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FIELD TRIP 1
THE SILURIAN-LOWER DEVONIAN VOLCANIC ROCKS OF THE
MACHIAS-EASTPORT AREA, MAINE

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This is a brief summary and road log for a one day field trip. For a detailed geologic map and a more complete summary, see the Geologic Map and Cross-sections of the Eastport Quadrangle, Maine (Gates, 1977).

Inland, these rocks rest unconformably with a basal conglomerate on Ordovician metamorphic rocks, are in fault contact with them (see accompanying field trip by A. Ludman and D. Westerman, this Guide), or are intruded by Lower to Middle Devonian (Acadian) granitic and gabbroic plutonic rocks.

These rocks are part of the coastal volcanic belt exposed elsewhere in northeastern Massachusetts, in the Penobscot Bay - Mt. Desert area, and in southern New Brunswick. The Machias-Eastport area contains the thickest (25,000 feet or more), most fossiliferous, and most complete section (Upper Llandovery to Gedinne) of any rocks in the coastal volcanic belt. The section represents deposition on the flanks of explosive submarine volcanoes and volcanic islands. As the volcanic pile grew in thickness, successive formations were deposited in increasingly shallow water until final emergence during Eastport deposition. Hydrothermal alteration with growth of chlorite, epidote and albite occurred during the volcanism and also after, probably during the Acadian orogeny.

STRATIGRAPHY

Upper Devonian


Lower Devonian

EASTPORT FORMATION (De). Basaltic-andesite flows and coarse tuff-breccias. Pink and maroon rhyolite flows, domes, tuff-breccias, bedded tuffs and shallow intrusions. Shallow-water maroon and green siltstones and shales. Brackish-water fauna of ostracodes, pelecypods, gastropods.

Gedinne:

HERSEY FORMATION (Sh). Ostracode studies (Jean Berdan) suggest Silurian-Devonian boundary lies within the Hersey formation. Maroon mudstones and siltstones. Shallow-water fauna of ostracodes, pelecypods and gastropods.

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Silurian

LEIGHTON FORMATION (Sl). Mostly gray siltstone and shale, locally limey, plus basaltic tuffs and flows, rhyolite avalanche tuff-breccias and bedded tuffs. Shallow-water marine (Salopina) brachiopod fauna with pelecypods, gastropods, trilobites. (Hersey and Leighton formations formerly classed as members of the Pembroke formation in Bastin and Williams, Eastport Folio, 1914).

Pridoli:

EDMUNDS FORMATION (Se). Pink, maroon, purple, green, white, gray dacite and rhyolite tuff-breccias (largely submarine volcanic avalanche or debris flows), bedded tuffs, flows, domes. Minor basaltic tuffs and olivine-bearing flows. Black fossiliferous shale and fine-grained bedded tuffs. Varied fauna of brachiopods, pelecypods, gastropods, trilobites, corals.

Ludlow:

DENNYS FORMATION (Sd). Dark gray, olive green, black basaltic tuff-breccias, bedded tuffs, lava flows. Keratophyric to rhyolitic tuff-breccias, flows, domes and vent breccias. Siliceous bedded tuffs and argillites. Varied fauna largely of brachiopods, with minor pelecypods, gastropods, corals.

Wenlock:

QUODDY FORMATION (Sq). Type section in the Quoddy fault block, separated from younger section by the Lubec fault zone, but inland some Su may be Quoddy. Deep-water pyritiferous, rusty weathering, siliceous siltstone and argillite with minor feldspathic ash fall laminations. Fauna of graptolites. The base of the formation is not exposed.

Upper Llandovery:

PETROLOGY

Chemical analyses and petrography indicate two strongly bimodal suites. The Silurian volcanics (Dennys to Leighton formations) consist of basalts and rhyolites (minor dacite) showing a non-iron enrichment trend on an AFM diagram. The basaltic-andesites and rhyolites of the Devonian Eastport formation form a second bimodal suite with a strong iron-enrichment trend.

The coastal volcanic belt originally was a belt of volcanic islands located along the southeast margin of the Silurian-Early Devonian sea now represented by the pelitic and clastic rocks of the Merrimack synclinorium and Fredericton trough. This margin was also probably the northwest border of the Avalonian continental block. The absence of andesites suggests that the volcanic islands were not an andesitic island arc overlying converging plate boundaries. The strong bimodalism suggests instead a tensional tectonic regime underlain by continental crust.

STRUCTURE

The two principal structures are: (1) the broad, open, faulted Cobscook anticline plunging to the east and having a steep south limb against the Lubec fault zone and a more gentle northeast limb; and (2) the Lubec fault zone, separating the Dennys-Eastport section of the Cobscook anticline from the Quoddy formation intruded by gabbro in the Quoddy block. The fault zone is about a mile wide, consists of poorly exposed, highly cleaved and locally isoclinally folded rocks, including a narrow syncline of Eastport formation. Movement on the fault occurred during the Acadian orogeny, and again during the Carboniferous.
Numerous other faults, minor folds, and a through-going northeast-trending cleavage which cuts obliquely across the Cobscook anticline are probably of Acadian age, but some of the faults bounding the Perry formation were contemporaneous with its deposition. Further faulting and folding in the Perry formation indicate post-Devonian, probably Carboniferous, deformation.

ROAD LOG

(Refer to FIGURE 1 - Machias toward Eastport)

<table>
<thead>
<tr>
<th>STOP</th>
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<td>8</td>
<td>17.8</td>
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<tr>
<td>19.3</td>
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U.S. Route 1 north out of Machias, in Parking Area just beyond the railroad tracks opposite Mack's Store. The trip generally goes up-section from the Dennys formation to the Perry conglomerate, except for a side trip to the Quoddy formation on West Quoddy Head.

DENNYS FORMATION

For the next 8 miles all outcrops along Route 1 are of the Dennys formation dipping to the southeast along the south flank of the Cobscook anticline.

2 Siliceous flows and tuffs, part of a belt 1000-4000' thick of keratophyric and rhyolitic flows, tuffs, tuff-breccias, vents and domes near the base of the Dennys formation.

3 Bedded basaltic tuffs. A lens of fossils (now completely quarried out) suggests Wenlock age. Basaltic tuffs like these and coarse basaltic tuff-breccias make up about two thirds of the Dennys formation.

4 Here, and 50 yards up the road on the right, are basaltic lavas composed of augite and labradorite with 49% SiO₂, much hydrothermally altered.

EDMUNDS FORMATION

5 Note change from dark basaltic rocks of Dennys formation to varicolored dacitic to rhyolitic tuff-breccias of the Edmunds formation.

6 Maroon basalt. Augite, labradorite and chlorite pseudomorphing olivine.

7 Highly cleaved tuff along northwest side of Lubec fault zone. The hill ahead is a gabbro sill.

8 Cleaved, isoclinally folded, fossiliferous Edmunds shale along the northwest margin of the Lubec fault zone.

19.3 Lowland area beyond the highway to the south is the Lubec fault zone. Road outcrops are of Eastport formation rocks in a block within the fault zone. The ridge beyond the lowland is gabbro intruding Quoddy shale in the Quoddy block.
STOP MILES
26.2 Texaco station. Turn right on road to West Quoddy Head.
28.9 Road forks - Keep left.

QUODDY FORMATION

9 30.1 Washington County Vocational Technical Institute. Turn left and park near buildings. Go down steep hill to the shore. Rusty weathering, pyritiferous dark siliceous argillite and siltstone of the Quoddy formation. Thin feldspathic laminations are ash falls. Graptolites indicate Late Llandovery age, oldest rocks of the entire coastal volcanic belt. If time allows, continue on road to West Quoddy Head State Park. Gabbros intrude Quoddy shale. Offshore, parallel to the coast, is the Fundy fault, the border fault of the Triassic rocks under­lying this part of the Bay of Fundy and exposed on Grand Manan Island, 7 miles southeast across the water.

Return by the same route to Route 1 at Whiting. EDMUNDS FORMATION continued.

44.1 Whiting. Turn right on Route 1. For the next 12 miles the road follows the Edmunds Formation dipping ENE along east flank of the Cobscook anticline.

10 45.8 Bedded tuffs on right overlie a coarse rhyolite tuff breccia exposed across the road and at an outcrop about 50 yards to the south on the road.

53.3 Dennys River - good salmon fishing.

11 53.8 Coarse tuff-breccia typical of Edmunds submarine avalanche deposits. Note black shale swept up into breccia as avalanche moved across muddy sea floor.

56.2 Up hill and around curve are the last outcrops of Edmunds fm. Road crosses lowlands ahead underlain by gray shales of the Leighton formation. Hills and ridges are coarse tuffs in the Leighton formation.

LEIGHTON FORMATION

56.3 Small outcrop of basalt near the base of the Leighton formation.

56.7 Small outcrop of Leighton formation gray shale.

57.6 Tuff-breccia avalanche deposit in Leighton. Road forks; keep left on Route 1. If time permits, take right fork to West Pembroke, where the Leighton formation shale is exposed along the shore.

12 58.9 Submarine avalanche tuff-breccia at the top of the Leighton formation. At the base is swirled and churned up Leighton shale. At the top is gradational contact with maroon Hersey formation siltstone.
HERSEY FORMATION

Just across Pennamaquan River is a coarse ophitic gabbro sill intruding Hersey formation, with contact metamorphism at the top of the sill.

Typical Hersey maroon mudstone. The ridge ahead is basaltic andesites of the Eastport formation.

EASTPORT FORMATION

Park just before the fence. Uphill is basal basaltic-andesitic tuff-breccia of the Eastport formation. For next 2 miles the rocks are basaltic-andesite flows and coarse tuff-breccias of the lower Eastport formation.

Thin basaltic-andesite flows with red weathered tops and red mudstone. Composed of augite, labradorite, about 55% SiO₂, and much hydrothermally altered.

Pink-maroon flowbanded rhyolite domes, flows and tuff-breccias of the middle Eastport formation continue to the next stop.

Park just beyond the fence. Cross railroad tracks to the shore and walk east. Bedded shallow-water (tidal mud flat?) shales, siltstones and conglomerates of upper Eastport formation. The northwest-trending Oak Bay fault, still apparently active according to historical seismicity data (The Maine Geologist, Vol. 3, No. 3), separates Eastport formation rocks from well foliated rocks of ? age on Deer Island, over water to the east.

Go back towards Route 1.

Turn left on small side road and stay on it. Outcrops along the road are of Eastport formation.

PERRY FORMATION

End of road. Along the shore to the north is typical Perry fluvial conglomerate deposited in a post-Acadian fault basin. The red granite cobbles are of the Acadian Red Beach granite exposed about 10 miles to the north along Route 1. The other clasts are of the Silurian-Lower Devonian volcanic section seen on this trip.

Turn around and take the 2nd left back to Route 1. On Route 1 towards Calais, the first 8 miles beyond Perry are in Perry formation, and then in Acadian granites and gabbros of the Bays-of-Maine complex which intrudes the Silurian-Lower Devonian volcanic rocks, and extends southwest to Penobscot Bay and eastward into New Brunswick.


