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Geology of the upper Androscoggin River region, Bethel, Maine, to Shelburne, New Hampshire

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GEOLOGY OF THE UPPER ANDROSCOGGIN RIVER REGION, BETHEL, MAINE, TO SHELBURNE, NEW HAMPSHIRE

Geological Society of Maine
&
Geological Society of New Hampshire

Summer Field Trip

July 19-20, 2014

Field Trip Leaders:

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Cover photo:

View looking SW across the Androscoggin River valley from a hilltop in Gilead, Maine. The river itself is hidden from sight by the foreground terrain. Just beyond the yellow trees, a pine-covered ridge extends across the full width of the photo. This is the part of the Androscoggin Moraine Complex that we'll visit at Stop 7. Immediately to the right of the yellow trees, and extending to the right edge of the photo, there is a glacial outwash terrace that we'll see at Stop 6.

Stock Farm Mountain - a bedrock hill in Shelburne, N.H. - appears in the middle distance, near the right margin of the photo. A moraine ridge slopes gently downward to the left (east) from Stock Farm Mountain. This moraine is shown in one of the figures for Stop 7.

In the far distance is the Carter-Moriah Range in the eastern White Mountains.

Photo by W. B. Thompson, November 2, 2007.

Acknowledgements

The trip leaders thank members of the Geological Societies of Maine and New Hampshire who helped with trip announcements, campground arrangements, and the Saturday evening cookout. Eusden would like to thank State Geologist Bob Marvinney and the staff of the Maine Geological Survey for their support of the bedrock mapping. Bates students Sula Watermulder and Saebyul Choe, and Bowdoin student Riley Eusden, served as excellent field assistants for the bedrock mapping.

We are grateful to the property owners and their representatives who made it possible to visit the stops on this trip:

Day 1 trip, Stops 1 and 2: David Stearns, Chadbourne Tree Farms, Bethel.
Stop 3: Coleman Concrete, Madison, NH.
Stop 6: Tim Bradstreet, Pike Industries.
Stop 7: Ford Reiche.
Day 2 trip: Sunday River Ski Area and Dan Crooker

Sunday River

Introduction

This field trip will visit sites in the Bethel-Gilead area in western Maine and right on the border with Shelburne, N.H. We will examine a variety of bedrock and glacial exposures, along with recent landslide activity and slope stability issues during the reconstruction of U. S. Route 2 in this area. Day 1 will focus on surficial, bedrock, and highway engineering topics in the Androscoggin and Wild River valleys. On Day 2 we will hike along ridge tops at Sunday River ski area to look at the well-exposed bedrock geology.

Most of the information presented here is derived from our work for the Maine Geological Survey (STATEMAP Program) and the Maine Department of Transportation. These projects made us aware of each other's work, and created a dialogue that enriched this interdisciplinary trip.

Bedrock Geology

Overview and previous work. The bedrock geology of portions of the Bethel and Gilead 7.5 minute quadrangles has recently been remapped by the Maine Geological Survey in an effort to better understand the regional geology and tectonics, and in part due to the rapid development around the Sunday River Ski area (Figure 1). Mapping was done by Dykstra Eusden (Bates Geology) and three students, Riley Eusden (Bowdoin '14), Saebyul Choe (Bates '14), and Sula Watermulder (Bates '14) (Eusden 2013a and 2013b).

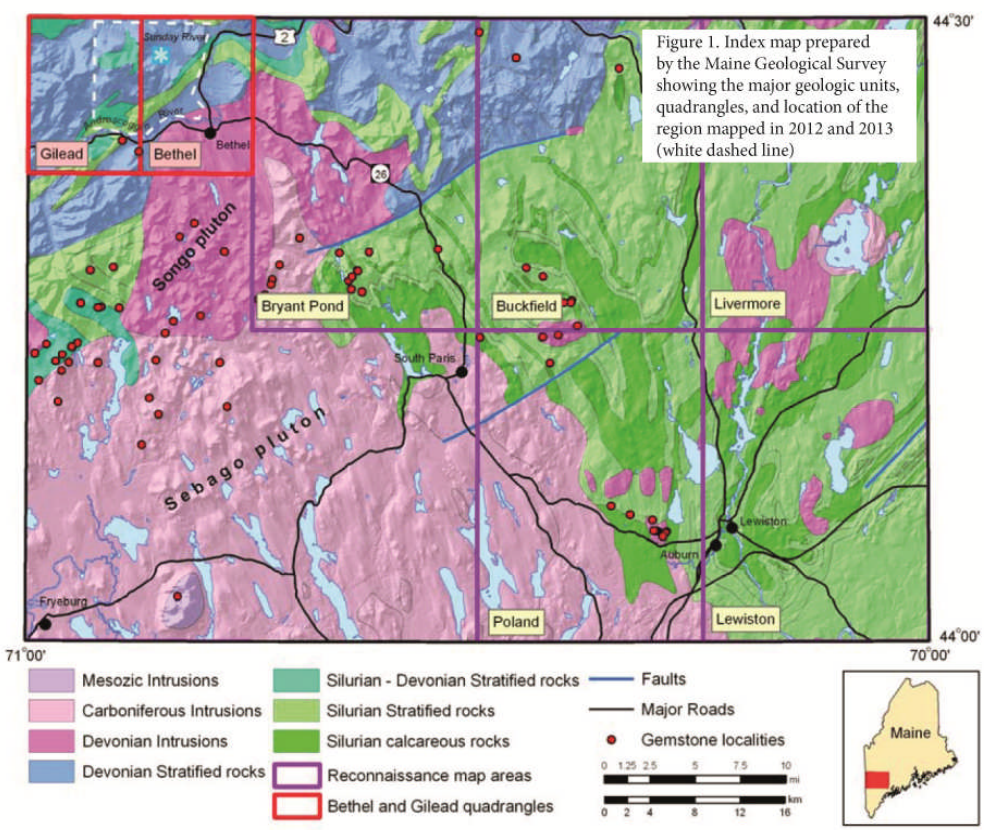


Figure 1. Index map prepared by the Maine Geological Survey showing the major geologic units, quadrangles, and location of the region mapped in 2012 and 2013 (white dashed line)

The metasedimentary rocks of the region had previously been mapped as the Devonian Littleton Formation with a few belts of the Silurian Madrid and Smalls Falls Formations (Osberg et al., 1985;

Moench et al., 1999). Intruding this stratigraphy are the Devonian Songo Pluton, a quartz diorite to tonalite suite (Gibson and Lux, 1989) and numerous Permian to Devonian two mica granites and associated pegmatites. Brady (1991) mapped the eastern portion of the Bethel quad as part of his M.S. thesis at Orono, breaking out many units that were variably correlated to portions of the Siluro-Devonian Rangeley stratigraphy of Moench and Boudette (1987). The Rangeley stratigraphy was extended through this area and into adjacent New Hampshire by Hatch et al. (1983) and those correlations formed the basis of the most recent lithotectonic compilation of the Appalachians by Hibbard et al. (2006).

Stratigraphic revisions. Twelve new metasedimentary units have been mapped in the region and define a stratigraphy that, overall, better correlates to the Early Silurian Rangeley Formation (Figures 2, 3, and 4). The new stratigraphy has terrible topping control with only a few scattered graded beds found in both quads, and it is pervaded by migmatite obscuring primary sedimentary features. Hence, correlation by lithologic similarity and sequence is the most useful, but the least certain, method to determine stratigraphic age. The presence of belts of rusty weathering schists and quartzites, biotite and calc-silicate granofels, and ubiquitous calc-silicate pods, blocks, and lenses are hallmarks of the Rangeley Formation in nearby New Hampshire (Eusden et al., 1996; Allen, 1996) and strengthen the arguments for the correlation. The calc-silicate blocks and pods may represent olistostromal facies that developed in an active tectonic setting (Eusden et al., 1996) during the Early Silurian Salinic orogeny (Hibbard et al., 2006). Sections of Silurian Perry Mountain Formation, Smalls Falls Formation, and Madrid Formation have also been mapped in the north portion of the Gilead and adjacent portion of the Old Speck 7.5 quads. The new stratigraphic assignments require significant changes to regional maps in western Maine and adjacent New Hampshire (Hibbard et al., 2006), as rocks previously mapped as Devonian Littleton Formation appear to be better designated as the Early Silurian Rangeley Formation (Figure 5).

Intrusive Rocks. Cross cutting the stratigraphy are several previously unmapped plutons of two major types found mostly within the Gilead 7.5' quad (Figure 2). The first type is a suite of discordant, Permian to Devonian (?), two mica granites and pegmatites, most likely correlative to granites of the Sebago batholith in southern Maine (Tomascak et al., 1996). The second type is a suite of Devonian (?) quartz diorite and tonalite sills that are most likely correlative to the Songo pluton mapped just south of the Androscoggin River (Gibson and Lux, 1989). These also likely correlate to the Spaulding and Winnipesaukee tonalites of the New Hampshire Plutonic Series (Dorais, 2003; Lyons et al., 1997; Billings and Fowler-Billings, 1975). The quartz diorite-tonalite suite of intrusives represent a new extension of the Piscataquis Magmatic Arc (Bradley and Tucker, 2002, and Bradley et al., 2000) that developed syn-tectonically on the leading edge of the migrating Acadian orogenic front in the Early Devonian (Figure 5). Preliminary XRF data done by Dr. David Gibson of U. Maine Farmington supports this as tectonic discrimination diagrams show the rocks plot as either within-plate or volcanic arc intrusives (Choe, 2013).

Pre-metamorphic faults. The earliest deformation in the region is seen as offset bedding on either side of a boundary that has been overprinted by migmatization. This was likely a pre-metamorphic gravity slide or tectonic fault similar to those recognized by Moench (1970) in the Rangeley area and may record the cryptic effects of the Early Silurian Salinic orogeny (Hibbard et al., 2006).

