped in the southeast corner of the quadrangle based on exposures to the south and east (Ayuso, 1984).

STRATIFIED ROCKS

Note about terminology. Stratified rocks in this quadrangle are in the lower greenschist facies of regional metamorphism. Because sedimentary features are widely preserved at such a low metamorphic grade, sedimentary rock names are used in the unit descriptions to emphasize their depositional character with the understanding that all stratified rocks have been metamorphosed.

Aroostook-Matapedia Basin

Silurian [S]

Prentiss Group

Ssr **Sam Rowe Ridge Formation.** Thinly bedded to medium-bedded (5–20 centimeters) turbidites with nearly equal proportions of pale gray or chalky buff weathering, variably calcareous siltstone to fine-grained sandstone and dark gray, strongly cleaved non-calcareous mudstone. 1–3 millimeter limonite spots weathered from pyrite and/or ankerite are locally characteristic of both siltstone and mudstone.

Miramichi terrane

Late Early Ordovician - early Middle Ordovician [O]

Osm **Stetson Mountain Formation.** Chalky white weathering felsic to intermediate, fine-grained to very fine grained ashfall tuffs and fine-grained to medium-grained crystal and lithic ashflow tuffs. Subordinate discontinuous horizons of thinly interbedded dark gray mudstone, feldspathic siltstone, and manganese-rich mudstone.

Obm **Bowers Mountain Formation.** Sulfidic, black, carbonaceous shale with subordinate beds 10–30 centimeters thick of quartzose sandstone passes upward in the formation into alternating zones of black (carbonaceous) and dark gray (non-carbonaceous) shale thinly interbedded with quartzose and quartz-feldspar siltstone. The upper part of the formation is exposed in and southeast of South Springfield. In the contact aureole of Passadumkeag River pluton, shales are converted to cordierite-biotite-muscovite hornfels; sandstones to dense quartzose hornfels.

Early Ordovician - Cambrian [O€]

O€bl **Baskahegan Lake Formation.** The typical rock type, exposed in adjacent quadrangles, consists of thick-bedded (up to 2.5 meters) quartzofeldspathic wackes and quartz arenites in massive beds and in graded turbidite sequences with siltstone and shale (Ludman and others, 1993; Ludman and Berry, 2003). In the Bottle Lake quadrangle, the Baskahegan Lake is mapped only on Almanac Mountain near the contact with the Passadumkeag River pluton, where it is hornfels. The hornfels is unusually rusty weathering, attributed to interaction with fluids from the pluton. Wackes are intensely recrystallized to medium to thick bedded (20–50 centimeters) quartz-feldspar granofels with abundant biotite and sparse cordierite. Subordinate pelitic hornfels is a coarse-grained metamorphic assemblage of cordierite + biotite + muscovite.

EXPLANATION OF PATTERNS

Region with abundant leucocratic dikes.

EXPLANATION OF SYMBOLS

Note: Structural symbols are drawn parallel to strike or trend of measured structural feature. Barb or tick indicates direction of dip, if known. Annotation gives dip or plunge angle, if known. For planar features, symbol is centered at observation point. For linear features, tail of symbol is at observation point. Multiple measurements at a site are represented by combined symbols. Symbols on the map are graphical representations of information stored in a bedrock database at the Maine Geological Survey. The database may contain additional information that is not displayed on this map.

- Outcrop of mapped unit (small exposure, large area of exposure).
- Outcrop of massive rock having no foliation.
- Leucocratic dike (inclined, vertical). v = variable dip; a = aplite; g = granite.
- Bedding, tops unknown (inclined, vertical).
- Inclined bedding, tops known (upright, overturned).
- Cleavage (inclined, vertical).
- Foliation (inclined, vertical). v = variable dip.
- Foliation in brittle shear zone (inclined).
- Fold axis (plunging).
- Joint or joint set (inclined, vertical). v = variable dip.
- 1 Photo location. Numbers refer to figure numbers in the report.

EXPLANATION OF LINES

Contact between rock units, of stratigraphic or intrusive origin. Location is constrained by bedrock outcrops indicated by symbols on the map. The location of some contacts is not well constrained.