FIELD TRIP 2
THE GEOLOGY OF THE INLAND ROCKS OF THE
CALAIS-WESLEY AREA, MAINE

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The northern limit of the Su unit on FIGURE 1 is a major contact that separates the slightly deformed, well dated, dominantly metavolcanic rocks of the coastal region from intensely deformed, poorly dated, dominantly metasedimentary rocks inland. The purpose of this trip is to examine the lithologies, structures, and contact relationships of the inland suite, and to illustrate the remaining problems of correlation. The area reported on is currently being studied by the trip leaders, and today’s trip is a report of progress of those studies.

Five stratigraphic units are recognized northwest of the Coastal Volcanic Belt, and may (?) be traceable from Wesley to Calais through intervening plutons. Portions of three of these units are dated by fossils. The oldest rocks are the Cambro (?)-Ordovician metasedimentary and minor metavolcanic rocks of the Cookson formation, and these are flanked on the northwest and southeast by apparently younger lithologies. To the southeast, the Cookson is unconformably overlain by the Silurian Oak Bay and Waweig formations; to the northwest, the un­fossiliferous (Silurian and Siluro-Devonian?) Digdeguash and Flume Ridge forma­tions appear to be faulted against the Cookson.

All units have been multiply deformed, first by upright isoclinal folding, and locally by as many as three later fold episodes. High-angle normal and strike-slip faults and a low-angle thrust have been postulated, and are thought to be in part responsible for the later folding. Interpretation of the apparent offset of major stratigraphic boundaries and metamorphic isograds suggests that the thrust was the earliest fault and was later broken by north- and northeast­trending high-angle faults. These were in turn offset by northwest-trending shears which appear to be the latest faulting event in the area.

Regional metamorphism up to biotite grade accompanied the early isoclinal folding. Emplacement first of ultramafic and mafic plutons, then intrusion of granitic bodies, produced a contact metamorphic overprint to as high as sillimanite-microcline zone. Shattering and mylonitization of the igneous rocks indicates that some faulting post-dates their emplacement. Concentration of recent seismic activity in northwest-trending zones as in Oak Bay and the Machias area suggests that this deformation continues today.

Potassium-argon dating of the earliest post-kinematic plutons yields ages of 408 and 423 million years. This brings into question the proposed age of the metasedimentary rocks and the timing of the major orogeny.

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ROAD LOG

(Refer to FIGURE 1 - Calais to Wesley)

<table>
<thead>
<tr>
<th>STOP</th>
<th>MILES</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00.0</td>
<td>Leave the municipal parking lot opposite the Calais Post Office and turn left (south) onto Route 1.</td>
</tr>
<tr>
<td>A</td>
<td>00.1</td>
<td>Turn right at the light and follow Route 1 south.</td>
</tr>
<tr>
<td></td>
<td>02.5</td>
<td>Park at the Dairy Whip on the right. Walk east to the cove and proceed south along the shore of the St. Croix River.</td>
</tr>
<tr>
<td>B</td>
<td>03.5</td>
<td>Turn right on Steamboat Street just past the St. Croix Country Club. Drive to the end of the road and park.</td>
</tr>
<tr>
<td></td>
<td>05.3</td>
<td>Turn left at the light and follow Route 1 to the north.</td>
</tr>
<tr>
<td></td>
<td>14.9</td>
<td>Turn left onto the Woodland Dump road.</td>
</tr>
<tr>
<td>C</td>
<td>15.8</td>
<td>Bear left at the ford and park near the quarry.</td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>Turn left onto the South Princeton Road.</td>
</tr>
</tbody>
</table>

OAK BAY AND WAWEIG FORMATIONS - A strongly deformed pebble and cobble conglomerate of the Oak Bay formation is exposed on the north side of the point. Clasts consist of quartzite, volcanic and plutonic rocks, and limestone. The large clasts decrease in abundance to the south, and the Oak Bay passes upward into the finer-grained metasandstones of the Waweig formation. These rocks are intruded by granitic veins associated with nearby plutons. The rocks of both formations can be directly traced ENE to Cookson Island in Oak Bay, New Brunswick.

Return to the cars, make a U-turn, and proceed north on Route 1.

COOKSON FORMATION - Variable bedded cordierite-bearing metasandstones are exposed upstream from the parking lot. Downstream, they are in contact with andalusite- and cordierite-bearing, highly carbonaceous pelites and minor black sulfidic siltstones. Suggestions as to the nature of this contact are welcome. The pelitic rocks are intensely folded and sheared.

Return to Route 1 and turn right (north).

COOKSON FORMATION - Thick but irregularly bedded cordierite-rich metasandstones displaying primary bedding features are exposed in the quarry wall and in blasted blocks. Fracturing here is related to two intersecting faults; mineralization in the fractures includes pyrite, chalcopyrite, bornite and quartz. About 20 yards east of the quarry are rhythmically and regularly bedded metasandstone and metapelite containing abundant cordierite and andalusite. Much of the thermal metamorphism is due to a layered gabbro visible across the town dump.

Return to Route 1 and turn left (north).
Proceed straight ahead onto the gravel road at the 4-corners.

**DIGDEGUASH FORMATION** - These gray, nonsulfidic graywackes which grade into dark gray, non-carbonaceous pelite are typical of the Digdeguash formation, but graded bedding is generally better developed than at this stop. The chiastolitic andalusite crystals are due to the presence of the Pocomooshine Gabbro-Diorite across the cove to the west.

Turn right onto the dirt lane and bear right at the first fork. Park at the furthest cabin and follow the path to the lake shore.

Return to the 4-corners and turn left (north).

**FLUME RIDGE FORMATION** - The variability of this unit is well displayed in the quarry. Thick-bedded calcareous metasandstone, "zebra-striped" calcisilicate granofels and biotite-rich granofels, thinly interbedded calcareous metasandstone, and metapelite are all present. The ribbed weathering visible here is characteristic of the Flume Ridge formation at biotite grade and above, but not of the chlorite grade rocks. Upright isoclinal folds in the SW part of the outcrop are refolded by steeply plunging cross-folds.

Make a U-turn and proceed south toward South Princeton.

**COOKSON FORMATION** - Outcrops are scattered along Route 9 from 45.5 to 46.7 miles. These rocks are biotite-chlorite-muscovite schists with partially retrograded cordierite and andalusite. They appear to have been foliated by movement on a northwest-trending fault, and metamorphosed by a large granite pluton which underlies the Fire Tower Hill. Rare garnet-rich units can be seen in these rocks, but are abundant in outcrops south of the tower.

Continue west on Route 9.

**DIGDEGUASH FORMATION** - Walk east along the beach past an outcrop at the water's edge of well-bedded gray metaquartzite with transsecting quartz veins which are offset along pelitic interbeds. At
the east end of the beach is a problematical outcrop. The rocks are mafic and igneous (?) but are garnet rich and possibly layered in part.

Walk 0.1 mile south to an isolated steep rise made of well-beded dark gray metasiltstone with metasandstone and metapelite interbeds. Bedding features and cleavage bedding relationships suggest that the rocks are overturned to the southeast.

Proceed by canoe, bearing S70E, to the far shore (0.2 mile). Outcrops of tightly folded metaconglomerate with finer-grained interbeds are exposed in several locations along the shore. Clasts are predominantly quartzite, with minor shale chips and volcanic fragments.

Return by canoe to the cars and drive back to Route 9.

Turn left (east) on Route 9, cross Chain Lake Stream (0.1 mile) and park. The outcrops are in the stream under the bridge.

**COOKSON FORMATION** - These rocks are predominantly metaquartzites and crenulated muscovite schists. Biotite, muscovite and chlorite of the initial foliation have been tightly refolded, with new phyllosilicates developed along the axial plane cleavage of the second folds. A third folding, best exposed downstream from the bridge, has produced gentle open folds which generally plunge moderately to the south.

Return to cars and continue east on Route 9.

Turn right (south) onto Route 192.

Turn right (west) onto a gravel road.

Cross Old Stream on a steel bridge; continue 0.15 mile west and park in the old logging road on the right. Walk west and then north to the end of the logging road. Continue due north, intersect Old Stream, and follow the shore upstream for about 1 mile. About 0.1 mile south of the mouth of Joe Hill Brook is a set of rapids with an island at the head. This is the base of the section for STOP I.

**OAK BAY and WAWEIG FORMATIONS (?)** - The base of the section consists of multiply deformed quartz pebble conglomerate with metasandstone interbeds. Downstream (up-section) the conglomerate becomes absent and minor, thick felsic volcanic units occur in a section of dominantly greenish-gray metasiltstones exhibiting two well-defined deformations. The nature of the contact between this section and the rocks of the Cookson formation to the north is not certain, but in this area it appears to be gradational. This problem will be discussed in the field.

Return downstream to the cars. Drive east back over the bridge and out to Route 192. Turn left (north) to get to Route 9, or turn right (south) to get to Route 1 in Machias.
Addendum to Field Trip 2

Numbered comments below refer to superscripts located in the preceding article.

1. References to works published since the time of this trip include:

Ludman, Allan, Ed. (1978), Guidebook for Field Trips in Southeastern Maine and Southwestern New Brunswick, NEIGC, 70th Annual Mt., Queens College Press, Flushing, New York, 183p. (This publication includes several pertinent articles.)


2. The significance of these ages was first discussed by Westerman (1973) in a GSA abstract (NE Section Mtg.), and has more recently been expanded on by Ludman (1981).

3. Permission to enter the blueberry fields should be obtained from the Gillispie family in Wesley. Great care should be taken to avoid damaging the bushes or fruit.

4. See Westerman (1978) in Ludman (1978) (referenced above) for discussion of correlation and age of these rocks.
INTRODUCTION

The purpose of this field trip is

1. To examine the different lithologic types in the Casco Bay Group in the Portland-Scarboro area;

2. To examine two critical localities for the determination of stratigraphic sequence in the Casco Bay Group; and

3. To observe the evidence for multiple deformation in the Cape Elizabeth formation of the Casco Bay Group.

Because of the uncertainty of access to two localities, as of July 15th, and further to allow for flexibility in the order in which field trip stops will be made, no road log for the field trip is given. Localities to be visited are plotted on detailed maps (FIGURE 1) accompanying the text of this field guide.

STRATIGRAPHY

The Casco Bay Group consists of a heterogeneous assemblage of rock types grouped into seven formations: the Cushing formation; Cape Elizabeth formation; Spring Point formation; Diamond Island formation; Scarboro formation; Spurwink limestone; and the Jewell formation. Lithologies of these formations are briefly summarized in TABLE I. Stops of the field trip will allow the participants to examine and study all except the Jewell formation. The rocks of the Casco Bay Group are believed to be of Cambro-Ordovician age on the basis of general lithic similarities with Cambro-Ordovician sequences in other parts of New England. Preliminary Rb-Sr radiometric ages (TABLE I) reported by Brookins and Huessey (1978) tentatively strengthen this contention. Uncertainties in the analytical data upon which these preliminary ages are based preclude using the reported ages as criteria of sequence of deposition. Primary sedimentary tops data present conflicting evidence of the stratigraphic sequence. Two of the critical localities will be examined during the trip, and the writer hopes that trip participants may advance some new insights that will help resolve the dilemma of the stratigraphic sequence of the Casco Bay Group.