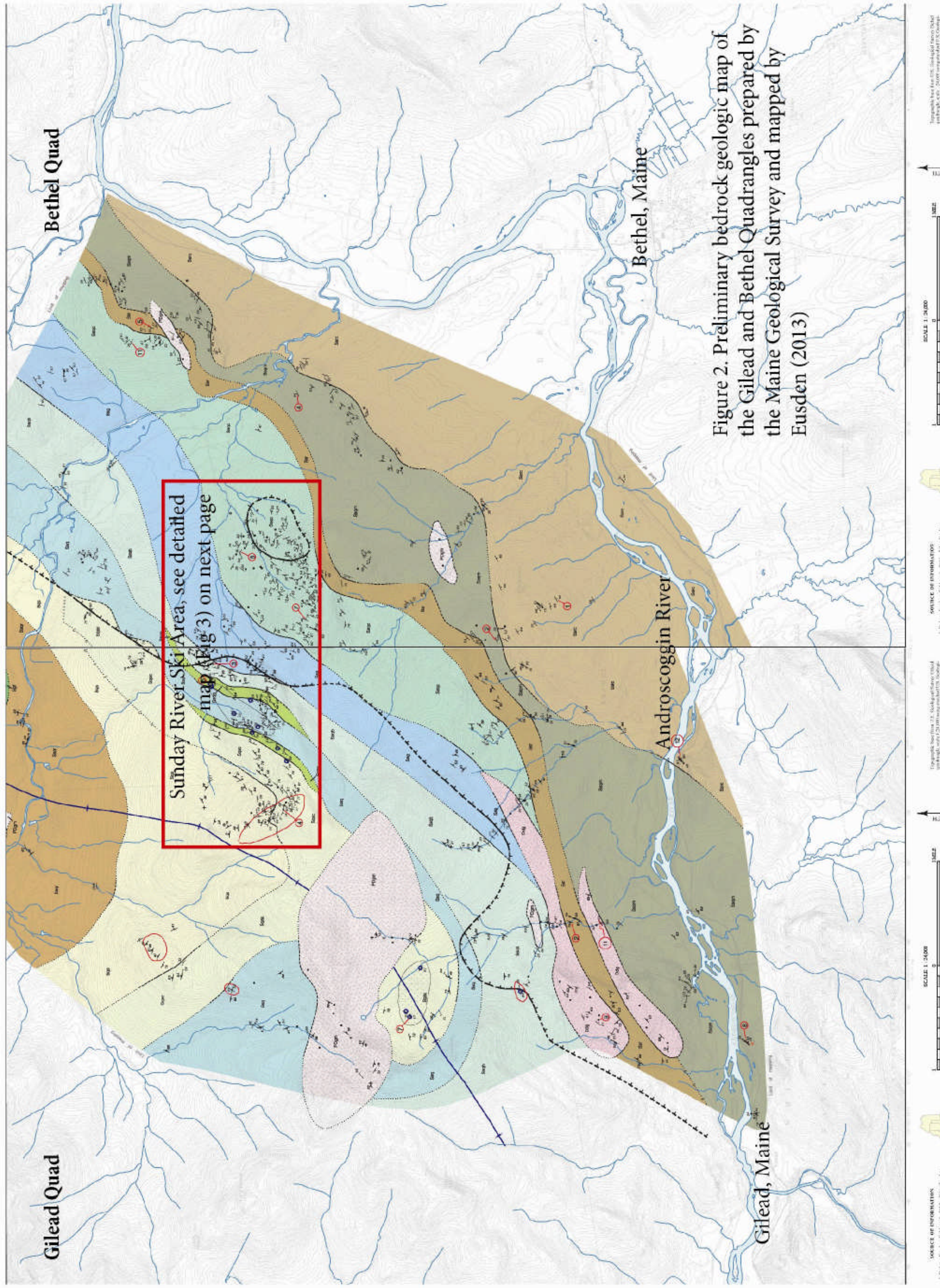


Figure 2. Preliminary bedrock geologic map of the Gilead and Bethel Quadrangles prepared by the Maine Geological Survey and mapped by Eusden (2013)

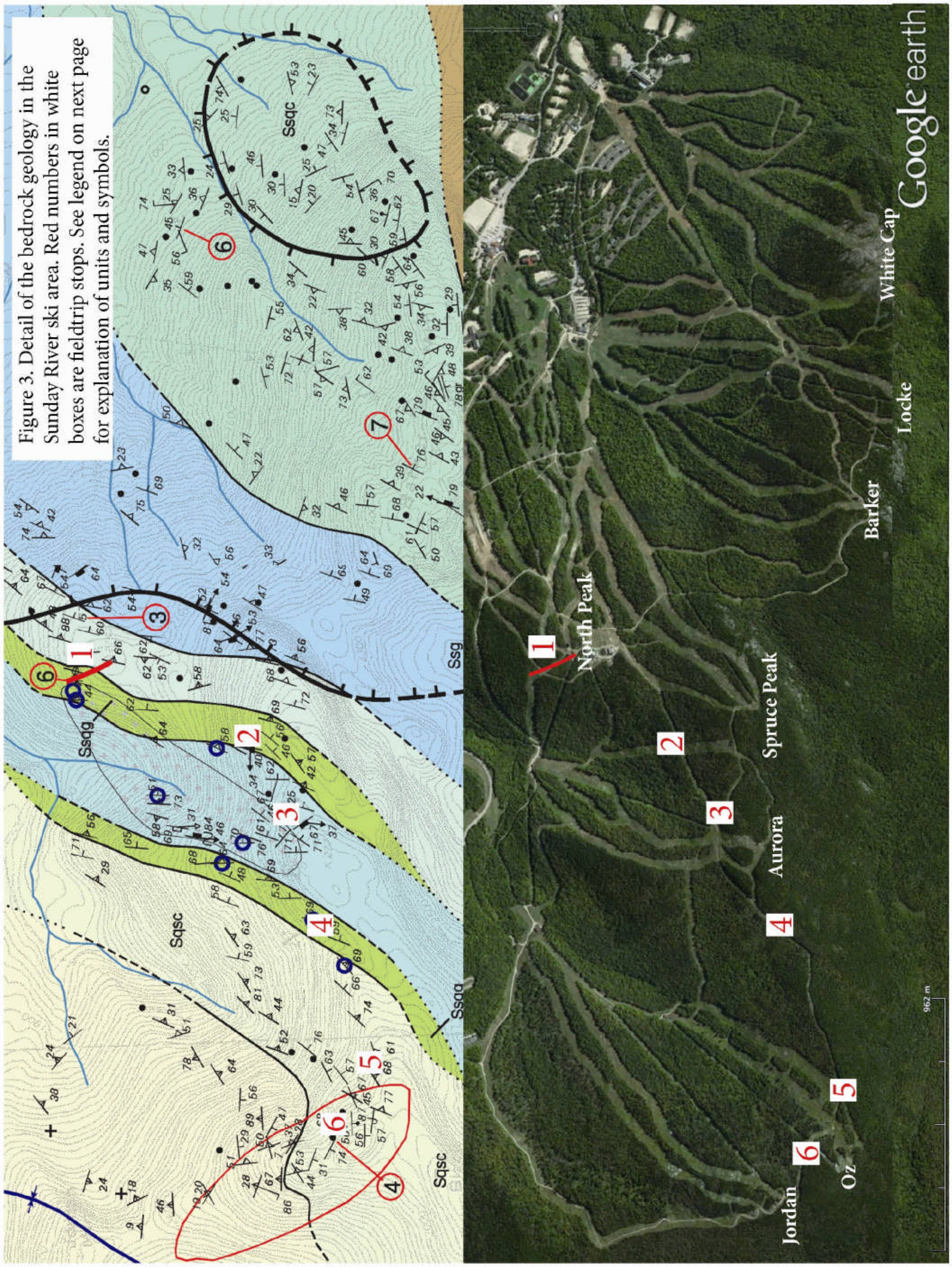


Figure 3. Detail of the bedrock geology in the Sunday River ski area. Red numbers in white boxes are fieldtrip stops. See legend on next page for explanation of units and symbols.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Permian-Devonian(?)

PDgm — **Muscovite-biotite granite and pegmatite.** Medium-grained to fine-grained granite, locally containing garnet + tourmaline. Pegmatite of the same mineralogy occurs with the granite, in various proportions. This granite and pegmatite unit occurs in several, mostly small, mappable plutons. Dikes and sills of the same granite and pegmatite are also present throughout the migmatite regions. This granite may be related to granites of the Sebago pluton in southern Maine.

Devonian(?)

Ddg — **Diorite and biotite granite, undifferentiated.** Fine-grained to medium-grained, equigranular, "salt-and-pepper" texture diorite and/or biotite granite. This rock unit is mapped in two plutons in the south-central part of the Gilead quadrangle. Both plutons are heterogeneous, containing thin dikes of diorite and biotite granite 1 to 10 meters across, as well as less abundant and smaller dikes of muscovite-biotite granite and pegmatite. These rocks may be related to those of the Songo Pluton, mapped south of the Androscoggin River (Gibson and Lux, 1989).

STRATIFIED ROCKS

Note: Age relationships of the stratified rock units are uncertain. They are listed here in order from youngest at the top to oldest at the bottom as currently interpreted, based on lithologic similarities with formations of the Rangeley, Maine, area (Moench and Boudette, 1987), as noted.

Silurian(?)

Sgf — **Biotite granofels.** Dark gray plagioclase-quartz-biotite granofels interlayered with rare purplish-gray to green calc-silicate granofels and gray schist. Layers of gray mica schist in places. (Possibly correlates with the Madrid Formation.)

Ssqr — **Rusty-weathering schist and quartzite.** Red-brown rusty-weathering, locally pyrrhotitic mica schist, interbedded with gray quartzite. Calc-silicate pods rare or absent. (Possibly correlates with the Smalls Falls Formation.)

Sqs — **Quartzite with minor gray schist.** Light gray quartzite, in medium to thick beds (10-50 cm); well bedded and poorly graded. Contains sparse, thin interbeds of gray schist, 1 to 5 cm in thickness. Calc-silicate pods rare or absent. (Possibly correlates with the Perry Mountain Formation.)

Sqsc — **Quartzite and schist with calc-silicate pods.** Light gray quartzite in beds 5 to 25 cm thick, somewhat thinner than those in unit **Sqs**; well bedded and poorly graded. Contains interbedded gray schist in beds 5 to 15 cm in thickness, and calc-silicate pods. Some calc-silicate pods are zoned, with cores richer in grossular + diopside and rims richer in biotite + plagioclase. In a region northeast of Campbell Mtn. Gilead, the schist contains coarse-grained aggregates of muscovite and quartz interpreted to be pseudomorphed andalusite porphyroblasts. (Possibly correlates with the Perry Mountain or the Rangeley Formation.)

Ssq — **Interbedded gray schist and quartzite.** Heterogeneous unit. Dominantly gray mica schist with thin (1-5 cm) quartzite interbeds. Subordinate rusty-weathering schist, biotite granofels, and calc-silicate granofels. Calc-silicate pods are common throughout the unit. Rare quartz-pebble conglomerate. Pseudomorphed andalusite porphyroblasts are interpreted to be present in the schist in a region south of Merrill Hill, Newry, near the east edge of the map. (Possibly part of the Rangeley Formation.)

Ssqg — **Biotite granofels member.** Medium-grained, granoblastic quartz-plagioclase-biotite granofels, with rare calc-silicate granofels layers and minor gray schist. Mapped in two lenses along the margins of unit **Ssq**.

Ssqb — **Interbedded gray schist and quartzite.** Gray mica schist with thin (1-5 cm) quartzite interbeds. Calc-silicate pods are common throughout the unit. Pseudomorphed andalusite porphyroblasts are interpreted to be present in the schist in one very small region southeast of Campbell Mtn. Gilead. (Possibly part of the Rangeley Formation.)

Ssg — **Gray schist.** Gray mica schist with rare interbedded thin (1-5 cm) quartzite. Calc-silicate pods rare or absent. (Possibly part of the Rangeley Formation.)

Ssqc — **Gray schist and quartzite with calc-silicate pods.** Heterogeneous unit of variably interbedded gray schist and quartzite (1-5 cm), with rare, discontinuous layers 1-3 meters in thickness of quartz-plagioclase-biotite granofels, and blocks of bedded, slightly rusty-weathering granofels in migmatite. Calc-silicate pods are common throughout the unit. (Possibly part of the Rangeley Formation.)

Ssr — **Rusty-weathering schist.** Red-brown rusty-weathering mica schist with rare interbedded quartzite, and minor, discontinuous layers 1-3 meters thick of quartz-plagioclase-biotite granofels. Calc-silicate pods are common throughout the unit. (Possibly part of the Rangeley Formation.)

Ssqm — **Interbedded gray schist and quartzite.** Gray mica schist with thin (1-5 cm) quartzite interbeds, in some places well bedded and with graded beds. Calc-silicate pods are common throughout the unit. (Possibly part of the Rangeley Formation.)

Ssrc — **Rusty-weathering schist.** Red-brown rusty-weathering mica schist with thin (1-5 cm) quartzite interbeds. Minor discontinuous layers 1-3 meters thick of quartz-plagioclase-biotite granofels and calc-silicate granofels. Some calc-silicate layers contain calcite. Calc-silicate pods rare or absent. (Possibly equivalent to part of the Rangeley or the Smalls Falls Formation.)

EXPLANATION OF PATTERNS

Region in which aggregates of quartz + muscovite are widespread in schists. The aggregates are interpreted to be pseudomorphs, in which andalusite porphyroblasts of an earlier metamorphic event have been completely replaced by quartz + muscovite in a later metamorphic event. No relict andalusite is known from these regions.