U / D — High-angle fault (well located, approximately located). The sense of inferred relative motion is indicated by U = up and D = down.

GEOLOGIC TIME SCALE

Geologic Age	Absolute Age*
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* In millions of years before present. (Walker, J.D., Geissman, J.W., Bowring, S.A., and Babcock, L.E., compilers, 2012 Geologic Time Scale v. 4.0: Geological Society of America, doi: 10.1130/2012.CTS004R3C.)

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SOURCES OF GEOLOGIC INFORMATION

Field work by Allan Ludman, 1979–2014.
Field work by J.T. Hopeck, 1986–1998.
Published mapping by R.A. Ayuso, 1984.

Maine

Springfield	Bowers Mountain	Dill Hill
Weir Pond	Bottle Lake	Scraggly Lake
Spring Lake	Duck Lake	Dark Cove Mountain

SCALE 1:24,000

1 Mile / 0.5 / 0
1000 0 1000 2000 3000 4000 5000 6000 7000 Feet
1 Kilometer / 0.5 / 0

CONTOUR INTERVAL 20 FEET

Approximate Mean Declination, 2017 17° W

Base map features from Maine Office of GIS - 1:24,000 USGS contour lines, E911 roads, 1:24,000 National Hydrography Dataset, USGS GNIS placenames and 1:24,000 political boundaries. Map projection Universal Transverse Mercator, North American Datum, 1927.

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Bedrock Geology of the
Weir Pond Quadrangle, Maine

Bedrock geologic mapping and compilation by
Allan Ludman and John T. Hopeck

Digital cartography by
Susan S. Tolman
Amber T. H. Whittaker

Geologic editing by
Henry N. Berry IV

Cartographic design by
Christian H. Halsted

Robert G. Marvinney
State Geologist

Funding for the field work and preparation of this map was provided by the Maine Geological Survey.

Maine Geological Survey
Address: 93 State House Station, Augusta, Maine 04333
Telephone: 207-287-2801 **E-mail:** mgs@maine.gov
Home page: www.maine.gov/dacf/mgs/

Open-File No. 20-22
2020
Plate 4

This map supersedes a portion of MGS Open File No. 90-25b.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Middle Devonian [D]

Bottle Lake Complex

Dbp — **Passadumkeag River pluton.** Coarse-grained biotite-hornblende granodiorite. Locally porphyritic with larger alkali feldspar phenocrysts up to 5 centimeters in a coarse-grained matrix. Mafic enclaves (xenoliths of Ayuso, 1984) are common.

Dbpr — **Rim facies.** Coarse-grained hornblende-biotite granite. Somewhat lower color index and higher ratio of biotite to hornblende than rocks in the core facies of the pluton.

STRATIFIED ROCKS

Note about terminology. Stratified rocks in this quadrangle are in the lower greenschist facies of regional metamorphism. Because sedimentary features are widely preserved at such a low metamorphic grade, sedimentary rock names are used in the unit descriptions to emphasize their depositional character with the understanding that all stratified rocks have been metamorphosed.

Aroostook-Matapedia Basin
Distal facies

Meduxnekeag Group

Silurian [S]

Ssm — **Smyrna Mills Formation.** Thinly interbedded (commonly 2–7 centimeters) silt-mud turbidites typically in well-graded couplets. Mudstone/slate makes up about 65% of formation overall but proportions vary within and between outcrops. Mudstones are typically medium to dark gray, siltstones medium gray but weathered siltstone surfaces are pale buff. Bedding is commonly obscured or obliterated by transposed layering parallel to axial planes of upright folds. Adjacent to the pluton, contact metamorphism has produced quartzofeldspathic granofels with red-brown biotite and cordierite-bearing mica-rich hornfels with a pitted appearance due to weathering of the cordierite.