STRUCTURE

The Casco Bay Group has been polydeformed, and two major episodes of folding are recognized in the field trip area. The earlier folds are recumbent and may be on the scale of regional nappé-like structures. The later folds are upright to slightly overturned and doubly plunging, and commonly exhibit axial plane schistosity. These later folds dominate the map pattern; axial traces shown on FIGURE 1 are of these later folds. The later folds are interpreted to have been formed during the Acadian orogeny. The earlier recumbent folds may also be Acadian inasmuch as initial deformation of the Silurian & Silurian (?) Merrimack Group was also recumbent folding.
The map pattern of the Casco Bay Group, dominated by the later upright folds, describes a major synclinorial structure for the outcrop belt of the Group in this area. At several localities contacts of formations can be seen to be deformed by the later folds, and consistently, at all such localities, the structural superposition of the formations is in the order given in TABLE I. If earlier recumbent folding of a regional nappe-like structure is a reality, refolding by the later upright folds involves only one limb of any such major recumbent structure.

The contacts of the Casco Bay Group with adjacent rocks of the Merrimack Group (Silurian & Silurian (?) age) is not exposed, but is inferred to be either a premetamorphic folded thrust, or an unconformity. In view of the lack of contact exposures, determination of the stratigraphic sequence of the Casco Bay Group is essential.

Major faults in the area are believed to be part of the Norumbega fault system mapped to the northeast in the Bangor region. All are post-metamorphic, but major movements appear to pre-date emplacement of calc-alkaline granites which were emplaced during the waning stages of the Acadian orogeny (Hussey and Newberg, 1978). Most of the faults in the map area are recognized on the basis of omission or truncation of stratigraphic units determined by regional mapping; however, the "Great Pond fault" (informal name for this field trip) is additionally marked by a series of silicified zones up to 15' thick, between Great Pond and the shore at Ram Island Farm.

METAMORPHISM

The Casco Bay Group has been metamorphosed from low Greenschist facies (chlorite zone) to high Amphibolite facies (sillimanite-K-spar) in a low pressure-intermediate facies series. In the field trip area the formations will be seen in two metamorphic grades - chlorite and garnet - separated from each other by the "Hunt Cove fault". Metamorphism is believed to be associated with the Acadian orogeny.

FIELD TRIP STOPS

(NOTE: MINIMAL use of hammers is requested)

STOP A. OUTCROP, SCOTTOW HILL GRAVEL PIT, SCARBORO

Directions to reach: Turn west off Route 1 in Scarboro onto Scottow Hill Road by the Beech Ridge Speedway sign. Proceed 0.4 miles and turn hard right onto gravel road that nearly doubles back parallel to Scottow Hill Road. Proceed to gravel pit, park, and walk to high ground at the north-west side of the gravel pit.

This is a registered locality in the Maine Critical Areas Program. 

A glacial pavement outcrop exposes the contact between CAPE ELIZABETH FORMATION on the west and SPRING POINT FORMATION on the east. Approximately 1 meter west of the contact a 10cm-thick graded bed indicates tops to the west, suggesting that the Cape Elizabeth formation overlies the Spring Point formation. The contact between the Cape Elizabeth and Spring Point formations appears to be conformable. Within the Cape Elizabeth formation are several folds with nearly vertically plunging axes, probably produced by refolding of earlier recumbent folds.
STOP B. TWO LIGHTS STATE PARK, CAPE ELIZABETH

Extensive shore-margin exposures here are of variably thin to thick-bedded, slightly calcareous and ankeritic metasiltstone (weathers with pale buff color due to alteration of ankerite to limonite on the weathered surface), and dark gray phyllite. These rocks are metamorphosed to chlorite grade. This is considered to be the type area for the CAPE ELIZABETH FORMATION by F. J. Katz (1917) who first mapped and named the formations. Bodine (1965) and Hussey & Pankiwskyj (1976) have considered these exposures also to belong to the Cape Elizabeth formation. Osberg (1977, personal communication) suggested to the author the possibility that these rocks are equivalent to the Vassalboro formation because of general lithic similarity, and in particular, the relatively high carbonate content. This, hopefully, will become a point of lively discussion during the field trip.

The rocks here have been poly-deformed. Early folds are recumbent, with west-over-east parasitic folds present. Graded bedding indicates that these parasitic folds are east-facing. The late folds are very gently developed upright to moderately overturned, with general bedding here dipping gently to the east.

STOP C. RAM ISLAND FARM, CAPE ELIZABETH

Seacliff and wave-cut bench exposures, almost unbroken over a distance of 3/4 mile, expose the upper part of the CUSHING FORMATION, CAPE ELIZABETH FORMATION, SPRING POINT FORMATION, DIAMOND ISLAND FORMATION and SCARBORO FORMATION, metamorphosed to garnet grade. Numerous east-over-west recumbent parasitic folds are present in the Cape Elizabeth formation; graded beds indicate that these folds are east-facing.

Question: Is this the same lithology as some of the thinner-bedded Cape Elizabeth formation metasiltstone and phyllite as at Two Lights State Park?

The Diamond Island/Spring Point formations contact, partially exposed, is interpreted to be deformed by an east-over-west parasitic fold, and by analogy with those in the Cape Elizabeth formation. These relations suggest for this locality that the Cushing formation is at the base and the Scarborough formation at the top of the sequence, which is opposite to that indicated at the Scottow Hill gravel pit locality.

Other features to be seen at this locality are numerous faults (both normal and reverse), and late Triassic (?) diabase dikes probably correlated with rifting events leading to the opening of the present Atlantic Ocean.

STOP D. CAPE ELIZABETH/CUSHING FORMATIONS CONTACT, POND COVE, CAPE ELIZABETH

The contact between light gray metafelsite tuff of the CUSHING FORMATION and thinly-to-medium interbedded metasiltstone (with minor calc-silicate) and garnet-mica schist of the CAPE ELIZABETH FORMATION is folded, and probably faulted. The principal purpose of this field stop is to continue the discussion of whether the rocks at Two Lights State Park are equivalent to the Cape Elizabeth formation exposed here and at Ram Island Farm, or whether they are Vassalboro formation equivalents.
STOP E. META-AGGLOMERATE & METATUFF, CUSHING FORMATION, DANFORD COVE, CAPE ELIZABETH

Rocks of the CUSHING FORMATION, here metamorphosed to garnet grade, retain original pyroclastic structures indicating these rocks were agglomerates and crystal tuff. The finer-grained rocks have conspicuous bluish quartz and whitish albite/oligoclase grains interpreted to be relict crystal fragments of a crystal tuff. Other parts of the Cushing formation preserve coarse fragmentary textures, indicating that the rock was originally felsic agglomerates. The agglomeratic clasts have been extremely stretched parallel to the axes of late folds.

STOP F. SPRING POINT, DIAMOND ISLAND & SCARBORO FORMATIONS, S.M.V.T.I., SOUTH PORTLAND

The seacliff along the east side of Spring Point at the campus of Southern Maine Vocational-Technical Institute exposes essentially continuous exposure between the upper part of the SPRING POINT FORMATION and the lower part of the SCARBORO FORMATION. The whole section of the DIAMOND ISLAND FORMATION, here about 100' thick, is exposed.

STOP G. CAPE ELIZABETH FORMATION, WILLARD BEACH, SOUTH PORTLAND

Seacliff exposures on the southeast side of Willard Beach, opposite Stop F, are of garnet-grade CAPE ELIZABETH FORMATION. Between these exposures and those at Stop F is inferred the South Portland fault, which is probably part of the Norumbega fault system. About one mile along strike to the southwest of this stop, the position of the fault is more closely defined, where Scarboro formation outcrops have been mapped less than 250' from Cushing Formation outcrops.

References Cited


Scottow Hill Locality, Scarboro. I now interpret the contact in the gravel pit on Scottow Hill to be between the Spring Point Formation on the east, and the Scarboro Formation (not the Cape Elizabeth Formation) on the west. The graded bed referred to in the original description of Stop A is now regarded to be in the Scarboro Formation, indicating that the Scarboro Formation overlies the Spring Point Formation. This now agrees with determinations of sequence at other localities, notably Ram Island Farm (Stop C), Chimney Rock (NE of Stop D), and the west shore of Peaks Island. The general geology of the Scottow Hill area is as modified in the map below.

REFERENCE CITED

TABLE I - LITHOLOGIES OF FORMATIONS OF THE CASCO BAY GROUP
(The formations are arranged in descending age sequence)

JEWELL FORMATION (J): Sulfidic (rusty weathering) and non-
sulfidic muscovite-biotite schist locally containing
granoard, staurolite, and andalusite; minor micaceous
quartzite; rare 15 to 20 centimeter amphibolite beds.

SPRUNG LIMESTONE (Sk): Medium gray, thinly interbedded
fine-grained marble and biotite phyllite. Typically has
appearance of ribbon candy on weathered surfaces.

SCARBO FORMATION (Sc): Same lithology as Jewell forma-
tion. Rb-Sr age 509 ± 45 million years.

DIAMOND ISLAND FORMATION (Di): Sulfidic, rusty weathering
coal-black quartz-graphite-muscovite phyllite.

SPRING POINT FORMATION (Sp): Medium greenish gray chlorite-
garnet (migmatite) phyllite; chlorite-schistcite phyllite; dark
green amphibolite with or without garnet; medium brownish
gray cummingtonite-hornblende phyllite; minor plagioclase-
quartz-garnet-biotite granulite; and quartz-plagioclase-biotite
gneiss. Rb-Sr 539 ± 50 m.y.

CAPE ELIZABETH FORMATION (Ca): Medium to light gray quartz-
plagioclase-biotite-muscovite schist with thin interbeds of
muscovite-rich schist locally containing garnet,
staurolite, andalusite, or sillimanite. The formation
includes local sulfidic, rusty-weathering schist lenses.
Rb-Sr age 495 ± 30 million years.

CUSING FORMATION (Ca): Numerous lithic types including
plagioclase-quartz-biotite gneiss locally with relic
fragmental volcanic structures; calc-silicate gneiss;
sillimanite-bearing quartz-feldspar-biotite gneiss;
amphibolite; and sulfidic rusty-weathering feldspar
biotite-muscovite schist. Rb-Sr age 461 ± 40 m.y.