Early (F_1?) hinge zone. Structural region in which schistosity (S_1) is not parallel to bedding (S_0). In most of the map area, schistosity is parallel to bedding, which implies position on the limbs of schistosity-related folds.

EXPLANATION OF LINES

Contact between rock units, of stratigraphic or intrusive origin. (well located, approximately located, poorly located, existence inferred)

Boundary of migmatite area. Hachures point toward migmatitic rocks. (well located, approximately located, poorly located)

Trace of axial surface of a regional syncline that formed early in the deformational sequence (F_1?). Location interpreted from map pattern of curved unit contacts.

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. For most planar features, symbol is centered at observation point; for joints, observation point is at end of strike line opposite dip tick. For linear features, tail of symbol is at observation point. Multiple measurements at a site are represented by combined symbols.

Outcrop. (of mapped unit, of pegmatite)

Occurrence of aggregates of muscovite+quartz, interpreted to be metamorphic pseudomorphs, possibly replacing andalusite.

Occurrence of pre-metamorphic fault, indicated by disruption in bedding. Not exposed well enough to determine orientation.

Bedding. (inclined, tops upward; inclined, tops downward; inclined, topping direction unknown; vertical, topping direction unknown)

Schistosity. (inclined, vertical)

Structural elements of folds which have schistosity parallel to their axial plane, and are presumably the same age as the schistosity. (fold axis, inclined axial plane)

Structural elements of folds which deform bedding and schistosity, and so are younger than the schistosity. (fold axis with unknown asymmetry; fold axis with right-handed asymmetry, inclined axial plane)

Basalt dike, presumably of Jurassic age. (inclined)

Dike of unusual composition. A single occurrence of brown, medium-grained, biotite-rich rock with granular texture. Straight, sharp contacts. Biotite has preferred alignment parallel to contacts. Dike is 1-15 cm wide.

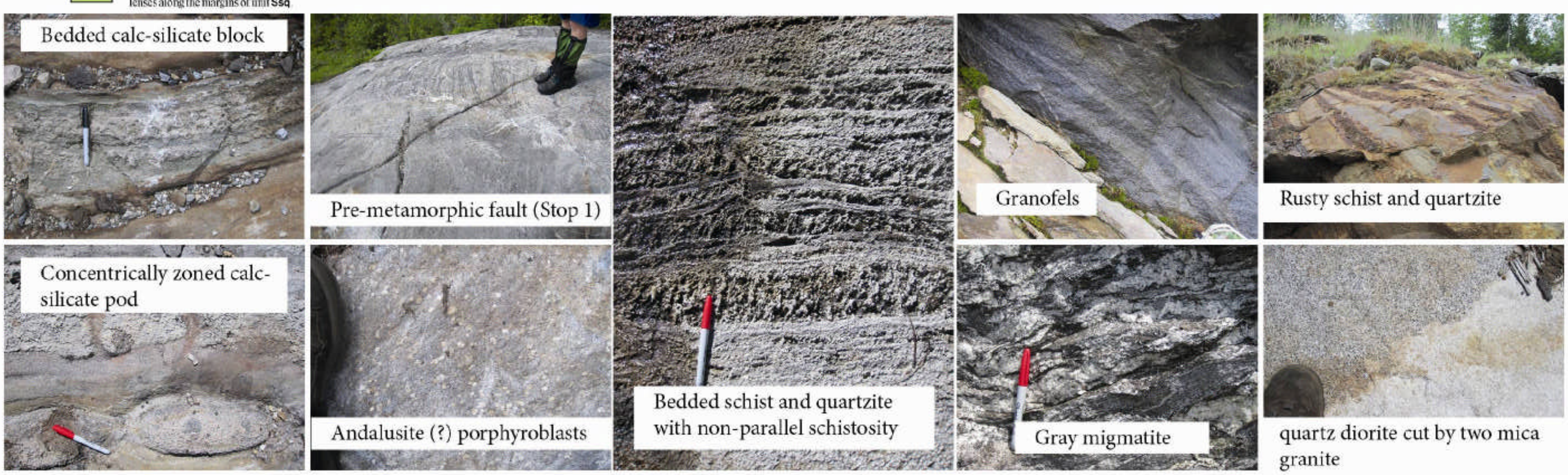
Minor fault, oblique sense of motion, unknown displacement. (inclined)

Slickenlines on fault surface. (plunging)

Joint. (inclined)

Location of numbered photograph shown in sidebar. Some photographs are from the Bethel quadrangle to the east (Eusden, 2013), or the Old Speck Mountain quadrangle to the north.

Figure 4. Explanation of units, symbols, and photo gallery.



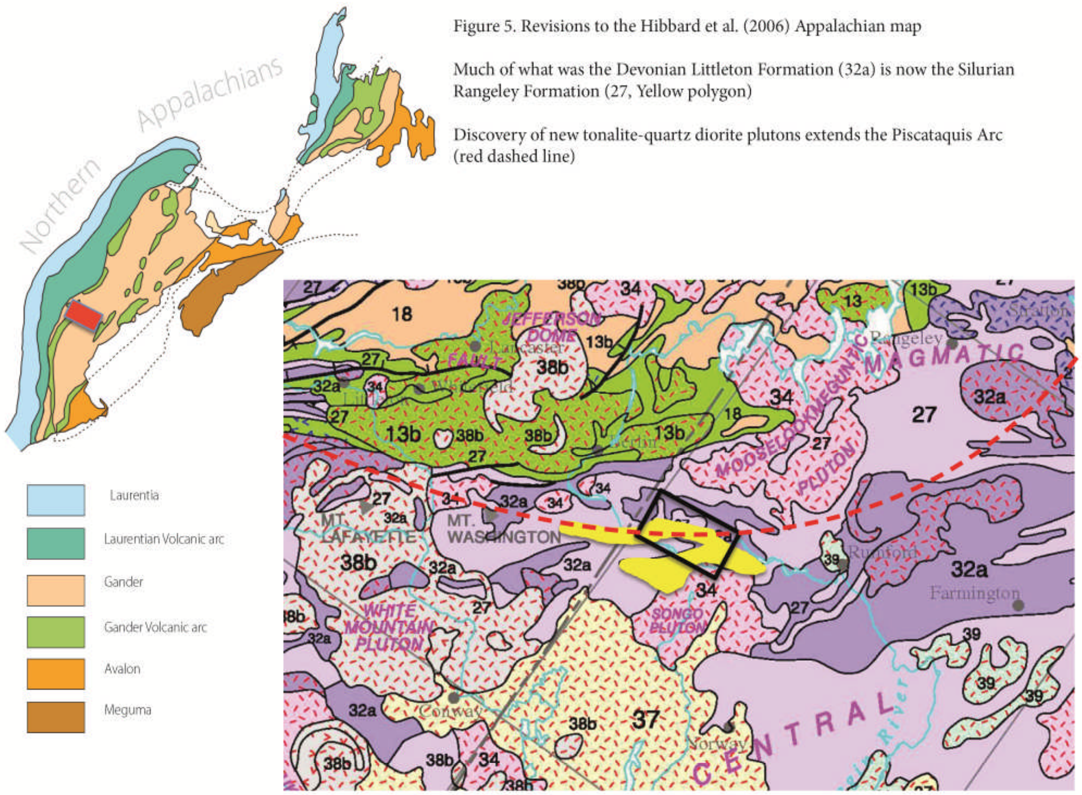


Figure 5. Revisions to the Hibbard et al. (2006) Appalachian map

Much of what was the Devonian Littleton Formation (32a) is now the Silurian Rangeley Formation (27, Yellow polygon)

Discovery of new tonalite-quartz diorite plutons extends the Piscataquis Arc (red dashed line)

D1 folding, early metamorphism, migmatization, quartz diorites, early pegmatites. An early isoclinal fold event, D1, occurred next and is characterized by a bedding (S_0)-parallel schistosity (S_1) throughout the region. In a few places bedding is not parallel to schistosity, indicating the location of an early, macroscopic fold hinge. The axial trace of this fold is seen on Figures 2 and 3 but its exact location elsewhere in the area is obscured by migmatization. Parasitic mesoscale D1 folding is fairly rare in the region. This early deformation likely records the onset of ductile deformation during the beginning of the Early Devonian Acadian Orogeny. The quartz diorite-tonalite suite has a weak foliation and likely intruded during this time. Pseudomorphs of possibly andalusite developed in the schists during D1 as early metamorphism was syn-kinematic. Migmatization also developed some time during D1 based on the observation that migmatitic leucosomes and melanosomes are generally parallel to schistosity. The migmatite front is shown on Figures 2 and 3 and generally follows the boundary between the Rangeley units (migmatized) and the Perry Mountain units (not migmatized). Preferential migmatization of the Rangeley is also seen in nearby New Hampshire (Eusden et al, 1996; Allen, 1996) suggesting some bulk compositional control on the temperature of partial melting or stratigraphic control on metamorphic fluid flux. The earliest pegmatites probably also intruded at this time.

D2 folding. Following D1, bedding, schistosity, and migmatite layering were folded about NE trending, shallow plunging axes that record the second deformation, D2. Early pegmatites are also folded by this deformation. The majority of the observed mesoscopic folds in the area are D2 in age. In outcrop and more commonly in thin section, scattered areas of crenulation exist and have been interpreted as part of D2. D2 is probably a continuation of the Acadian or the Late Devonian NeoAcadian orogeny.

Post-kinematic metamorphism and late two mica intrusions. Late, coarse-grained, randomly oriented muscovite is found in both outcrop and thin section, especially in the migmatites. Pegmatites and discordant two mica granite plutons are probably synchronous with this muscovite growth. Collectively these may record the intrusion and contact thermal effects of numerous Sebago-like intrusions that developed during the Carboniferous to Permian Alleghenian Orogeny.

Late stage alteration, jointing, brittle faulting, and basalt intrusion. Widely distributed here and there throughout the region is post-kinematic, chlorite and sericite alteration in the schists principally observed in thin sections. This alteration may be synchronous with the ubiquitous jointing, rare brittle faults, and rare basalt intrusions found in the quads. These collectively record the complex hydrothermal alteration, brittle deformation, and basalt injection that occurred during the Mesozoic rifting of Pangea.

Glacial Features

Glacial flow directions. Most glacial striations in this part of Maine indicate glacial flow directions ranging from SE to SSE. This flow probably occurred during the maximum phase of late Wisconsinan glaciation, when glacially streamlined hills were sculpted with the same orientation. However, striations on the west peak of Barker Mountain at Sunday River ski area reveal a progressive shift in flow from 157^{o} to 187^{o} (Thompson, 2003b). Evidence of this shift has likewise been recorded in the Fryeburg quadrangle (Thompson, 1999) and elsewhere in southwestern Maine. The S to SSW movement may have resulted from reorganization of ice flow as the glacier thinned over the Mahoosuc Range to the north in late-glacial time (Thompson and Koteff, 1995; Thompson, 2001).

In the Gilead-Shelburne part of the Androscoggin Valley, eastward glacial flow parallel to the valley is recorded by striations, roche moutonnées, drift tails, and the Androscoggin Moraine Complex. This eastward flow probably resulted from topographic influence on the ice sheet during deglaciation.

Eskers. A discontinuous esker system extends from the lower Bear River valley eastward down the Androscoggin. It consists of ridges of gravel and sand deposited by meltwater streams flowing in tunnels at the bottom of the last glacial ice sheet. It is part of a segmented esker system that can be traced E and SE for many miles to glacial-marine deltas in the Poland-New Gloucester area. The best esker exposures in the Bethel area have occurred in the Chadbourne Pit (Stop 2). Excavations of the esker core show poorly sorted, nonstratified pebble-boulder gravel. Other esker ridges in the trip area record a second tunnel system that followed the Androscoggin Valley in Gilead and Shelburne.