Silurian-Ordovician [SO]

SOcm — **Carys Mills Formation.** Interbedded dark gray micrite and lighter gray dolomicrite with subordinate calcareous and non-calcareous phyllite and sparse calcareous wacke. Bedding commonly obscured or obliterated by transposed layering. When visible, beds range from 5 to 15 centimeters; transposed layers are thinner (millimeter to centimeter scale). Adjacent to the pluton, the rock has recrystallized during contact metamorphism to banded greenish-white calc-silicate hornfels and dark purple-gray biotite-rich hornfels.

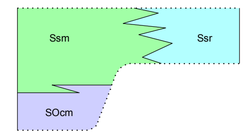
Aroostook-Matapedia Basin
Intermediate facies

Prentiss Group

Silurian [S]

Ssr — **Sam Rowe Ridge Formation.** Thinly bedded to medium-bedded (5–20 centimeters) turbidites with nearly equal proportions of pale gray or chalky buff weathering, variably calcareous siltstone to fine-grained sandstone and dark gray, strongly cleaved non-calcareous mudstone. 1–3 millimeter limonite spots weathered from pyrite and/or ankerite are locally characteristic of both siltstone and mudstone.

INTERPRETIVE STRATIGRAPHIC RELATIONSHIPS



Miramichi terrane

Late Early Ordovician - early Middle Ordovician [O]

Obm — **Bowers Mountain Formation.** Sulfidic, black, carbonaceous shale with subordinate beds 10–30 cm thick of quartzose sandstone passes upward in the formation into alternating zones of black (carbonaceous) and dark gray (non-carbonaceous) shale thinly interbedded with quartzose and quartz-feldspar siltstone. In the contact aureole of Passadumkeag River pluton, shales are converted to cordierite-biotite-muscovite hornfels; sandstones to dense quartzose hornfels.

EXPLANATION OF SYMBOLS

Note: Structural symbols are drawn parallel to strike or trend of measured structural feature. Barb or tick indicates direction of dip, if known. Annotation gives dip or plunge angle, if known. For planar features, symbol is centered at observation point. For linear features, tail of symbol is at observation point. Multiple measurements at a site are represented by combined symbols. Symbols on the map are graphical representations of information stored in a bedrock database at the Maine Geological Survey. The database may contain additional information that is not displayed on this map.

- Outcrop of mapped unit.
- Outcrop of massive rock having no foliation.
- Float presumed to represent underlying bedrock.
- Leucocratic dike (inclined, vertical). v = variable dip.
- Bedding, tops unknown (inclined, vertical).
- Cleavage (inclined, vertical).
- Feldspar alignment in plutonic rock (vertical).
- Fold axis (plunging).
- Cataclastic surface (vertical).
- Joint or joint set (inclined, vertical). v = variable dip.
- 1 — Photo location. Numbers refer to figure numbers in the report.

EXPLANATION OF LINES

Contact between rock units, of stratigraphic or intrusive origin.
Location is constrained by bedrock outcrops indicated by symbols on the map.
The location of some contacts is not well constrained.

U / D — High-angle fault (well located, approximately located).
The sense of inferred relative motion is indicated by U = up and D = down.
Arrows indicate sense of strike-slip motion.

Thrust fault.
Teeth on upper plate.

GEOLOGIC TIME SCALE

Geologic Age	Absolute Age*
Cenozoic Era (Cz)	0-66
Mesozoic Era (Mz)	
Cretaceous Period (K)	66-145
Jurassic Period (J)	145-201
Triassic Period (Tr)	201-252
Paleozoic Era (Pz)	
Permian Period (P)	252-299
Carboniferous Period (C)	299-359
Devonian Period (D)	359-419
Silurian Period (S)	419-444
Ordovician Period (O)	444-485
Cambrian Period (Є)	485-541
Precambrian time (pЄ)	Older than 541

* In millions of years before present. (Walker, J.D., Geissman, J.W., Bowring, S.A., and Babcock, L.E., compilers, 2012 Geologic Time Scale v. 4.0: Geological Society of America, doi: 10.1130/2012.CTS004R3C.)

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SCALE 1:24,000

1 Mile 0 0.5 1

7000 Feet 6000 5000 4000 3000 2000 1000 0 1000

1 Kilometer 0 0.5 1

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