FIGURE 1
PORTLAND AREA
A.M. HUSSEY II
FIELD TRIP 4
BEDROCK GEOLOGY IN THE COOPERS MILLS-LIBERTY AREA, MAINE

Kost A. Pankiwskyj
(Maine Geological Survey)
Department of Geology & Geophysics
University of Hawaii, Honolulu, Hawaii

ROAD LOG

(Refer to FIGURE 1 - Coopers Mills to Lincoln)

<table>
<thead>
<tr>
<th>STOP</th>
<th>MILES</th>
</tr>
</thead>
<tbody>
<tr>
<td>00.00</td>
<td>MEETING PLACE, in the D.O.T. picnic area at Coopers Mills, in the southeast corner of the Vassalboro 15' quadrangle, about 13.5 miles southeast on Maine Route 17 from the traffic circle on the east side of the Kennebec River bridge at Augusta. The U.S.G.S. topographic quadrangles used for this trip are the Vassalboro 15' sheet and the Razorville, Liberty, Palermo, Washington and North Whitefield 7½' sheets. Leave the Coopers Mills picnic area and turn east on Route 17. About 0.3 miles east of the picnic area are good outcrops of sillimanite-zone metasandstone and metapelite of the CAPE ELIZABETH FORMATION.</td>
</tr>
<tr>
<td>00.25</td>
<td>Route 32 branches off to the south; stay on Route 17.</td>
</tr>
<tr>
<td>00.40</td>
<td>Enter North Whitefield 7½' quadrangle; Travel Pond is to the north of the highway.</td>
</tr>
<tr>
<td>00.80</td>
<td>Turn left (north) onto an unimproved dirt road just east of the small bridge across Brann Brook, and after 200' enter the Vassalboro 15' quadrangle.</td>
</tr>
<tr>
<td>00.90</td>
<td>A dirt road branches at a right angle to the left; keep straight.</td>
</tr>
<tr>
<td>01.10</td>
<td>Another dirt road branches left; stay to the right.</td>
</tr>
<tr>
<td>01.30</td>
<td>Pull off on the road which branches to the east and park. Walk along the original road for about 100'. On the west side of the road is a boulder (!) of ultramylonite of rocks of the CAPE ELIZABETH FORMATION. There is a large outcrop of this rock on the east shore of Travel Pond which can be reached by walking out the dirt road at MILE 01.10, but the boulder at STOP 1 is much cleaner. The regional trend of the bedrock layering is N50°E, 80°NW (in this unattached boulder it is about N05°E, 55°NW). Alternating purplish and gray layers, 0.1 to 5mm thick, are composed of 90% rock flour of light colored grains and pleochroic flakes of biotite and a few percent of resolvable grains of muscovite and garnet. About 5% of larger grains of quartz and feldspar are scattered throughout this rock flour. The layers are offset by two intersecting fractures: a northeast-trending one (N20°W in this boulder) which commonly produces dextral drags; and an east-west-trending one (N40°E in this boulder) which locally produces...</td>
</tr>
</tbody>
</table>
sinistral drags, but which more commonly is a joint set which does not show offsets. The very dark layers are pseudotachylite which is isotropic under crossed polarizers.

01.80  Return to Route 17 and turn east.
02.70  Pass under high-tension power line.
03.10  Pass dirt road to north, next to cemetery; enter Vassalboro 15' sheet on Route 17.
03.40  Enter Razorville 7½' quadrangle on Route 17.
03.75  Dirt road to the left; exit Jefferson Township, enter Somerville Plantation. Outcrop is a pavement on the north side of the highway.

CAPE ELIZABETH FORMATION - Thinly laminated micaceous metasandstone and mica schist injected with quartz veins and crinkled along axial planes at N55ºW and steep. A thin seam of amphibolite either cuts across these beds or is faulted against them. Dark stringers of pseudotachylite cut across the rocks, and include rafts of angular fragments of host rock brought in during the injection of these veins.

05.55  Continue for 2.7 miles on Route 17 past Jones Corner and the Lincoln-Knox County line.
06.45  Turn north on Route 206.
08.10  Junction of Route 105; continue straight (to the north).
10.10  Exit Washington Township, enter Somerville Plantation.
10.85  Turn right (northeast) onto dirt road at Sandhill Corner.
12.45  Turn right on main road.
12.80  Road comes to a "T"; turn right (to the east).
13.25  Pass sand pits on both sides of the road.
13.40  Turn right (north) onto a dirt road at mailbox with names: Bradstreet, Cross, Hale.
14.15  Turn right, away from cleared area and houses.
14.75  Road branches. Park around the loop and walk northwest on road past house and onto a narrow peninsula in Sheepscot Pond.

Wilson Cove Member of the CUSHING FORMATION - Massive to moderately foliated, rusty weathering metavolcanics composed here of garnet, hornblende, grunerite, biotite, quartz, apatite and ore minerals. This unmistakable member of the Cushing formation has been traced from the shore of Casco Bay to the central part of the Brooks quadrangle. Typically it is at or close to the contact with the Cape Elizabeth formation. In the Liberty area this contact is
sheared and injected with veins of clear or rusty-stained quartz, commonly with cavities bearing terminated quartz crystals. Gold has reportedly been recovered from some of these veins in the local area.

16.10 Return to Bradstreet et al mailbox and turn left (to the east).
18.85 Road becomes paved.
20.00 Junction with Route 3 in East Palermo; turn right (to the east).
20.30 Exit Palermo and enter Liberty Township.

4 20.40 Park on side of road, past the white wood fence line. Outcrops are along the north side of the road and scattered in the field. Perhaps the best one is the one farthest east, characterized by prominent quartz veins on its south face.

CAPE ELIZABETH FORMATION - mylonitized metasandstone and metapelite. The metasandstone has preserved cross laminations and shows tight drag folds which typically plunge shallowly to the northeast. The metapelite is more thoroughly mylonitized and contains megacrysts of mica, quartz and feldspar. These megacrysts are folded by the drag folds and display curved extinctions in thin section. Veins of quartz and of pegmatite are typically parallel to the bedding of the metasediments, and are also folded.

22.25 Continue east on Route 3, and turn right (north) at Sherman's Corner in the Liberty 7½' sheet.

5 22.50 Park near the end of the pasture on the left side of the road, just before the blue house on the left and the long driveway on the right. Walk left (east) across top of field and follow the dirt road which starts just north of a stand of white birch. About 65 paces on this road through some alders brings one to an open field. Turn right, cross a small gully outlined by a line of trees, and continue to the low east corner of the field which has a stand of oak. Contour northeastward for about 85 paces. The first outcrop, rounded and about 100' from the lake shore, is the subject: a slice of metultramafic rocks bounded by faults. The main mass is a coarse-grained pale green/white, cut by numerous stringers of quartz. On the north side the rock is sheared and in contact with pegmatite which contains inclusions of metasediments. Crinkled metapelite of the Cape Elizabeth formation crops out near the lake shore, and also uphill north of the ultramafic sliver.

6 23.00 Return to cars and continue south toward Lake St. George. Park next to granite outcrops on right side of the road. Much better exposures occur at Sherman's Landing on the lake about 0.1 miles further along. That, however, constitutes a favorite swimming area, and the arrival of a battalion of hammer-swinging geologists might prove to be an unwelcome highlight of the weekend for the local congregation.
LAKE ST. GEORGE GRANITE - typically strongly lineated or foliated by elongate flakes of biotite and muscovite. This feature is commonly drag-folded in the same manner as the beds in the Cape Elizabeth formation, which the granite intrudes.

23.10 Continue south on the road, passing the before-mentioned Sherman's Landing.

24.10 Scattered Cape Elizabeth formation outcrops on blueberry slopes to the south.

7 25.10 In the Washington 7½' sheet, junction with Route 220. Park and proceed to the outcrops across the road from the radio tower.

SPRING POINT FORMATION - Amphibole schist. The trend of the foliation averages N55°W, steep NW dip. There is a prominent joint set at N45°W, vertical; and a shear at N35°E, 75°NW, producing dextral drag folds. These are the most common late drags in the region, and the shapes of Cargill and Washington Ponds are probably controlled by this shear orientation.

South on Route 220 is first an outcrop of thinly laminated felsic metavolcanic rocks of the Spring Point formation, drag-folded along axes plunging shallowly to the northeast. Further south are strongly rusty-weathering quartzites of the DIAMOND ISLAND FORMATION. These are characteristically charcoal gray, thinly laminated, injected with thin-to-lensoid veins of quartz and intricately drag folded, but with dominant dextral sense.

Return to cars; turn left (north) on Route 220.

28.10 Stop sign at bridge over the St. George River. Route 220 comes in from the left. Turn right (southeast) onto Route 173.

28.40 Historical Landmark - Octagonal Postoffice in Liberty Village.

28.90 Turn right (south) on Route 173. Follow south into Washington 7½' sheet.

30.40 Pass a dirt road going off to the right.

30.60 Road swings to the left.

30.75 Turn right (south) on dirt road (Prescott Hill Road).

31.15 Pond in field on the left side of the road.

8 31.20 Park and walk into field on left (southeast) side of road. Scattered outcrops of SEARMONT GRANITE and the LINCOLN SILL. A small outcrop near a juniper bush under a maple tree shows a contact between these units. The nearest outcrop to the south has veins of granite cutting across the Lincoln Sill.

31.35 Continue south to turn around via a dirt road on the right side of the road.
Retrace the route toward Liberty (into the Liberty 7½' sheet) to the turn in Route 173 (same as MILE 28.90 above). Turn right (east), away from Liberty Village.

Bridge over Trues Pond, immediately followed by Leave Liberty/Enter Montville sign.

Turn left (northwest) off Route 173 onto a dirt road.

Junction with Route 3. Turn left (to the west).

Park at outcrops on both sides of highway.

**SCARBORO FORMATION** - Richly aluminous, dark gray, weakly rusty-weathering metapelite and metasandstone. Abundant lenses of coticule stand out as pale pink. Abundant quartz veins contain pink andalusite and garnet. These minerals are also abundant in the schist, where they, along with micas, are folded around the numerous crinkles.

Continue west on Route 3.

Pass through Clark's Corner, at junction with Route 220.

Leave Lake St. George State Park on the left.

Pass through Sherman's Corner on Route 3.

Leave Liberty/Enter Palermo Township (Razorville 7½' sheet).

Boat landing at Sheepscot Pond to left of Route 3 (Palermo 7½' sheet).

Park at outcrops on the right (north) side of Route 3. Watch out for traffic.

**CUSHING FORMATION** - Dominantly pin-striped, salt-and-pepper light gray felsic metavolcanics, cut by veins of quartz and pegmatite. On the eastern end of the outcrop are amphibolites interlayered with more felsic metavolcanics. Abundant lenses contain pale green diopsidic augite, plagioclase, biotite and garnet.

Continue west on Route 3, passing Greely (44.50) and Longfellow Corners (44.95).

Turn right on road to Palermo Village.

Turn right in the Village, just past the Old Maine Country Store.

Perkins Cemetery on west side of road; stay on paved road. Pass white house on the left at 50.55 miles.

Outcrop on east side of road, and an overgrown dirt road into the woods on the northwest side of road. Park on road. Note first the road outcrop.
CUSHING FORMATION — Typical fine-grained, biotitic, salt-and-pepper felsic metavolcanic rock. Walking west on the overgrown woods road: (1) after 45 paces is a small pavement outcrop of rocks much like at road; (2) after 60 paces on the left and after 67 paces on the right are large outcrops of coarse-grained, weakly rusty-weathering kyanite-staurolite mica schist altering to chlorite-serpentine-white mica and cordierite; (3) after 95 paces, low outcrops of interbedded calc-silicate granofels and biotite schist; (4) after 100 paces, outcrops of biotitic meta­sandstone; (5) from 102 to 142 paces, gray biotitic marble. All of the above are mapped as part of the Cushing formation of the Casco Bay Sequence.