Deglaciation. Meltwater channels provide clues to the pattern of ice recession in the Bethel area. There are channels carved by glacial streams on both sides of the Androscoggin valley. The surficial geologic map of the Bethel quadrangle shows these sloping channels west and northwest of the Bethel airport, and across the valley near Farwell Mountain (Thompson, 2003b). They formed in a progressive series as meltwater flowed southwest alongside a thinning lobe of glacial ice in the valley bottom. This lobe receded northeastward down the Androscoggin valley. Drainage of the valley would have been temporarily blocked by the ice during the inception of glacial Lake Bethel, so at least the early phase of the lake probably spilled southward through one of the outlet channels described below.

Additional evidence of glacial retreat is provided by the topography and sedimentary structures of sand and gravel deposited in streams and lakes. In West Bethel, delta foreset beds of glacial Lake Bethel record eastward drainage from an ice tongue receding up the Androscoggin valley toward Gorham. Meltwater channels carved on hillsides further indicate westward ice recession in the Gilead quadrangle, as do the ice-contact sand and gravel deposits along both sides of the Androscoggin valley. Continued ice retreat opened the valley bottom and allowed outwash to be deposited in Gilead and Shelburne. Some of the Androscoggin outwash may include glacial-lake deltas, as we will see on the field trip.

Glacial Lake Bethel. A large glacial lake developed as the late Wisconsinan ice sheet receded from the lowlands around Bethel. This water body was named "Lake Bethel" by Thompson and Fowler (1989). It formerly occupied the Androscoggin Valley between Gilead and the very narrow part of the valley north of Middle Intervale in Bethel. The lake also flooded tributary valleys in the southern part of the Bethel quadrangle. Evidence of the lake includes: (1) a delta reaches elevations of about 710 ft on both sides of the Androscoggin valley near West Bethel; and (2) considerable thicknesses of lake-bottom sand, silt, and clay encountered in test borings. Well data on the surficial materials map (Thompson and Locke, 2003) show depths to bedrock that reach nearly 200 ft in the area of Lake Bethel.

The spillway (outlet) for Lake Bethel has proven difficult to locate. If the former lake elevation was about 690-700 ft, there are several possible spillway locations at approximately the same elevation. Candidates include an abandoned channel near the north end of Songo Pond (East Stoneham quadrangle), a channel west of Route 5 in the southern part of the Bethel quadrangle, and the very narrow stretch of the Androscoggin River in the northeast part of the quadrangle. The first two sites show the erosional features of former channels, but they could have been carved by streams issuing directly from the receding ice margin, instead of (or in addition to) drainage from Lake Bethel. At the third site the Androscoggin River has cut through till deposits that formerly could have dammed the river and impounded Lake Bethel. Contours on the topographic map suggest that this "Androscoggin spillway" had an elevation as high as 700 ft prior to being downcut. Boulders in this stretch of the river bed were winnowed from the till as the river eroded down to its present level.

The outlet of Lake Bethel may have changed position over time. When postglacial uplift and tilt is considered, the Androscoggin spillway probably was about 15 ft lower at the time of deglaciation, relative to the other spillways to the south. This suggests that it was an outlet for Lake Bethel, although the other spillways could have drained the lake before glacial retreat uncovered the Androscoggin route.

Alluvial fans. Alluvial fans are common in the mountains of western Maine. They are sloping, fan-shaped deposits of coarse gravel that formed where steep brooks join larger trunk streams. The decrease in stream gradient upon entering the larger valleys caused the brooks to drop the heaviest portions of their sediment loads. Rapid fan accumulation probably occurred immediately after the disappearance of glacial ice, when the barren mountain sides and unstable sediments on slopes were vulnerable to erosion.

Most of these fans are rarely flooded today, with the notable exception of Chapman Brook in Bethel. In 2007 a very heavy and localized rainstorm impacted steep slopes on the south sides of Barker and Locke Mountains. A huge surge of flood water – and/or debris flows – swept down Chapman Brook, totally filling the town reservoir with boulder gravel!

Highway Geology

In the years between 2005 and 2011, MaineDOT had five separate projects to completely rebuild Route 2 between Bethel and the New Hampshire border and portions of Route 113 in Gilead. The original road was in poor condition and difficult to maintain, and did not meet current standards for highway safety. These projects were extremely challenging due to the terrain and geology in the Gilead area. The design team had to set an alignment for the highway that met current Federal design standards while minimizing excavation south of the highway and avoiding impacts to the St. Lawrence and Atlantic railroad to the north.

The geotechnical challenges were steep, unstable slopes and unstable or marginally stable rock slopes south of the roadway, and steep slopes and the railroad tracks to the north. It was not feasible to move the roadway further north to create flatter slopes because railroad tracks are very close to the highway throughout this area. Some of the stabilization measures were designed during construction of the projects because information available during the design process was not sufficient for geotechnical design. Many boulders in this area are very large, and until excavation began it was not known which exposed rocks were massive boulders and which were bedrock. The bedrock surface is irregular, and variations in the underground surface of the bedrock could not be determined during design. It was not feasible to get a drill rig up these slopes; seismic refraction was done, however due to the steepness of the bedrock surface the data from this technique was unreliable.

US Route 2 prior to reconstruction

DAY 1 ITINERARY

The vehicle caravan for this trip will assemble in the Telstar High School parking lot, on Route 26 just south of Bethel village. Driving directions and mileages are given between stops. ***Note that Stops 1, 2, 3, 6, and 7 are on private property. You are visiting these stops at your own risk, and permission from the owners is needed for any future visits!***
Assemble at the high school starting at 8:00 AM. We hope to do some car pooling and will leave at 8:30 sharp.

-- Turn R out of school parking lot, onto Route 26. Drive 0.9 mile toward Bethel village.
-- Turn R on Intervale Road and go N for 2.2 miles.
-- Turn R on Farwell Road (dirt) and drive 1.2 miles E up the valley side to large open area where road curves to R. Park here.

STOP 1. Farwell Mountain eolian sand deposits (Bethel; Bethel 1:24,000 quadrangle). Eolian (windblown) sand deposits in southern Maine resulted from wind erosion of glacial-lake and glacial marine sediments. They probably formed in late-glacial time, when vegetation cover was sparse. The prevailing winds blew from the west, as they do today (McKeon, 1989).

A very large area of eolian sand occurs on the lower west slopes of Farwell Mountains, east of the Androscoggin River in Bethel. Woods roads in this area show numerous exposures of the sand, which in some places forms longitudinal dune ridges parallel to former wind directions. One typical ridge was noted to be about 10 ft high and extends southeast for hundreds of feet. It was difficult to locate the boundary between the eolian deposits and Lake Bethel sands to the west. There is no obvious topographic or compositional break between these units. An approximate contact was mapped on the basis of elevation, degree of sorting, and presence or absence of stones.

In some parts of this area, surface exposures show intermingled eolian sand patches and bouldery till. One such deposit is a narrow dune ridge, located along a snowmobile trail where it passes through the saddle between Farwell Mountain and the small unnamed hill to the southwest. The dune is only about 5 ft high and 25 ft across, but is very long. It probably formed as winds blew southeast and funneled through the gap at the head of a glacial meltwater channel (see surficial geologic map of Bethel quad).

-- Return to Intervale Road and back to Route 26. Turn R and head toward Bethel village for 0.2 mile.
-- Turn R onto Maybell (or Parkway?) Road and go 0.4 mile to jct. with U. S. Route 2.
-- Turn R and proceed on Route 2 N/E for 5.6 miles (Note Bethel Outdoor Adventures campground on R at 0.5 mile, where our evening BBQ will be held).
-- Turn L onto Route 26 and immediately R onto dirt access road leading into the Chadbourne Pit.
-- Drive N across pit floor, keeping to R of asphalt plant, and follow trip leader to upper level of pit.

STOP 2. Chadbourne Pit, Newry, ME (Newry; Bethel 7.5-minute quadrangle).

The Chadbourne gravel pit (owned by Chadbourne Tree Farms in Bethel) has existed for many years, during which expansion of the pit to the N and NW revealed good exposures of glacial meltwater deposits. Three drainages meet here: the Androscoggin River, Bear River, and Stony Brook (Figure 6). The interaction of glacial and postglacial streams in these valleys has resulted in a complex history. Based on many visits to the pit since 1984, Thompson (2003b) proposed the following sequence for the area shown in Figure 6:

(1) An esker system (map unit Pge) developed in the Bear and Androscoggin River valleys. The topographic map shows two esker segments in the area of the Chadbourne Pit. The southeastern segment was removed long ago by expansion of the pit, while the segment to the northwest has been partly excavated since the photo in Figure 7 was taken. Esker exposures in the northwest end of the pit showed poorly sorted coarse gravel with boulders to 3 ft in diameter. Ice-contact sand and gravel with greatly deformed bedding occurs extensively in the northern part of the pit complex, and even in the bank of the nearby Bear River. Some of these deposits may be buried eskers indicating multiple ice tunnels, while other parts appear to be collapsed lacustrine deltaic sediments (see below).

(2) Deltaic sand and gravel (Pldi) was deposited in a small glacial lake adjacent to remnants of glacial ice in the valley. These deposits are best preserved just east of Stony Brook, on the north side of the Androscoggin River, where they form a terrace reaching about 750 ft in elevation. The lake probably was small and confined by ice choking the Androscoggin Valley to the east. It possibly drained southward where the valley greatly narrows between Newry and Middle Intervale (and thence into the early Lake Bethel), or maybe through the meltwater channel along the road east of the river.