MERRIMACK GROUP — A 4-pace hiatus follows the gray biotitic marble of the Cushing formation, and for the next one mile are outcrops of purplish, pin-striped biotitic metasandstones and coarsely-biotitic metapelite, with local beds of calc-silicate granofels. These rocks are assigned to the Merrimack Group, Vassalboro formation perhaps.

Return to cars and drive a short distance to Carrs Corner, make a U-turn, and return by the former route to Palermo Village. There turn left and continue to Route 3, and turn right (northwest) on Route 3 (at 55.50 miles).

VASSALBORO FORMATION — Pin-striped biotitic metasandstone with some stringers of calc-silicate granofels. Pinching of beds produces boudins containing coarse-grained quartz and mica in the pull-apart areas. On the west side of the exposure are typical sulfidic metasandstone and metapelite of the Vassalboro formation. Many of the faults mapped within this formation are in such sulfidic units.

Continuing westward, exit Palermo/Enter China Township of Kennebec County.

VASSALBORO FORMATION — Richly micaceous garnet-sillimanite mica schist. The foliation trends N20°E, 70°NW, and contains a lineation roughly at N10°E, 15°, which is folded across axes plunging N65°W, 65°. Metasandstone beds with coticules are present. Quartz veins are abundant. The rocks range from gray to strongly rusty-weathering. A well defined shear zone passes through these outcrops and can be seen in the Vassalboro 15' quadrangle to the west as the strong lineament of Dearborn Brook and the Sheepscot River, trending about N37°E through Windsor Township.

END OF TRIP To return to Augusta, continue west on Route 3.
GENERALIZED BEDROCK GEOLOGY - LIBERTY 15' QUADRANGLE VICINITY


INTRODUCTION

This article and trip description are revisions of a preliminary guidebook that was prepared for the GSM field trip in 1980. The preliminary guidebook given to the participants during the trip consisted almost entirely of the trip log and contained insufficient discussion of the general bedrock and surficial geology of the region. Since 1980, both authors have spent another field season (1981) massaging and extending the earlier work which now permits more complete discussions to be presented.

The 1979 field work was funded by an Army Corps of Engineers contract to the Maine Geological Survey (MGS) to do a careful evaluation of the mineral potential of the region to be affected by the impoundments of the proposed Dickey-Lincoln School Lakes Project. The focus of the project, which included geochemical and magnetic surveys, was the pre-Devonian stratigraphy and surficial geology between Rocky Mountain and Seven Islands as delineated by Baudette and others (1976) who conducted a USGS reconnaissance mapping project in the late sixties, also for the Corps of Engineers. Baudette and others (1976) were successful in defining most of the important rock units in the region; the MGS project refined the bedrock map considerably in the areas of concentrated effort and produced the first surficial map of a large portion of northwestern Maine.

The present guidebook article reviews the highlights of the bedrock and surficial geology as it is understood now but no new stops are added to the itinerary. The trip area is completely forested with an elaborate network of logging roads. The road network is undergoing constant change and old roads quickly become difficult or impossible to travel. Stops scheduled in this guide are, with one or two exceptions, on main lumber roads which are generally well maintained. Users of this guidebook are reminded that virtually all of the area covered is private land and access is controlled by gates for which permission is required. At the time of this writing the North Maine Woods administers the gates. Fire permits are required by the Maine Forest Service which has a regional headquarters.

*Field work in 1979 was done while located at the University of Maine at Orono.
in Allagash. United States and Canadian customs/immigration stations are located at the Estcourt and St. Pamphile-Seven Island border crossings as well as at Fort Kent about thirty miles east of Allagash on Maine Route 161.

The road log covers portions of the Allagash, Beau Lake, Rocky Brook, Rocky Mountain, Little East Lake, and Seven Islands 15-minute quadrangles. All but the Allagash Quadrangle are published only in provisional versions.

BEDROCK GEOLOGY

A generalized bedrock map for the upper St. John River area is given in Figure 1. This map is based on 1:62,500 maps produced by Roy (1980a and 1982) that are available from the Maine Geological Survey. The distribution of formational units is largely controlled by two major strike faults, the Dead Brook and Rocky Mountain faults. Boudette and others (1976) recognized the importance of both strike and cross-strike faults in the region but the locations of faults in Figure 1 differ somewhat from the positions suggested by Boudette and others while retaining in some cases the fault names originally used. Northwest of the Dead Brook Fault is the Estcourt Road Formation which includes rocks assigned previously to the "Estcourt Road Sequence" and the "Lac Landry Sequence", as well as to a now abandoned undifferentiated unit called the "Rocky Brook Terrane". Between the faults are the Depot Mountain Formation, Fivemile Brook Formation, and the Rocky Mountain Quartz Latite. Southeast of the Rocky Mountain Fault is the Seboomook Formation which occupies the broad axial terrane of the Connecticut Valley-Gaspé Synclinorium Roy (1980b). The only exception to this pattern occurs in the Fivemile Brook area where a sliver of Seboomook lies between the Dead Brook Fault on the northwest and the Shields Branch Fault on the southeast (not labeled on Figure 1).

Both paleontologic data and structural history suggest that the formational belts become younger to the southwest (Roy 1982). The stratigraphy of the region is summarized in Figure 2. All subdivisions of formations are shown on the map of Figure 1 except for the variegated slate and quartzite (60er) of the Estcourt Road Formation whose distribution is incompletely established.

Comments on the Stratigraphy

Estcourt Road Formation

The Estcourt Road Formation (STOP B-3) is a correlative of the Quebec Group along strike to the northeast (Lajoie and others, 1968), and probably of the Rosaire Group to the west and southwest in Quebec. The thinly interlayered phyllite and quartzo-feldspathic sandstone together with massive quartzite and local limestone conglomerates suggest affinities of the Estcourt Road formation with the Cambro-Ordovician continental margin sequences typical of the western side of the Appalachian orogen. The formation is in the ensialic part of the Internal Domain the Quebec Appalachians as defined by St. Julien and Hubert (1975). Much remains to be learned about the internal stratigraphy of the Estcourt Road Formation; however, bedding transposition parallel to
BEDROCK GEOLOGY
OF THE UPPER ST. JOHN RIVER AREA

BY
DAVID C. ROY
Boston College
1982

Figure 1.

STRATIFIED ROCKS
EARLY DEVONIAN

Seboomook Formation
(Dss,Dsg)
Hafey Mountain Member (Dsh)

SILURIAN

Rocky Mountain Quartz Latite
Five mile Brook Formation
Greenstone Member

ORDOVICIAN AND/OR SILURIAN

Depot Mountain Formation
Aquagene Tuff Member

CAMBRIAN AND/OR ORDOVICIAN

Estcourt Road Formation
**Figure 2.** Generalized stratigraphic column for the Upper St. John River Area. Asterisks indicate locations of fossil localities in northwestern Maine.
the prominent slaty cleavage \( (S_1) \) that is suggestive of a melange history greatly reduces the chances of working out stratigraphy within the formation.

**Depot Mountain Formation**

The sandstone and slate of the Depot Mountain Formation are distinctive and quite similar to the rock types of the Cabano Formation of the Temiscouata area of Quebec to the northeast (STOPS B-2, B-5, and B-6). The sandstone beds are lithic graywacke composed of abundant black slate fragments which are commonly rotated parallel to the foliation. The graywacke beds range from a few centimeters to a few meters thick, are typically of medium grain size, and show features typical of turbidites. Outcrops of graywacke predominate and suggest its greater abundance but in stream exposures the relative abundances of slate and graywacke appear to be more equal. Graptolites in the Aquagene Tuff Member at Depot Mountain itself suggest a Medial Ordovician (Caradocian) age (Boudette and others, 1976) for at least part of the formation and correlation with the fossiliferous Cabano Formation and possibly also the Pointe Aux Trembles Formation along strike to the northeast suggest that it may range into the Early Silurian. Fossil locality F117 of Boudette and others (1976) is presently assigned to the Depot Mountain Formation. R.B. Neuman suggested a probable Silurian age for the collection he obtained from this locality but the fauna indicated only a definite Siluro-Devonian age.

The Depot Mountain Formation represents a southwestern extension into Maine of the post-Taconian Mistigougueche Basin (Roy, 1980b; Lajoie and Lesperance, 1968). The basin appears to have developed in the Late Ordovician and to be a northeastward extension of the late-to-post Taconian St. Victor Flysch basin (Magog Group) which St. Julien and Hubert (1975) have interpreted as a back-arc basin to the Ascot-Weedon volcanic arc. The pyroclastic rocks of the Depot Mountain Formation might reflect ash-falls and resedimented volcanic detritus from the arc. It is interesting that the Cabano Formation, which is in nearly all other respects identical to the Depot Mountain Formation, lacks the pyroclastic rocks, but the overlying Pointe Aux Trembles Formation contains volcanogenic sandstone and felsic tuff. Rocks of the Ascot-Weedon volcanic belt do not appear in northwestern Maine but may be covered by Devonian rocks along the western margin of the Connecticut Valley-Gaspé Synclinorium.

**Fivemile Brook Formation**

Between the Dead Brook and the Rocky Mountain faults the Depot Mountain is overlain by the Fivemile Brook Formation. The contact has not been observed as yet but is probably a disconformity. As seen at STOP 4 the Fivemile Brook Formation is composed of light greenish gray, calcareous phyllite with abundant thin beds and lenses of biomicrite. The sedimentary rocks suggest a shallow subtidal environment in which the corals Halysites and Favosites flourished and were commonly preserved in growth positions. Basaltic lava-flow sequences up to 1000 meters thick form mappable members within the sequence and indicate a tectonically unstable setting. The formation is pretty well dated as Late-Silurian (Ludlovian) based on the coral assemblage obtained from outcrops at STOP 4 (Boudette and others, 1976).
Rocky Mountain Quartz Latite

The Rocky Mountain Quartz Latite is a thick succession of felsic volcanic rocks that forms the highest elevation in the region at Rocky Mountain. The unit appears to consist of siliceous rocks ranging from latite to rhyolite with lesser more mafic rocks as well. Along the western slopes of Rocky Mountain the Depot Mountain Formation underlies the volcanic sequence suggesting a possible temporal equivalency of these siliceous volcanic rocks and the basaltic flows of the Fivemile Brook Formation. It is considered likely that the two suites of volcanic rocks are indeed basically coeval (Roy 1982) but they are mapped separately since the units are lithologically distinctive and the precise age range of the Rocky Mountain Quartz Latite is unknown. Felsic volcanic rocks that are interlayered with graywacke and slate at and near STOP B-5 were originally assigned to the Rocky Mountain Quartz Latite by Roy (1980a) but more recent mapping of the Beau Lake and Rocky Brook quadrangles indicates that these more northerly volcanic rocks are within the Depot Mountain Formation and are therefore presently assigned to the Aquagene Tuff Member of that formation. The presence of two felsic volcanic sequences complicates the stratigraphic picture somewhat but as presently desciribed in Figure 1 the Rocky Mountain Quartz Latite contains no interbedded sedimentary rocks and is everywhere stratigraphically above adjacent rocks of the Depot Mountain. The few outcrops of phyllite, limestone, and basalt of the Fivemile Brook Formation along the main road passing south of Rocky Mountain (east of STOP B-2; see the trip itinerary) are inferred to interfinger northward with the felsitic rocks of Rocky Mountain itself, but as yet no firm confirmation of this stratigraphic relationship is available. If in fact the Fivemile Brook Formation and Rocky Mountain Quartz Latite are of the same age then bimodal volcanism took place in the region during the Late Silurian.