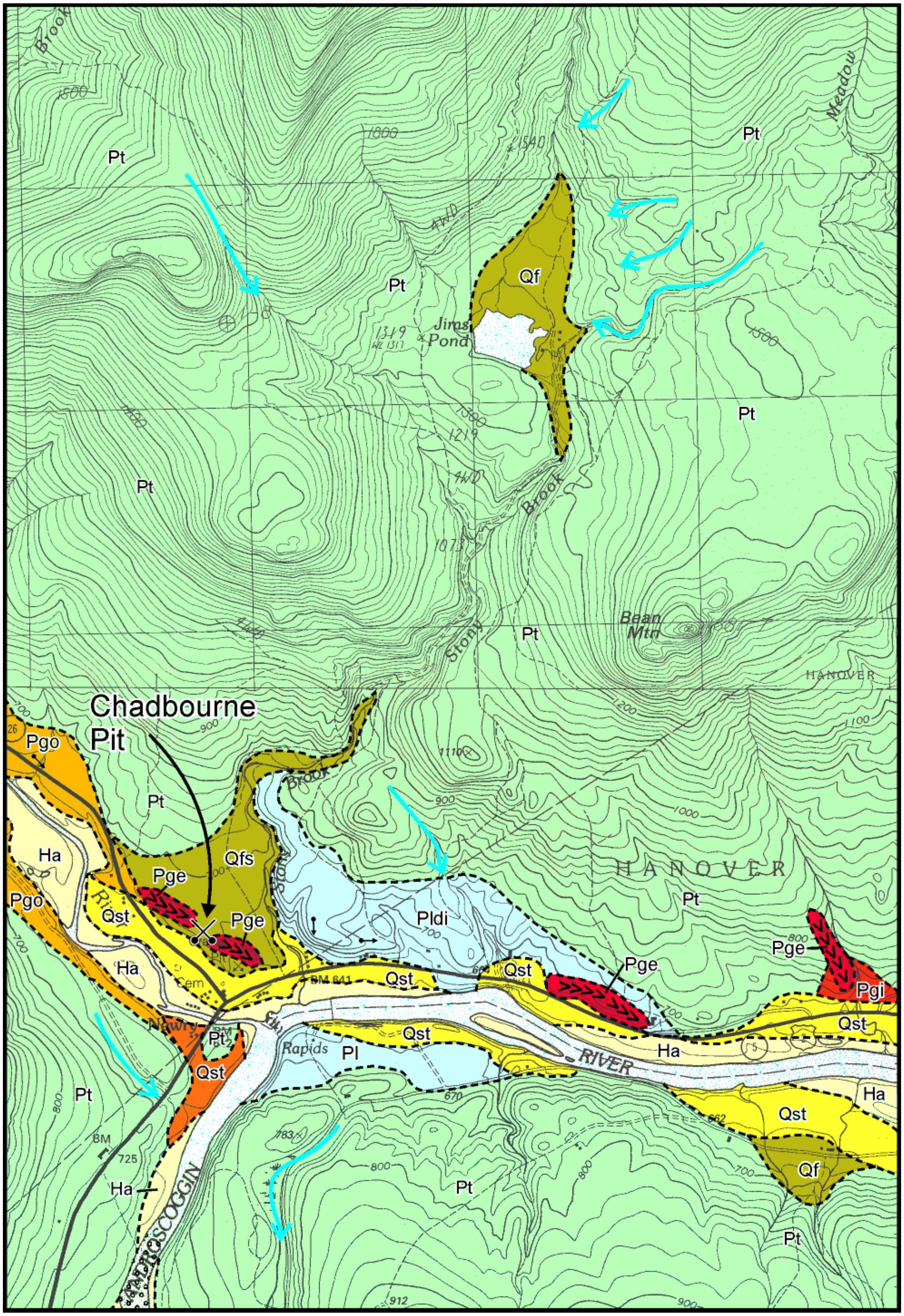


Figure 6. Surficial geologic map of the Chadbourne Pit area in the Bethel and Puzzle Mtn. quads. From Maine Geological Survey Open-File Map 08-79 and Report 03-45 by W. Thompson.

Figure 7. Esker ridge in NW part of Chadbourne Pit. Gravel of the Stony Brook alluvial fan (map unit Qfs) is seen in foreground. Photo taken in 1992. From Thompson (2003b).

Figure 8. Stony Brook fan gravel unconformably overlying collapsed ice-contact lacustrine sand beds in northern part of Chadbourne Pit. Photo taken in 1993. From Thompson (2003b).

Eroded remnants of glacial-lake sediments are widespread in the Chadbourne Pit, where they have exposed thicknesses up to 20-30 ft. This material is believed to have been deposited in the same water body as unit Pldi. Sections in the pit expose delta foreset beds, and fine-grained, thin-bedded lake-bottom sediments. Faulting and deformed bedding occur locally next to the esker segments.

(3) The last glacial ice remnants dissipated in the Androscoggin Valley. As the Pldi lake drained and base level became lower, ponded water in the area of the Chadbourne Pit was replaced by a higher-energy stream environment. The change is recorded by a transitional stratigraphic unit that occurs locally in the pit complex. It consists of 3-10 ft of well-stratified gravel and sand lying between older lacustrine deposits and the thin surface gravel of the Stony Brook fan.

(4) A large alluvial fan (Qfs) was built by Stony Brook. The Stony Brook valley is deeply incised, and in its headwaters there is a group of glacial meltwater channels northeast of Jims Pond (Puzzle Mountain quadrangle). All of these channels conveyed meltwater from thick glacial ice that lay to the northeast. However, there is no definite continuity between the channels and the fan deposits in the pit area. The fan gravel may consist largely or entirely of postglacial alluvium derived from slopes farther upstream, rather than outwash from melting glacial ice.

Numerous exposures in the pit have shown that the southern part of the fan is only 3-6 ft thick. Over a large area of the pit, it truncates collapsed ice-contact beds that locally have been tipped to a vertical orientation (Figure 8). The generally undeformed fan gravel is believed to have formed when local glacial ice had melted away. A possible exception was seen where a small quantity of fan gravel had slumped into a fissure in deformed ice-contact sediments. This was either an ice-wedge filling, or it showed that traces of buried ice still remained when the fan was deposited.

(5) The sediment supply to the valley diminished as a consequence of deglaciation and stabilization of hill slopes, accompanied by crustal uplift and tilt. Streams responded by eroding downward, and terraces formed in the Bear River valley at elevations between 640 and 660 ft. Two terrace levels can be distinguished along Route 26 in the fields southwest of the Chadbourne Pit, at elevations intermediate between the Bear River outwash and the modern flood plain. Downcutting has also occurred on the Stony Brook fan, causing a subtle terracing of the fan surface. The distal edge of the fan appears to have been graded to the same level as the higher Bear River terrace (~650 ft).

(6) The Androscoggin River cut through a till barrier at the narrows just south of Newry. This gap may have been the final spillway for glacial Lake Bethel, as proposed by Thompson and Fowler (1989). The lake emptied as the spillway eroded, and the modern river drainage was established.

-- Return to Route 2 and drive W for 10.0 miles to pit entrance on R. We will drive in if gate is unlocked.
STOP 3. Coleman Concrete pit (West Bethel; Bethel 1:24,000 quadrangle)

At this locality the internal structure of the West Bethel delta has been exposed by the Androscoggin River and operation of the Coleman Pit. The major spring flood of 1987 eroded a fresh section of this delta on the south bank of the river, just north of the pit. Foreset beds exposed in the river bank suggested that the surface elevation of glacial Lake Bethel was at least 690-700 ft. A similar estimate was obtained from an excellent former exposure of the delta in the Douglass Pit, located across the river to the northeast. ***Please stay off the river bank – it drops steeply into the water!***

Two stratigraphic units are exposed in the Coleman Pit. The lower level shows sandy delta foreset beds, and the upper level reveals ~12 ft of fluvial gravel and sand. Cross bedding in both of these units indicates generally eastward water flow. However, the origin of the upper unit is uncertain. The early postglacial Androscoggin River may have eroded the top of the West Bethel delta, causing the topset beds to be stripped away and replaced by younger river gravels at lower elevations. If this is true, the original delta top and lake surface would have been higher than 700 ft. Exposures in a pit just west of here, on the other side of Route 2 (Gilead quad), clearly showed that the upper fluvial unit was associated with erosion of delta foresets. Another gravel pit in the eastern Gilead quadrangle (at jct. of Route 2 and Bog Rd.) shows delta foreset beds as high as 760 ft. Comparably high deposits also occur on the north side of the Androscoggin Valley in this area, suggesting an early higher level of Lake Bethel that is not well understood.

-- Continue W on Route 2 for 1.4 miles to large bedrock road cut on L. ***Very carefully drive across the road and park on wide shoulder next to the outcrop.***

STOP 4. Highway slope stability and bedrock geology, U. S. Route 2 road cuts (Gilead; Gilead 1:24,000 quadrangle)

Stop 4-A: Peaked Hill Outcrop (just beyond antique shop at base of Peaked Hill)

This outcrop exposes the contact zone between the migmatized units Ssrc and Ssqm. Ssrc is exposed on the eastern end of the crop and is a variably rusty weathering schist with minor thin quartzite, rare meter-thick granofels, and rare calc-silicate pods. There is a Mesozoic (?) basalt dike intruding the rustiest portion of the outcrop. Ssqm is an interbedded gray schist and quartzite with calc-silicate pods. At the west end of the outcrop there is a section of thicker granofels. A few D2 folds of the layers in the migmatite are observed. Pegmatites and small intrusions of two-mica and biotite granite are common. A bizarre set of biotite-rich dikes occur here injected along joint surfaces and cross cutting the migmatite layering. Perhaps these reflect remobilized material from the host migmatite?

The 1826 landslide

The 1826 landslide on Peaked Hill in Gilead was described in dramatic terms by Benjamin Willey in his book titled "Incidents in White Mountain History" (Willey, 1856). The following quote is from Willey's chapter on the early history of Gilead, which is reproduced in the Bethel Historical Society's website:

"During the terrible storm of 1826, when my brother's [Samuel Willey] family was destroyed at the [Crawford] Notch, slides also took place on many of the mountains in this town. From Picked Hill came rushing down thousands of tons of earth, and rocks, and trees, and water, destroying all that lay in their path. No lives were lost, but the consternation of the inhabitants was great. The darkness was so intense as almost to be felt. The vivid lightnings and long streams of fire, covering the sides of the mountains, caused by the concussion of the rocks, only served to make the darkness more visible. Amid the deluge of rain, the terrific crashings of the thunder, and, over all, the deafening roar of the descending slides, it was impossible to make one's self heard. The valley rocked as though an earthquake was shaking the earth. The frightful scene did not last long; but, during its continuance, more terror was crowded into it than during an ordinary lifetime. The inhabitants under these mountains alone can appreciate the awful scene through which my brother and his family passed on that terrible night."

One of the principal geotechnical design challenges was design of the slopes above Route 2 on the north side of Peaked Hill. MaineDOT had extensive aerial mapping in this area, and in the area from Station 9+500 to Station 10+500, approximately 1.25 km west of the Bog Road, it appeared that a combination of previous railroad and highway construction and the current project would remove the final remnants of the toe berm created by the 1826 landslide described in "Incidents in White Mountain History". This left a thin, unstable layer of soil over a shallow bedrock surface, with water flowing at the soil-bedrock interface. Slopes of 1H:1V were necessary to minimize excavation in the slopes above the highway. The majority of this slope was stabilized using a system of rock dowels with a vegetated mesh surface manufactured by the Geobrugg Corporation that is widely used in Europe. After the slope was excavated, holes were drilled through the soil into the bedrock, and steel rods were inserted and grouted into the holes. This form of retaining wall allows water to drain freely through the surface and reduced the problem of trapped groundwater. Crews worked tied off from ropes above the work area, with hand equipment to drill and grout nails in this area (Figure 9).

Figure 9. Workers tied off on the slope, clearing trees and scaling loose rock to prepare the slope for excavation and soil nail installation. Photo by K. Breskin.

Figure 10. Rock cut slopes are high in this area, and rock was line drilled and pre-split to ensure long term stability of the slopes. Photo by K. Breskin.

Substantial rock excavation was required to provide a rockfall zone and allow adequate room to build shoulders to the highway. A small access road was built on the east side of this rock cut to get the drilling equipment to the top of the cut area. Blasts had to be carefully controlled to prevent flyrock from landing on the railroad tracks. The blasting contractor was given 15-minute maximum road closures to minimize traffic delays.

Unstable boulders at the perimeter of the construction area were removed when this was possible, but unstable boulders further up the slope were left in place. Rock and icefall from further up the slope on Peaked Hill is a continuing problem for MaineDOT Maintenance forces. Construction of a rockfall catchment fence at the top of the construction area would have minimized this problem, however the cost was prohibitive.

Unstable rocks at the perimeter of construction could not be removed without destabilizing the upper slopes, and rock bolting was required to ensure that sections of adversely jointed rock did not break off and begin to move down the slope. Nine dowels, 15 to 25-feet in length, were installed between Station 10+200 and 10+400.

-- Drive about another 1.5 miles to the next highway cut on the S side of Route 2. Park carefully on shoulder along N side of road.

Stop 4-B: Middle Outcrop

Exposed here is unit Ssqm - an interbedded gray schist and quartzite with calc-silicate pods. The unit is again highly migmatized with scattered two-mica granites and zoned pegmatites throughout the outcrop. There is a section of thicker granofels at the east end of the outcrop. Late, non-foliated, coarse-grained mica is also commonly found and we attribute this to post-kinematic metamorphism related to the Sebago-like two-mica intrusions in the region. Of note here is a change in the regional dip of layering to the NW from the more typical SE dip.