There are no formal stops in the Rocky Mountain Quartz Latite in the trip itinerary but a suggested additional stop is given.

Seboomook Formation

The name "Seboomook Formation" is widely applied to virtually all gray slates and graywacke of Devonian age in northwestern Maine. Except for a few areas, mostly along the southeastern margin of the Connecticut Valley-Gaspé Synclinorium, the stratigraphy of this widespread and thick slate-rich sequence is poorly understood. Since the focus of present bedrock studies in the region has been the pre-Devonian, nothing significant has been added to the information concerning the Devonian provided by Baudette and others (1976) who first applied the name to the formation in this part of northwestern Maine. In Quebec to the northeast the same rocks are assigned to the Temiscouata and Fortin formations (Lajoie and Lesperance, 1968).

In the upper St. John River area it has proven convenient to subdivide the formation into a presumed lower graywacke-rich phase (STOPS B-7 and B-9) and an inferred upper slate-rich phase (STOP B-1) as shown in Figure 1. The Rafey Mountain Member, composed of massive quartz arenite (quartzite), appears to be within the graywacke-rich portion of the formation (STOP B-8). The age range of the formation is unknown beyond the general certainty that it is Devonian based on regional correlations and three widely scattered fossil localities of Early Devonian (Becraft-Oriskany) age reported by Boudette and others (1976).
Structure

Folds

The Depot Mountain, Fivemile Brook, and Seboomook formation which are all pelite-rich units show a single slaty cleavage that is axial planar to generally upright and nearly isoclinal folds. The folds strike N35°E and typically have shallow plunges. Bedding transposition parallel to the cleavage is rarely seen. The cleavage is considered to be regional $S_2$ and is assigned to the Acadian Orogeny of Late Early Devonian or earliest Medial Devonian age (Roy, 1982).

The Estcourt Road Formation displays at least two cleavages and therefore has experienced a more complicated structural history (Roy, 1982). The prominent foliation seen in outcrop and along which there has been considerable bedding transposition is interpreted to be regional $S_1$. This $S_1$ cleavage shows considerable variation in orientation which is attributed to later folds. $F_1$ fold closures are not commonly seen and typically are delimiting by the transposition along $S_1$. Upright to overturned regional $F_2$ folds are fairly common and are associated with an $S_2$ crenulation or slip cleavage. The $S_1$ cleavage and $F_1$ folds are assigned to the Taconian Orogeny which appears to have been an Early-to-Medial Ordovician event in this part of Maine.

Faults

Two major strike faults and several cross faults are presently mapped in the region. The two strike faults, the Dead Brook and Rocky Mountain faults, were first recognized by Boudette and others (1976) and confirmed by more recent work. As more outcrop information has become available the inferred positions of these faults have changed, especially along strike well away from their "type areas" near Rocky Mountain and Dead Brook. Both faults appear to be steeply dipping with upthrown blocks to the east. It is not certain whether they are normal or reverse faults but it is considered probable that they are reverse faults. Both faults (and the Shields Branch Fault in the southern part of area) appear to be Acadian in age since they both cut Devonian rocks, but the Dead Brook Fault may have a Taconian ancestry as well. The several northwest trending cross-faults are mapped to explain apparent offsets of the strike faults and the truncation of the Fivemile Brook belt southwest of Rocky Mountain and near Seven Islands. Some of these cross-faults appear to have strike-slip displacements and they seem to follow topographic lineaments. They are presumed to be of late-Acadian or post-Acadian origin.

SURFICIAL GEOLOGY

Field work in the summer of 1981 expanded the mapping of Lowell (1980) and allowed the production of a surficial-deposit map (Figure 3) and striation map (Figure 4) that cover the northwestern portion of Maine. Because of the forest cover and limited road access, the surficial history of the region can not be adequately covered in a short field trip. In fact, many of the features that provide clues to the surficial history are far removed from any convenient access. However, in the limited trip time two topics can be examined; till character and ice flow direction.
Till

The surface till covers nearly 75 percent of the area in a variety of morphologies and with varied textural character. Generally thin till over the uplands thickens on the north flanks of bedrock hills or in the valley bottoms. In the lowlands, hummocky moraine ("hm" of Figure 3) is the predominant cover. This unit is really a mixture of till and gravel that formed as stagnant ice disintegrated. Some of the gravel results from the fluvial activity that accompanied southeast ice retreat. Till, formed into morainal segments ("M" of Figure 3), marks former ice recessional positions. Several segments lie approximately parallel to the international boundary from St. Pamphile to Twomile Brook. These appear to correlate with extensive ice contact features present in the Little Black valley, these features seem to mark major ice still-stand positions during deglaciation.

The diverse textural character of the surface till can best be explained as resulting from differences in bedrock source, depositional processes and post-depositional modification. The till ranges in color from light brown to brown (2.5Y 5/2 - 2.5Y 5/4), in texture from sandy to silty-clayey, and is generally non-calcareous. Till in exposures below the oxidation zone is gray to dark gray (5Y 5/2 - 5B 5/1) and calcareous. Till stratigraphy in northern Maine is based on a limited number of deep exposures that show units similar to those described above. Correlation from these sections to shallow roadside exposures, where different units are present due to changes in ice flow direction, is nearly impossible.

Our understanding of the till stratigraphy has been recently improved by Becker (1982). He provides detailed descriptions of three sections on the St. John River downstream from Allagash.

Ice Flow Directions

Ice flow directions are inferred from three types of data; distribution of erratics, till fabrics, and eroded bedrock surfaces. The widespread but small number of Canadian Shield erratics (less than one percent) result from Laurentide ice that flowed into the region from the northwest or west. It is here suggested that this occurred during early phases of late Wisconsin. Striated bedrock surfaces show striae that indicate an early ice flow direction that was nearly east underlying striae that show a northward ice flow. Lowell (1980) suggested two subsequent movements to the north. Additional data show that the direction of the younger flow may relate to topographic features. For example, in northernmost Maine, ice flow appears to have been northward nearly parallel to the long axis of the Notre-Dame Mountains. However, near St. Pamphile contemporaneous flow was toward the northeast around the southern end of the mountains. These directions show deflection of ice flow around the mountain chain and later ice flow seems to have been even more controlled by topography. The last ice flow appears to have been northwestward, everywhere in the study area generally parallel to the tributary streams of the St. John River. This implies continued ice activity during deglaciation.
SURFICIAL GEOLOGIC MAP
OF THE
UPPER ST. JOHN RIVER AREA

al  alluvium
ad  ablation drift
d  delta
e  esker
hm  hummocky moraine
ic  ice contact drift
k  kame

T.V. LOWELL 1982

Figure 3.
Figure 4. Map showing ice movement directions (arrows) and trends (bars) suggested by glacial striae on bedrock surfaces in northwestern Maine.
Final Deglaciation

Final deglaciation of the area begins as thinning ice exposed the Quebec uplands and retreated into Maine. Against this margin, meltwater formed several pro-glacial lakes. These temporary features drained across the topographic slope via several routes. Numerous meltwater channels, deltas and outwash deposits mark the drainage history of this meltwater that preceded the development of the paleo-St. John River.

REFERENCES


The itinerary below is based on the two-day trip conducted in 1980 which originated in Presque Isle, Maine. The actual trip-time is about one and a half days and it is possible to do the trip from Allagash without camping overnight in the woods as indicated in the itinerary. Figure 5 is a road map showing the roads used on the trip and the main access roads from St. Pamphile and Estcourt. At all of the intersections of these roads there are signs that provide directions. Also shown and named on Figure 5 are the important streams and rivers; only some of these are indicated by signs on the bridges across them. The mileage log starts at the Allagash Historical Society building at the Dickey bridge across the St. John River.

Day One

MILEAGE

0.0 Start: Allagash Historical Society, Dickey, Maine. Follow the tar road across the St. John River.

0.9 Cross the Little Black River.

1.4 This flat surface is a Holocene delta formed at the confluence of the St. John and Little Black Rivers.

2.1 End of the tar road; continue on the gravel road.

4.1 Bear right (west).

4.4 STOP B-1: Large road cut on the left (east) side of the road at intersection. This exposure is one of the best on our route for viewing the slate-rich upper phase of the Seboomook Formation. This exposure has not been studied in detail but seems typical of the Seboomook in the St. John River Valley. The upper phase of the formation displays less graywacke than the lower phase which we will see in later stops. Here bedding and cleavage are essentially parallel but slumping disturbs much of the exposure.

Proceed on the right (west) road leaving the intersection. We have called this the "Rocky Mountain Road"; it goes by a variety of names.

9.4 Cross Johnson Brook.

9.8 Keep left (west).
Figure 5. Road map showing the major roads and water courses in the region of the field trip as well as the bedrock (B) and surficial (S) stops. Ft. Kent is about 20 miles east of the map area on route 161.
Cross Johnson Brook.

Continue straight past Nine Mile Road on the left (south).

Trail to Rocky Mt. fire tower on right (north).
POSSIBLE ADDITIONAL BEDROCK STOP: The fire tower on top of Rock Mountain is about 1.5 miles in on this road/trail. Excellent exposures of the Rocky Mountain Quartz Latite may be seen along the trail and especially at the tower itself.

Keep left (south) on a portion of the original road that is cut off the present road. The cut-off portion may be allowed to deteriorate.

Proceed north through "Rabbit Turn", a very sharp turn which is the reason this part of the road was cut off.

STOPS B-2 and S-1: Exposure of bedrock and till on the floor and walls of a borrow pit on the right (east) side of road.

STOP B-2: The Depot Mountain Formation (OSdm) is exposed in this shallow pit. The pit shows both highly weathered and fresh bedrock. The formation is characterized by dark gray to black slate interlayered with generally equal or greater amounts of dark gray, slate-chip rich graywacke. The lithic graywacke is a characteristic lithology of this unit which is a correlative of the Cabano Formation (Early Silurian) along strike to the northeast in Quebec. The best exposure of the Depot Mountain Formation is along Good Brook in the Depot Lake Quadrangle to the southwest. Polymictic conglomerate is locally abundant in the formation but is not separately mappable as suggested by Boudette and others (1976). An Aquagene Tuff Member (Roy, 1980) of the unit will be seen at STOP B-5. We are here stratigraphically below the Rocky Mountain Quartz Latite which overlies the Depot Mountain Formation and forms the core of a synclinal structure just to the east of here (Figure 1).

STOP S-1: Overlying the Depot Mountain Formation is 3 to 4 meters of till. Within the till are incorporated pieces of the underlying bedrock which are up to 3 meters in length that have been deformed during their incorporation into the till. Elongate clasts in the till have a preferred north-south orientation and dip predominantly to the south. Erratic lithology and a sandy matrix distinguish the glacially transported material from the in-place bedrock: the till/rock contact is best displayed
on the west wall. A frost wedge cast, 35cm. wide at the top, and 140 cm. deep, was observed during the summer of 1979, but subsequent activity has removed it. Till of this character occurs where the bedrock is suitable. Continue north on the old road and rejoin the "Rocky Mountain Road".