Other Route 2 design and construction challenges came from marginally stable boulders and unfavorable joints in the rock which were encountered during construction. In many areas of this project extensive rock excavation was required to improve the alignment of the highway, create shoulders and ditches, and provide an adequate rockfall catchment area. Some borings were drilled during the design process, but it is never possible to adequately characterize subsurface conditions, and due to the rugged terrain this project had fewer borings than would normally have been drilled. Areas of groundwater seeping out of rock faces and adverse jointing were encountered during construction that required remediation to protect the roadway.

The area between Station 8+240 and Station 8+315 required extensive rock excavation. An adversely dipping zone of weathered bedrock supported an unstable block of rock above the road. Rock bolting and rock drains were required to remediate unstable rock masses encountered during construction – drains were installed were groundwater was observed flowing out of the rock face. Twenty-six rock dowels and 9 rock drains were installed in the rock face between Station 8+240 and Station 8+315. Dowels were 10-feet to 25-feet in length and rock drains extended 15-feet into the rock.

Figure 11. This rock cut slope at Stop 4-B experienced several rockfall events during the winter of 2010, after rock excavation shown on the plans was completed but before final remediation with drains and dowels. Photo by K. Breskin.

-- Drive ~ another 1.4 miles to the next major highway cut on the S side of Rte. 2. Park carefully on R.

Stop 4-C: "The Big Pegmatite" Outcrop

Exposed here again is unit Ssqm (see description from last stop). There are multiple generations of pegmatite with the most spectacular being the long, 1-2 meter wide, sub-horizontal, zoned pegmatite with multiple offshoots that cut through the outcrop. A minor brittle fault with unknown displacement is also found. Forming a low region in front of the outcrop is a basalt dike that is in places vesicular to amygdaloidal (filled with a pale greenish mineral, perhaps prehnite?). The basalt can be found at both the E and W ends of the long outcrop.

Glacial grooves can be seen in numerous places on the low part of the original ledge surface. They indicate flow in a general eastward direction, presumably due to late-glacial channeling of the thinning Androscoggin ice tongue parallel to the valley.

This is another area where adverse jointing left unstable rock slopes after construction. Twenty dowels and six rock drains were installed to stabilize the upper blocks in the cut zone, and some tree removal was done to minimize root jacking of the rock face.

On the south side of the road, a small pond created by construction of the railroad embankment limited the slopes that could be built as the highway was widened, and a reinforced soil slope was constructed to provide a stable 1H:1V slope out of granular fill materials.

-- Continue W 1.0 mile to picnic area on L (**Lunch Stop**). After lunch, continue W 0.4 mile and turn L onto Rte.113 (Evans Notch road) in Gilead. Go S for 1.7 miles and park in turnout next to Wild River (located just before seasonal road gate).

STOP 5. Floods, landslides, till stratigraphy and glacial-lake deposits in the lower Wild River valley
(Gilead and Batchelders Grant; Gilead and Speckled Mountain 1:24,000 quadrangles)

Exposures on the sides of the lower Wild River valley suggest that this north-draining stream was dammed by glacial ice, impounding a temporary deep lake. Debris flows from the glacier entered the lake, forming waterlain tills interbedded with clay, silt, and sand. The valley probably experienced multiple episodes of ponding, which could have occurred during the advance and retreat phases of each glacial cycle. The number of these ponding events is unknown, but at least some of the waterlain till and lake sediments in the Wild River valley were deposited during retreat of the last ice sheet. In many ways the stratigraphy here resembles that of sections along the lower Peabody River in Gorham, New Hampshire (Fowler, 1999).

Down over the river bank from the parking lot here, the stream bed exposes nicely laminated clay-silt. This unit is a glacial-lake deposit, and its low stratigraphic position in the valley may indicate considerable age. Angular to well-rounded stones embedded in the clay may be ice-rafted dropstones that fell to the lake bottom. Thin laminae of whitish fine sand occur in the clay, and should not be confused with the modern coarse brownish sand left by the river.

Several complex sections were seen during a traverse down the hillside across the river from here, but they are not continuous and thus the complete stratigraphy has not been determined. The sections show interbedded till and glacial-lake sediments, with a cumulative thickness of at least 250 ft! Part-way down the hillside, some of the till is a dense, compact lodgement facies, with possible oxidation suggesting a pre-late Wisconsinan age.

The 1998 landslide and other slope instability, Wild River Valley

Numerous slope failures have occurred in the thick deposits of interbedded till and glacial lake sediments in the Wild River valley. In July, 1998, a notable landslide occurred in the ravine along a small intermittent brook on the west side of the valley, ~0.20 mile N of here (Thompson, 2003c). A sequence of interbedded till and waterlain glacial sediments in the head of the ravine slumped and triggered a debris flow that traveled a quarter mile down the brook. The moving slide debris became up to 20 ft thick, snapped tree trunks along the sides of the ravine, and carried them into the Wild River. The slide almost blocked the river, riled up the water for weeks, and left mud caps on large river boulders that were still visible several months later.

Exposures along the landslide path revealed dense lodgement till that had been swept bare during this event (Figure 12). Toward the head of the ravine, where it curves to the southwest, a freshly scoured bank exposed laminated glacial-lake clays (with dropstones) overlying till. A complex section at the head of the slide showed olive-gray silty-sandy diamict with thin sand beds, grading upward into interbedded diamict-silt-sand-pebble layers, and finally to stratified, poorly-sorted, angular gravel with thin diamict interbeds in the uppermost part of the section. Another slide that occurred in this same area in 2007 is shown in Figure 13.

Other recent landslide scars occur near here on the east side of the Wild River valley, uphill from "BM 744" on Route 113 (~ 0.45 mile N of Stop 5). One of these slides continues to shed debris onto the road, and the retaining wall on the east side of the road was built in an attempt to limit the damage. At the head of the latter slide, there is a good exposure of lodgement till (Figure 14).

Figure 12. Scar from landslide of July, 1998, in till along ravine on west side of Wild River valley. Photo taken November 3, 1998. From MGS Open-File Map 03-57 by W. Thompson.

Figure 13. Head scarp of fresh landslide on W side of Wild River valley, just N of the head of the 1998 slide. Photo by W. Thompson, July 17, 2007. GPS coordinates: 0341006 E; 4915550 N.

Figure 14. Head scarp of till slide on the east side of the Wild River Valley.
Photo by K. Breskin, ca. late 2005

An area of steep slopes along Route 113 extends along the east shore of the Wild River to the gated portion of the highway. One large and several small slide areas scar the hillside in this area, and MaineDOT Maintenance staff regularly cleans mud and debris out of the roadway in the spring. In 2009, a section of this roadway was rebuilt to protect it against undermining by the Wild River, and the slope east of the road was armored with a thick layer of riprap. However, full remediation of this landslide area would have required excavation for distances well beyond the highway, and was not feasible for a minor roadway. An area of soft, blue glacial lake clays was encountered under the highway during construction and other clay areas can be found nearby along the river.

-- Return to Route 2. Turn R (E) and then a quick L onto Bridge Street in Gilead. Cross the Androscoggin River on narrow one-lane bridge (watch for oncoming traffic). Immediately beyond bridge, turn L onto North Road. Go W ~ 2.1 miles to gravel pit entrance road on R. If gate can be opened for the trip, we will drive into the pit. Otherwise we'll continue a very short distance on North Road, parking in one or two places as directed, and access Stops 6 and 7 from that point.

STOP 6. Pike Industries Pit (Gilead**;** Shelburne, N.H.-Maine 1:24,000 quadrangle**)**

This is one of the newer pits in the area, and is still active. The original topography was an outwash terrace with a hummocky top at ~740 ft. It is bounded by a kettle pond to the southwest and the Lary Brook flood plain to the northeast (Figure 15). An esker follows the opposite side of Lary Brook, beyond which is a second brook and another outwash terrace. These waterlaid glacial deposits wrap around the north side of Hark Hill, and they are believed to have filled an ancestral course of the Androscoggin River. This would classify Hark Hill as a geomorphic feature called an "umlaufberg"!

Exposures seen in the Pike Pit during a few occasional visits since 2008 have been varied and confusing! In 2008-2009, the pit face showed ~ 25 ft of sand and gravel with cut-and-fill channels and cross bedding suggesting a proglacial fluvial deposit. Since the pit has expanded to the northwest and become deeper, there are now widespread exposures of sandy delta foreset beds in the intermediate and lower levels. A glacial lake apparently existed in this area, but its relationship to other possible lacustrine deposits between here and West Bethel is still a mystery.

STOP 7. Androscoggin Moraine Complex (Shelburne, N.H. - Gilead, Maine; Shelburne, N.H.-Maine 1:24,000 quadrangle**)**

This is a group of high moraine ridges that form an arcuate, en-echelon cluster spanning both sides of the Androscoggin River valley (Figure 15). They are located on the Maine-New Hampshire border and were built by a tongue of the Laurentide Ice Sheet flowing eastward down the valley from Gorham. We will visit the part of this moraine that was first recognized and illustrated by George Stone (Figure 16; Stone, 1880, 1899). Thompson (1983,1984) named the moraine complex and mapped many parts of it that had not been previous recognized.

Many boulders are strewn over the surfaces of the moraine ridges, and near this stop they are as large as 25 ft across (Figure 17). The higher moraine segments are very steep-sided, and ridge No. 1 that projects east from Stock Farm Mountain is at least 100 ft high. Figure 18 is a view looking down along the crest of this ridge. Backhoe test pits were dug in three of the moraines, revealing various facies of till and flowtill with some washed lenses and even some water-laid diamicton in ridge No. 15 (Thompson and Fower, 1989).

The sources of rock types in the moraine complex were described as follows by Thompson and Fowler (1989, p. 80):

"**Provenance.** Large areas of bedrock are exposed upvalley from the Androscoggin Moraine. Billings and Fowler-Billings' (1975) map of the Gorham 15-minute quadrangle shows three principal rock types in the 5-km section of the Androscoggin River valley just west of the moraine system. In decreasing order of abundance, these are: Littleton Formation (Dl), consisting mostly of high-grade paragneiss, schist, and quartzite; medium-grained, gray biotite quartz diorite (qd); and Concord quartz monzonite (co), a medium-grained gray rock containing both muscovite and biotite. These rock types can be seen in road cuts along U. S. Route 2 in Shelburne. Much of what Billings and Fowler-Billings (1975) considered to be Littleton Formation in the Shelburne area was later reassigned to the Rangeley, Smalls Falls, and Madrid Formations by Hatch and Moench (1984) and Moench (1984).

Most of the boulders in the Androscoggin Moraine are the same rock types that outcrop immediately upvalley. Coarse, variably rusty, two-mica gneisses and schists of the Rangeley Formation (formerly … the Dlg member of the Littleton Formation), and biotite quartz diorite are particularly common. For example, moraine 4 [Fig. 15] contains many large boulders (1-3 m), with a great concentration on the proximal side. Most of these boulders are the quartz diorite that outcrops as near as 0.25 km to the northwest. The area of outcrop of this intrusion extends across the northeast slope of Stock Farm Mtn. and is somewhat larger than shown on Billings and Fowler-Billings' map."

The moraine complex was deposited during a significant pause in the retreat of the Androscoggin ice tongue of the Laurentide Ice Sheet from western Maine back into northern New Hampshire. The latest proposed deglaciation chronology for Maine indicates that the Androscoggin Moraine Complex should

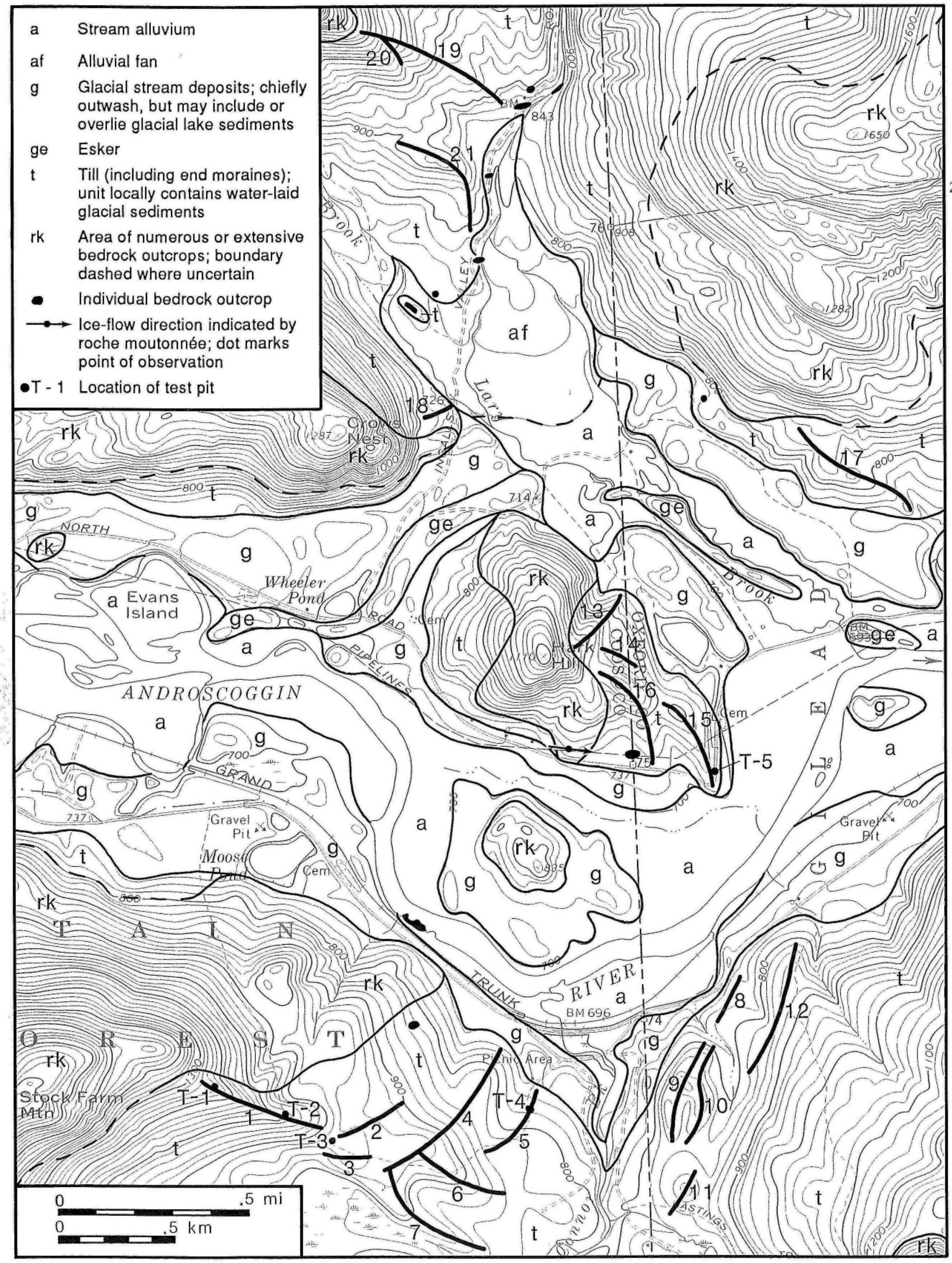
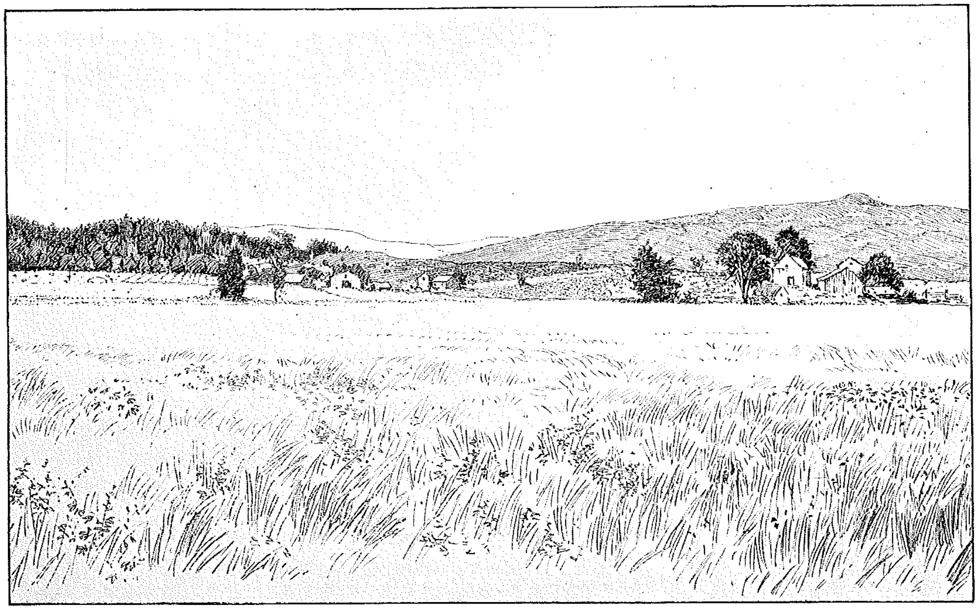


Figure 15. Map of the Androscoggin Moraine Complex and associated surficial deposits. From Thompson and Fowler (1989). Numbered lines indicate crests of moraine ridges.



B. TERMINAL MORAINE OF LOCAL ANDROSCOGGIN GLACIER; GILEAD.

Figure 16. View of moraine ridges at Stop 7, looking N from the AndroscogginRiver flood plain. From Stone (1899).

Figure 17. Large boulders on proximal side of Moraine 16. Photo taken November 2, 2007 by W. Thompson.

Figure 18. View looking E along crest of Moraine 1 where it projects abruptly from flank of Stock Farm Mountain. Photo taken November 5, 2008, by W. Thompson.

Figure 19. Gordon Bromley sampling boulder on SW part of Moraine 4, for cosmogenic nuclide exposure dating. Photo taken November 29, 2009, by W. Thompson.

be about 14,500 years old (Thompson et al., in review). This would be consistent with the estimated age of 14,000 yr for the Berlin Moraines, located farther up the valley, northwest of the city of Berlin, N.H (Thompson et al., 2009). However, recent cosmogenic nuclide exposure dating of boulders on the Androscoggin moraines yielded surprisingly young ages of 14,100 to 12,900 yr, averaging about 13,500 yr (Figure 19; Bromley et al., 2013). Pending ages on samples from the Berlin Moraines hopefully will shed further light on this problem.

DAY 2 ITINERARY

From the South Ridge lodge we'll be taking the Chondola chairlift to the top of North Peak (elev. 2,100 ft.). We will walk uphill along the less steep ski trails 2.2 miles to the observation deck at the peak of Jordan Bowl (elev. 3,000 ft.) examining bedrock along the way. We retrace our route back down to the chairlift for a total distance of 4.0 miles walked. The trip ends with a chairlift ride back down to South Ridge lodge. Figure 3 shows the bedrock geology and locations of the stops. You should bring a lunch, water, and wear hiking boots.

Hiking Log

Cumulative Miles 0.0 From the top of the Chondola lift, walk downhill past the North Peak Lodge and then up the short hill to the top of the North Peak Express chairlift.

Miles 0.1 Stop/traverse 1. We will walk downhill along the Quantum Leap trial (double diamond) to just below the trail junction with the Polaris trail (green dot), traversing .2 miles of the section.

We start at the top in unit Ssqb - Interbedded gray schist and quartzite. The bedding is generally thin (1-5 cm), there are scattered calc-silicate pods, a few pseudomorphed andalusite (?) spots, and pegmatite/aplite veins. We are just west of the migmatite front, on the lower grade side, with schist assemblages of bio+garnet+sillimanite (musc+qtz+plag). Bedding, S_0, is parallel to the S_1 schistosity here indicating the isoclinal nature of the early D1 folds. Some late D2 folding is visible here and there.

Below this but above the junction with the Polaris trail we walk across the second unit Ssqg - Biotite granofels member. This is a medium-grained, granoblastic quartz-plagioclase-biotite granofels, with rare calc-silicate pods, and minor gray schist.

Crossing the Polaris trail we see less granofels and more interbedded schist and quartzite as we approach the third unit, Ssq - Interbedded gray schist and quartzite with a few calc-silicate pods. Layers of schist with oval, spotted, 1-2 cm long porphyroblasts (?) are observed. Some of the spots are largely composed of quartz and have hollow, darker cores. Some of these also look like quartz clasts so there is a possibility that some layers may be conglomerate (which we have recognized nearby). Distinguishing quartz conglomerate clasts from quartz-rich porphyroblasts can be very difficult in these outcrops! What do you think? The highlight of this traverse is a sharp boundary offsetting two units of different bed thickness. The whole outcrop has been metamorphosed to the same degree so the boundary (a fault? a slump?) is pre-metamorphic in age. This could be a soft sediment slump or a tectonic fault that developed in an active setting during the Early Silurian Salinic orogeny.

Miles .3 Walk up the Backside trail (green dot) back to the Chondola chair lift top and then proceed slightly uphill to turn SW on to the Lights Out trail (green dot). Proceed up Lights Out till you reach the junction with the Vortex trail (double diamond).

Miles .8 Stop 2. On the NE corner of that intersection is an outcrop with a nicely exposed, bedded, grossular-diopside calc-silicate block surrounded by gray schist and quartzite of the unit Ssq. Bedded blocks like this are fairly common in the region. These, and the more common, concentrically zoned, calc-silicate pods or "footballs" may represent clasts in turbidites that were part of an olistostromal facies, again indicative of an active tectonic setting during deposition. Calc-silicate pods are common throughout the Silurian Rangeley Formation of western Maine and northern New Hampshire.

Continue walking up the Lights Out trails until the junction with the Aludra trail (green dot) just before the Aurora chairlift passes over Lights Out. Proceed up the Aludra trail about 50 yards.

Miles 1.1 Stop 3. Examine the downhill end of the blasted outcrop on the S side of Aludra trail. The unit is Ssq again and we stop here to see whether you think there is a graded bed preserved. Our guess is that the thin quartzite grades into the thicker schist in a couple of places here and that the tops are inverted. Very tough to call though, and on our map we've not found more than a few places in both the Gilead or Bethel quads where grading in bedding is clear. The overall lack of topping control in this region means that our stratigraphic assignments are based primarily on lithologic correlation and stratigraphic sequence.

Continue up Lights Out, which now changes names to become the Kansas trail (green dot), until just above the junction with the Witch Way (blue square) trail.

Miles 1.5 Stop 4. Exposed in a number of trail outcrops is the second granofels unit, also labeled Ssqg. The granofels has, in places, a bit more of the typical flaggy weathering commonly associated with granofels seen elsewhere in western Maine and northern New Hampshire. Coarse-grained andalusite (?) porphyroblasts are again found throughout the schist-rich horizons.

Continue up Kansas to the junction of the Cowardly Lion (green dot) and Emerald City (double diamond) trails and examine the outcrops immediately above the Kansas trail.