19.6 Continue straight past "Pocwock Stream Road" on the left (south).

20.7 Continue straight past "Chase Brook Road" on the right (north).

21.35 Approximate location of fossil locality Fl17 (Silurian-Devonian) of Boudette and others (1976). The locality is presently included within the Depot Mountain Formation.

23.3 Cross Campbell Branch of the Little Black River and keep right (north).

23.6 Turn left (south) at this intersection with what we have called the "Estcourt Road" since it is the main haul road between Estcourt to the north and Seven Islands and St. Pamphile to the south. Park on the west side of the Estcourt Road about 100 meters south of the intersection.

STOP S-2: Up to 1.5 m of pebbly sand with silt stringers overlies a till unit in the ditch. The fluvial unit of this exposure is associated with outwash that extends north and south of this location and is best exposed in borrow pits 0.2 miles north of this location. Beneath the sand lies a till unit with a surface color of brown-tan (Muncell color 5y 5/3, wet). Compaction depends on water saturation; with high saturation the till is soft and plastic, with low saturation the till is compact. Trying to avoid the ground water draining from the sand/till contact, approximately 50 cm. of the till should be excavated. During the excavation, note the changes in color, texture, location and abundance of soil weathering products and the degree of weathering rinds on clasts. A granite gneiss cobble was removed from the upper portion of the till during preliminary excavation.

Continue south on Estcourt Road toward St. Pamphile.

24.2 Keep left (east).

28.0 Cross West Branch Pocwock Stream.

33.1 Cross Pocwock Stream.

33.7 Pavement exposures of Estcourt Road Formation at intersection with haul road to right (west). POSSIBLE ADDITIONAL STOP (see comment at mileage 47.7)

35.1 Cross Chimenticook Stream.
MILEAGE

38.7  Major intersection with road to right (southwest; continuation of "Estcourt Road" and the way to St. Pamphile). We will come back here shortly, but, continue straight for the moment.

39.0  Turn right (southwest) onto a lesser logging road. This road may not last long and you may wish to walk.

39.4  STOP S-3: Exposures in a loading cut on the right (west) side of the road. Matrix of the upper (till) unit is sandy with some silt-rich veins. Sieving analysis of the less than 4 mm portion shows 30.4 percent gravel (4-2 mm), 29.7 percent sand (2-.0625 mm) and 34.3 percent silt and clay (less than .0625 mm). Elongated stones within the unit show a random orientation. The upper unit rests on a 40 cm thick zone of weathered rock which contains relict bedding structures. Two points to ponder: what is the mode of till emplacement; and is the rock weathering pre- or post-till deposition? The bedrock here is of the Five-mile Brook Formation.

Turn around and return to the main road.

39.8  Turn left (northwest) onto the main road. Note: A right turn here will take you eventually to the St. John River (see Figure 5)

40.0  Turn left (southwest) onto "Estcourt Road" heading toward St. Pamphile.

41.2  Keep left (more easterly of the roads).

41.8  Cross North Branch Twomile Brook.

42.6  Twomile Road on the right (west), continue straight.

44.9  Cross South Branch Twomile Brook.

47.7  Sharp turn right (west) onto Robinson Road. Note: Bedrock STOP 3 is on a logging road off Robinson Road. However, a bad bridge on the road may prevent some vehicles from crossing a small stream. If so, the rock unit will be examined at a location near the West Branch of Pocock Stream on Estcourt Road (see mileage 33.7).

49.3  Turn left (west)

49.4  Cross the first "bridge" (may be out).
Cross the second "bridge" (may be out)

STOP B-3: Pavement exposures extending for .7 miles further north along the road. The Estcourt Road Sequence (EOe). These pavement exposures display the essential features of the oldest rock unit in the area. The sequence consists of tectonically disrupted and locally thinly interlayered gray or black sulfidic slate and quartz-rich light gray, commonly calcareous, micaceous siltstone and fine-grained sandstone. The dark-colored slate predominates. Locally, as in these exposures, green and red slate as well as thick-bedded siliceous quartz arenite are present. These rocks correlate lithologically with the Quebec Group along strike to the northeast and are hence considered to be Cambrian-Early Ordovician in age (Boudette and others, 1976; Roy, 1980). The tectonic disruption of bedding results from bedding transposition during an isoclinal folding episode that produced the apparent "delimbed" fold hinges (F1) seen in some of these pavements. The Estcourt Road Sequence is therefore polydeformed; the principal cleavage here is thought to be Taconian. The Depot Mountain Formation, previously seen, does not share the seemingly pre-Acadian history displayed by this unit; thus the Estcourt Road Sequence is probably pre-Medial Ordovician and Taconian deformation of it is likely.

Note on Surficial Features: Although the pavements are not given a surficial stop number, they show several different striation trends. Trends of 5°, 56°, 87°, 140° and 180° are noted, and some of these cross-cut and thus provide relative age relationships. Discussion might center around which direction the ice moved in producing these striation trends and what were the relative changes in ice flow direction.

Turn around and return to the "Estcourt Road".

"Estcourt Road". Turn right (south).

Park near the "upper" bridge that crosses Fivemile Brook.

STOP B4: Exposures are located in the stream bed downstream from the Bridge. Stream wading is required. This series of exposures constitutes the "type section" of the Fivemile Brook Formation (Sf). The section faces downstream (southeast) and begins with the fossiliferous and cleaved argillaceous limestone and phyllite (locality P275 of Boudette and others, 1976) which has yielded Silurian fossils. Up-section are sill/dikes of basalt intrusive into the argillaceous limestone followed downstream by a series of basaltic flows and tuffs with minor interlayered sedimentary rocks. The stratigraphically highest
exposures are of cleaved limestone and phyllite again. A higher but unexposed interval of volcanic rocks is inferred based on magnetic data (Roy, 1980a). The volcanic rocks are designated the Greenstone Member (Sfg). A shallow spaced-cleavage (approx. N35W28S) is prominent in the sedimentary rocks here but as yet is not recognized elsewhere. For surficial stops 4 and 5 continue south on the St. Pamphile Road.

58.7
Four road intersection. Turn left (east).

59.5
Park near the "lower" bridge over Fivemile Brook.

STOP S-4: Just downstream from the "lower" bridge across Fivemile Brook on the west bank is a till exposure. This exposure can be broken into three units. The upper, from 0 to 115 cm. depth, contains the A and B soil horizons. Below 50 cm. the unit is a silty till with a weakly calcareous matrix of 31.6 percent gravel, 22.1 percent sand and 46.3 percent silt and clay. Wet color is 5Y 5/3. Elongated clasts positioned below 1.0 m. are randomly oriented. A sharp contact at 115 cm. marks the second unit that extends down to a gradational contact with the lower unit at 1.5 m. The matrix is loose, non-calcareous, gravely (46.8 percent gravel, 35.8 percent sand, 17.4 percent silt and clay) and tan-gray (5Y 5/4 wet).

The lower unit is a compact, gray (5B 5/1 wet) clayey till. At a depth of 3.7 m. the matrix is 22.2 percent gravel, 25.1 percent sand and 52.7 percent silt and clay. Clasts in this matrix show a very strong east-west alignment and dip to the west. Boulders exposed along this bank show the east-west orientation. Note a granite boulder situated toward the bridge from the main exposure of till.

Return to the bridge and wade upstream approximately .2 miles to another exposure on the right (east) bank of the stream.

STOP S-5: Original observation of this exposure was made in August 1979, however, sometime before a revisit in June 1980, considerable slump has revealed new faces and covered others. The two rectangles in Figure 6 indicate where contacts between various units were observed in June 1980. The uppermost stratigraphic unit is an organic-rich, silty alluvium that overlies a cobble alluvium facies. The alluvium is exposed up and down stream from the central portion of the exposure. The next lower stratigraphic unit is 1.6 m. of a brown sandy till exposed in the right portion of the face. This overlies a compact silty red till with Fe-stains along fractures. At depths greater than 1.8 m., a blue-gray compact till is present. In August 1979
Figure 6. Sketch of exposure at STOP S-5 along Fivemile Brook as seen in June 1980.

Figure 7. Sketch map showing ice-flow directions (arrows) and ice-flow trends (bars) indicated by striae on bedrock pavements along "Hafey Mountain Road" at STOP S-7. The beginning of the old haul road to Hafey Mountain itself is shown.
the brown till completely covered lenses of the gray till, and in some places the brown till extended down to the silt unit (see below). Field examination should focus on the identification of contacts between the different till units.

The blue-gray till overlies a second red till unit which also forms stringers in the blue-gray till. These tills overlie contorted sand and silt beds up to 2 m. thick. Load casts and other deformation structures are well displayed. Within this unit is a bed of massive sand. Questions to consider after examining this exposure might include: How is the stratigraphy here related to that of Stop 4? What process is responsible for the three different colored tills?

Return to vehicles at the bridge and turn around.

Return to the "upper" bridge across Fivemile Brook (at previous mileage of 57.7)

61.3 "Upper" bridge over Fivemile Brook. Proceed north on "Estcourt Road".

67.5 Turn right (east) into the old partly overgrown road. (Do not cross North Branch of Twomile Brook). This road has a hard surface, but locally has a high center...so be careful!

67.6 The field at the site of an old logging camp is our campsite. This is a nice campsite on the North Branch of Twomile Brook and care should be made to leave it looking nice.

Day Two

MILEAGE

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Leave the campsite, turn right (north) and proceed.</td>
</tr>
<tr>
<td>0.4</td>
<td>Cross North Branch of Twomile Brook.</td>
</tr>
<tr>
<td>2.2</td>
<td>Turn left (northwest) and proceed.</td>
</tr>
<tr>
<td>17.4</td>
<td>Continue straight (west) past the intersection with &quot;Rocky Mountain Road&quot;.</td>
</tr>
<tr>
<td>18.1</td>
<td>Keep left (west) to bypass the logging camp.</td>
</tr>
</tbody>
</table>
POSSIBLE ADDITIONAL BEDROCK STOP. Large pavements on left (west) side of the road near the north entrance road of the lumber camp. Exposures of limestone conglomerate in the Estcourt Road Formation.

Cross "Dead Eye Bridge" (Morrison Branch of the Little Black River).

Cross Little Black River.

Continue straight (north) past Gravel Pit Road. The gravel pits are in a large esker that drained north. POSSIBLE ADDITIONAL SURFICIAL STOP.

Continue straight (north) past "Rocky Brook Road".

Caron Curve.

Continue straight (north) past "Beaver Brook Road".

Cross Rocky Brook.

Turn left (southeast) onto "Hafey Mountain Road" (our name). Sign to Allagash.

Cross Rocky Brook.

Sharp turn to left (east).

STOP B-5: Large pavements on the left (north) side of the road. Felsic volcanic rocks of the Aguagene Tuff Member of the Depot Mountain Formation are well exposed here. A variety of textures are present here including those suggesting lithic tuff, crystal tuff, and spheriolitic tuff. Interlayered slate and lithic graywacke are also present and are common along the road near here. The sedimentary rocks, especially the graywacke, is fairly typical of the Depot Mountain Formation although the slate is usually siliceous near the volcanic rocks.