Miles 2.0 Stop 5. Exposed here is the unit Sqsc - quartzite and schist with calc-silicate pods. The number of calc-silicate pods has decreased considerably and the proportion of quartzite has increased over that of schist. Bedding is also thicker on average with some beds up to 50 cm in thickness. A rough, knobby texture is seen in the quartz-rich schists as defined by circular, .5 cm diameter, porphyroblasts (of andalusite ?). In places these knobby schists appear to grade into less knobby quartzites and it is tempting to interpret grading. However, we have not been able to convince ourselves of a unique topping direction here. What do you think? The increase in the quartzite proportion coupled with the decrease in calc-silicate pods suggests that the best correlation for Ssqc is the Perry Mountain Formation.

Continue up Kansas passing under the chairlift to Oz.

Miles 2.2 Stop 6. This is our last stop and exposed here on a long joint face, on the S side of Kansas, is more of the unit Sqsc. Bedding is very distinct here and there are some thick quartzites intermixed with thinner porphyroblastic schists. Calc-silicate pods are either absent or rare here. Of note here is the obliquity of bedding S_0 and the schistosity S_1. In most other regions the fabrics are parallel, but here the two fabrics are nearly perpendicular, indicating that these outcrops are within the hinge zone of an early D1 isoclinal fold. This structural relationship is found in a few other regions in the Gilead quad, but mapping out the early fold axial trace has proven to be difficult, especially in the migmatized regions.

Continue up to the top of Jordan Bowl peak and climb to the viewing platform for the great view of Goose

Eye, Old Speck, and the Presidential Range of New Hampshire.

Miles 2.3 Lunch! This is the end of the geology part of the trip. We'll retrace our path on Kansas and Lights Out to the Chondola Lift top to take the chair down.

Miles 4.0 Chondola chairlift top. End of trip.

Selected References

Allen, T., 1996, A Stratigraphic and Structural Traverse of Mount Moriah, New Hampshire, *in* Mark Van Baalen, editor, Guidebook to Field Trips in Northern New Hampshire and Adjacent Regions of Maine and Vermont: New England Intercollegiate Geological Conference, 88th Annual Meeting, pp. 155-169.

Billings, M. P. & Fowler-Billings, K., 1975, The Geology of the Gorham Quadrangle, New Hampshire and Maine: Bulletin 6, Concord: State of New Hampshire Department of Resources and Economic Development.

Bradley, D. C. & Tucker, R., 2002, Emsian Synorogenic Paleogeography of the Maine Appalachians: Journal of Geology, 110, 10/8/2013-483-492.

Bradley, D. C., Tucker, R. D., Lux, D. R., Harris, A. G., and McGregor, C. C., 2000, Migration of the Acadian Orogen and Foreland Basin across the Northern Appalachians: U.S. Geological Survey, Professional paper 1624, 49 p.

Brady, J. J., 1991, The Bedrock Geology of the Bethel, Maine Area: M.S. Thesis, University of Maine, Orono, 150 p.

Bromley, G., Hall, B. L., Thompson, W. B., Garcia, J. L., Kaplan, M. R., and Schaefer, J. M., 2013, Age of the Androscoggin Moraine, western Maine and eastern New Hampshire, from ^{10}Be surface exposure-age dating (abs.): Geological Society of America, Abstracts with programs, v. 45, no. 1, p. 105.

Choe, S. C., 2014, Analysis and Tectonic Implications of the Plutons in the Gilead 7.5 Quadrangle: Connections to the Piscataquis Volcanic Arc and Sebago Batholith: Bates College Geology Department Senior Thesis, 68 p.

Eusden, J. D., 2013a. Bedrock Geology of Part of the Gilead Quadrangle, Maine: Maine Geological Survey.

Eusden, J. D., 2013b. Bedrock Geology of Part of the Bethel Quadrangle, Maine: Maine Geological Survey.

Eusden, J. D., Jr., Garesche, J., Johnson, A., Maconochie, J., Peters, S. C., Rosbrook, J., and Widmann, B., 1996, Stratigraphy, and ductile structure of the Presidential Range, N. H.: Tectonic implications for the Acadian orogeny: Geological Society of America Bulletin, v. 108, pp. 417-436.

Dorais, M.J., 2003, The petrogenesis and emplacement of the New Hampshire plutonic suite: American Journal of Science, v. 303, p. 447-487.

Fowler, B. K., 1999, Pre-Late Wisconsinan age for part of the glaciolacustrine stratigraphy, lower Peabody valley, northern White Mountains, Gorham, New Hampshire, *in* Thompson, W. B., Fowler, B. K., and

Davis, P. T., eds., Late Quaternary history of the White Mountains, New Hampshire and Adjacent Southeastern Québec: Géographie physique et Quaternaire, v. 53, no. 1, p. 109-117.

Gibson, D. and Lux, 1989, Petrographic and geochemical variations within the Songo pluton, western Maine, *in* Tucker, R. D. and Marvinney, R. G., eds., Studies in Maine Geology: Vol 4 - Igneous and metamorphic geology: Maine Geological Survey, p. 87-100.

Hatch, N. L., Moench, R. H., and Lyons, J. B., 1983, Silurian-Lower Devonian Stratigraphy of Eastern and South-Central New Hampshire: Extensions from Western Maine: American Journal of Science, 283, 739-761.

Hibbard, J. P., van Staal, C. R., Rankin, D. W., and Williams, H., 2006, Lithotectonic map of the Appalachian orogen, Canada – United States of America: Geological Survey of Canada Map 02096A, 2 sheets, scale 1:500,000.

Lyons, J.B., Bothner, W.A., Moench, R.H., and Thompson, J.B., 1997, Bedrock geologic map of New Hampshire: U.S. Geological Survey, scale 1: 250,000.

McKeon, J. B., 1989, Late-glacial dunes, ventifacts, and wind direction in west-central Maine, *in* Tucker, R. D., and Marvinney, R. G., eds., Studies in Maine geology -- Volume 6: Quaternary geology: Augusta, Maine Geological Survey, p. 89-101.

Moench, R. H., Boudette, E. L., and Bothner, W. A., 1999. Tectonic lithofacies, geophysical, and mineral-resource appraisal maps of the Sherbrooke-Lewiston area, Maine, New Hampshire, and Vermont, United States, and Quebec, Canada: USGS IMAP: 1898-E.

Moench R.H. and Boudette, E L., 1987, Stratigraphy of the Rangeley area, western Maine, *in* Roy, D. C., ed., Northeast Section of the Geological Society of America, Centennial Field Guide, v. 5, p. 273-278.

Moench, R. H., 1970, Premetamorphic down-to-basin faulting, folding, and tectonic dewatering, Rangeley area, western Maine: Geological Society of America Bulletin, vol. 81, p. 1463–1469.

Neil, C. D., 1998, Significant sand and gravel aquifers map of the Bethel quadrangle, Maine: Augusta, Maine Geological Survey, Open-File No. 03-98.

Prescott, G. C., Jr., 1980, Records of selected wells, springs, and test holes in the upper Androscoggin River basin in Maine: U. S. Geological Survey, Open-File Report 80-412, 84 p.

Stone, G. H., 1899, The glacial gravels of Maine and their associated deposits: U. S. Geological Survey, Monograph 34, 499 p.

Stone, G. H., 1880, Note on the Androscoggin glacier: American Naturalist, v. 14, p. 299-302.

Thompson, W. B., 2003c, Surficial geology of the Gilead 7.5-minute quadrangle, Oxford County, Maine: Augusta, Maine Geological Survey, Open-File Report 03-58, 9 p. (map published separately as Open-File Map 03-57).

Thompson, W. B., 2003b, Surficial geology of the Bethel 7.5-minute quadrangle, Oxford County, Maine: Augusta, Maine Geological Survey, Open-File Report 03-45, 14 p. (map published separately as Open-File Map 08-79).

Thompson, W. B., 2003a, Surficial geology of the Speckled Mountain 7.5-minute quadrangle, Oxford County, Maine: Augusta, Maine Geological Survey, Open-File Map 03-5, 9 p. (map published separately as Open-File Map 02-144).

Thompson, W. B., 2001, Deglaciation of western Maine, *in* Weddle, T. K., and Retelle, M. J., eds., Deglaciation history and relative sea-level changes, northern New England and adjacent Canada: Geological Society of America, Special Paper 351, p. 109-123.

Thompson, W. B., 1999, Surficial geology of the Fryeburg 7.5-minute quadrangle, Oxford County, Maine: Augusta, Maine Geological Survey, Open-File Report No. 99-8 (map published separately as Open-File Map 99-7).

Thompson, W. B., 1989, Glacial geology of the Androscoggin River valley in Oxford County, western Maine, *in* Berry, A. W., Jr., ed., Guidebook for field trips in southern and west-central Maine: University of Maine at Farmington, guidebook for 81st annual New England Intercollegiate Geological Conference, Trip B-2/C-2, p. 165-182.

Thompson, W. B., 1986, Glacial geology of the White Mountain foothills, southwestern Maine, *in* Newberg, D. W., ed., Guidebook for field trips in southwestern Maine (New England Intercollegiate Geological Conference, 78th Annual Meeting): Lewiston, Maine, Bates College, p. 275-288.

Thompson, W. B., 1984, Large glacial moraine discovered in the White Mountains: Appalachia, v. XLIV, no. 4 (Winter 1983-1984), p. 186-188.

Thompson, W. B., 1983, The Androscoggin Moraine: The Maine Geologist [Geological Society of Maine newsletter], v. 9, no. 3, p. 5

Thompson, W. B., Weddle, T. K., and Borns, H. W., Jr., in review, Revision of deglaciation chronology for the State of Maine, U.S.A.: report submitted to the MOCA North American deglacial margin chronology revision project, 6 p. and maps.

Thompson, W. B., Boisvert, R. A., Dorion, C. C., Kirby, G. A., and Pollock, S. G., 2009, Glacial geology, climate history, and late-glacial archaeology of the northern White Mountains, New Hampshire (Part 2), Trip C3 *in* Westerman, D. S., and Lathrop, A. S., eds., Guidebook for field trips in the Northeast Kingdom of Vermont and Adjacent Regions: Lyndon State College, Lyndonville, VT, 101st annual New England Intercollegiate Geological Conference, p. 225-242.

Thompson, W. B., and Locke, D. B., 2003, Surficial materials map of the Bethel quadrangle, Maine: Augusta, Maine Geological Survey, Open-File No. 03-43.

Thompson, W. B., Fowler, B. K., and Dorion, C. C., 1999, Deglaciation of the northwestern White Mountains, New Hampshire: Géographie physique et Quaternaire, v. 53, no. 1, p. 59-77.

Thompson, W. B., and Koteff, C., 1995, Deglaciation sequence in southwestern Maine: stratigraphic, geomorphic, and radiocarbon evidence (abs.): Geological Society of America, Abstracts with programs, v. 27, no. 1, p. 87.

Thompson, W. B., and Fowler, B. K., 1989, Deglaciation of the upper Androscoggin River valley and northwestern White Mountains, Maine and New Hampshire, *in* Tucker, R. D., and Marvinney, R. G., eds., Studies in Maine geology, Vol. 6, Quaternary geology: Augusta, Maine Geological Survey, p. 71-88.

Thompson, W. B., and Borns, H. W., Jr., 1985, Till stratigraphy and late Wisconsinan deglaciation of southern Maine: A review: Géographie physique et Quaternaire, v. 39, no. 2, p. 199-214.

Tomascak, P., Krogstad, E.J., and Walker, R.J., 1996, Nature of the crust in Maine, USA: Evidence from the Sebago Batholith: Contributions to Mineralogy and Petrology, v. 125, p. 45-59.

Watermulder, S., 2014, Depositional Setting and Deformation History of Central-Western Maine: Silurian Stratigraphic Revisions for the Newry-Gilead Region: Bates College Geology Department Senior Thesis, 41 p.

Willey, B. G., 1856, Incidents in White Mountain History: Boston, Nathaniel Noyes, 316 p.