Continue straight (east) on "Hafey Mountain Road".

STOP S-6: Bedrock surfaces on left just east of the small stream. Bedrock here is felsic volcanic rock from the Aguagene Tuff Member of the Depot Mountain Formation. The fine-grained texture of these rocks is particularly well suited to the preservation of glacial polish and striations. Stoss and lee forms up to 5 cm. in height can be observed on the outcrop surface. On the stoss face, striations trend 170° and the asymmetry of the form allows a direction assignment of 350° to these striations. On the lee face, and thus protected from
the northward moving ice, are striations trending 100°. Miniature forms associated with these striations indicate ice moving from the west to the east.

Continue straight (east) on "Hafey Mountain Road".

33.0
Turn right (south) toward Allagash at "T" intersection. Road to left goes north into the Yankeetuladi Brook Valley.

33.4
STOP B-6: Exposure in a small pit on the left (northeast) side of the road. The Depot Mountain Formation (OSdm). Typical graywacke and conglomerate of the formation is exposed here together with laminated slate. We are here just northwest of the Rocky Mountain Fault (Figure 1) which we will cross shortly as we head south. Compare these rocks with the Devonian slate and graywacke at the next few stops. (Also note the character of the till overlying the Depot Mountain Formation).

Continue straight (southeast) on "Hafey Mountain Road".

35.4
Cross Little Hafey Brook.

35.6
STOP B-7: Exposure in a small pit on the right (northeast) of the road. These rocks are assigned to the lower graywacke-rich phase of the Seboomook Formation (Dsg). Gray, brown-weathering slate and gray, cleaved, brown-weathering graywacke are typical of the Seboomook east of the Rocky Mountain Fault in the Rocky Mountain area.

Continue straight (southeast) on the "Hafey Mountain Road".

36.7
STOP B-8: Pavements on the left (northeast) side of the road at the base of Hafey Mountain. Hafey Mountain Member of the Seboomook Formation (Dsh). These pavements display the siliceous quartz arenites ("quartzites") of the Hafey Mountain Member which can be traced southwest from here for about 10 miles. The member appears to be well up in the Seboomook section but its exact position is not well known.

Continue straight (southeast) on "Hafey Mountain Road".

37.3
STOPS B-9 and S-7: Pavements on the right (northeast) side of the road on the west side of Oxbow Brook.
STOP B-9: Lower phase of the Seboomook Formation (Dsg) stratigraphically above (?) the Hafey Mountain Member. Thinly interbedded slate and graywacke showing turbidite features. Facing here is to the southeast.

STOP S-7: Several exposures in the area of Oxbow Brook display glacial striations. To the west of the brook in a pit, two striation sets of 155° and 175° can be observed. Slightly bent bedrock beds in this pit suggest ice flow to the north-northwest. Exposures further confirm this and show earlier ice movement to the east (Figure 7). From this location we can see Hafey Mountain. As ice was moving toward the mountain from our location, ice flow must have been strong to move directly over Hafey Mountain.

Continue straight (southeast) on "Hafey Mountain Road".

41.3 Keep right (south) on "Hafey Mountain Road".

45.0 STOP S-8: Striated pavement north of the brook here about 15 m. off the road. The obvious trend of the striations here is 160°, but close examination shows trends of 65°, 80°, 104°, 170° and perhaps others. From other exposures and till fabric data throughout the St. John River area, Lowell (1980) interprets the evidence to suggest the following ice flow history. Early ice flow was due east. An abrupt shift to northward flowing ice was followed by a gradual shift to the northwest. Topography was largely ignored during the first two phases but it controlled the last phase.

Continue straight (southeast) on "Hafey Mountain Road".

47.7 Turn right (south) at the "T" intersection.

47.8 Check out at the North Maine Woods gate. This is the "Little Black River Gate".

49.0 Turn left (southeast) on to the tar road.

49.9 Cross the one lane bridge over St. John River to the Allagash Historical Society.

Follow Route 161 through Dickey and Allagash to Fort Kent.
Acknowledgements

The authors wish to thank the people of Allagash for their kind hospitality to us during our field work. Mr. Roy Gardner has on numerous occasions been particularly helpful as have the personnel of the Maine Forest Service. D.C. Roy acknowledges able assistance by Kevin Maher (1979) and Daniel Carey (1981). T.V. Lowell is grateful for assistance by Nick Colas (1979) and Dale Becker (1981) and wishes to thank Steve Kite who did an able job of "pinch-hitting" as trip leader on the 1980 field trip.
Introduction

The purpose of this field trip is to examine the deformational history of the rocks exposed in the Gardiner 15' quadrangle and to identify in that quadrangle, as well as the Wiscasset 15' quadrangle to the east, those structures which appear to belong to the Norumbega Fault system (Stewart and Wones, 1974). Field trip #8 by Dave Westerman will examine outcrop evidence for the extrapolation of these structures along strike to the northeast.

Trip stops in the two quadrangles have been chosen largely on the basis of their ability to demonstrate deformational history vis-a-vis depositional environments and sequence. Figure 1 shows the location of the stops and indicates the sources of the data used in its compilation.

Summary

Rocks exposed in the Gardiner quadrangle consist of metasedimentary and metavolcanic rocks of the Cushing Formation and metasedimentary rocks of the Cape Elizabeth, Vassalboro, Waterville, and Sangerville formations. Sillimanite is abundant in rocks of the appropriate composition, hence all of the rocks are at sillimanite, or higher, metamorphic grade. Chloritization during retrograde metamorphism associated with post-metamorphic faulting is locally important. Syntectonic granitic intrusives and pegmatites of Acadian age intrude all formations and in places migmatization is such that the nature of the host lithology is obscure.

Three separable fold events are recognized in the Gardiner quadrangle. The first, (F-1), involved large-scale recumbent folding associated with thrust faulting. (The major thrust which separates the Vassalboro and Cushing formations is interpreted as an earlier fault.) These early folds have very large amplitude. Near Starbird Corner in Bowdoin, transposition of bedding can be seen in the Vassalboro on the hinge of a minor F-1 fold. It seems likely that in most outcrops of the Vassalboro Formation in this area, the attitude of "compositional" surfaces defines the attitude of F-1 axial plane foliation, not of bedding. Large early recumbent folds have not been recognized in the Cushing rocks. They may be present, but lack of expression in the map pattern is due to incomplete knowledge of the "internal" stratigraphy within the Cushing Formation. Alternatively, the Cushing may record an older deformational event which has affected the Casco Bay Group rocks, but not the rocks of the Merrimack Group (see Hussey, 1978a).

The second fold event, (F-2), involved re-folding about axes which plunge gently to the northeast and southwest. The upright isoclinal structures which resulted have influenced all the rocks exposed in the Gardiner quadrangle. This re-folding is responsible for the map pattern shown by the Waterville units in
the northwestern part of the quadrangle. The youngest fold event recognized, (F-3), is evidenced by small cross folds with northwest trending axes and axial planar fracture cleavage. In pelitic units, close-spaced F-2 foliation has been chevron folded by this (F-3) event. The folds are temporally associated with the emplacement of Acadian granites and pegmatites.

Steeply dipping(?) post-metamorphic faults (dip slip components indicated on structure section AA', Fig. 1) further complicate the map pattern. These structures are indicated by mylonitization or brecciation, retrograde chloritization and/or sulfide mineralization. In a general way they account for topographic lows, the most prominent of which is the Pleasant Pond lineament. Their northeast trends suggest that they are subsidiary to a group of sub-parallel faults which trend from Casco Bay through Merrymeeting Bay on the lower Kennebec River to Palermo in the Liberty 15' quadrangle...(see trip 8). The most prominent of these structures is the Eastern River Fault exposed at Twing Point on the east side of the Kennebec River in Woolwich. Outcrops near the fault contain angular fragments of a dark fine grained material (pseudotachylite ?) in silicified zones. These zones are cut by fractures along which minor offset has occurred. These relationships are suggestive of recurrent movement on the fault. To the northeast this structure cuts the Blinn Hill granodiorite in the Wiscasset quadrangle. The granodiorite is considered a syn-tectonic intrusive. Hence, geologic mapping establishes faulting as post emplacement of the Blinn Hill granodiorite, while seismic data suggest that this structure and/or structures parallel to it are presently active.

References


<table>
<thead>
<tr>
<th>STOP</th>
<th>MILES</th>
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<tbody>
<tr>
<td>0.8</td>
<td>exposure on the left of the Mt. Ararat member of the Cushing Formation. This unit consists of biotite rich feldspathic granulites presumed to represent a sequence of metamorphosed intermediate to basic volcanics. Locally, as here, sillimanite bearing, rusty weathering pelitic volcaniclastic metasediments are interbedded with the flows. A late antiformal cross fold with its axial surface dipping 30° NE and its axis oriented 320°, 20° may also be seen in this outcrop.</td>
</tr>
<tr>
<td>3.8</td>
<td>intersection of route #24 at Richmond... the Kennebec River is straight ahead with Swan Island beyond... turn left</td>
</tr>
<tr>
<td>4.3</td>
<td>intersection of routes #24 and #197 ... bear right.</td>
</tr>
<tr>
<td>4.7</td>
<td>bridge over the Kennebec River</td>
</tr>
<tr>
<td>5.3</td>
<td>intersection of route #128 ... turn right</td>
</tr>
<tr>
<td>7.6</td>
<td>bridge over Eastern River ... Cape Elizabeth Formation crops out below the bridge and to the right. The Cushing/Cape Elizabeth contact is not exposed in this area presumably buried under glacial drift, river silts, and the soils which yield Dresden's excellent potatoes</td>
</tr>
<tr>
<td>9.8</td>
<td>private road to Carney Point ... turn right and continue down the hill. When parking please leave room for vehicles to pass.</td>
</tr>
<tr>
<td>10.1</td>
<td>excellent exposures along the Kennebec River of the Cape Elizabeth Formation and the Nehumkeag Pond member of the Cushing Formation, the latter consisting predominantly of pyroclastic metavolcanics and amphibolite. The western-most outcrops along the shore are calc-silicate bearing granulites of the Cape Elizabeth Formation; low tide exposes zones of protomylonite in which the fragments are predominantly plagioclase feldspar. Also, near the high water mark is a narrow zone of silicified breccia in which the fragments are either dark grey, flinty ultramylinite or pseudotachylite. The several fault zones exposed, or inferred, here are part of the Eastern River Fault which is the apparent strike extension of the Great Pond Fault (Hussey, 1978, p. 3). Hatheway (1969) has traced this structure through the Blinn Hill granodiorite, and to the northeast along the west shore of Weary Pond. (see Fig. 1, stop 9) ...return to main road.</td>
</tr>
<tr>
<td>10.6</td>
<td>route #128 ... turn right and continue south</td>
</tr>
<tr>
<td>11.2</td>
<td>Lincoln-Sagadahoc County line ... entering Town of Woolwich</td>
</tr>
<tr>
<td>12.2</td>
<td>small red house on left, large white house on knoll on right ... turn right by a row of mailboxes onto a dirt road ... continue on road and park north of house (12.6) ... walk west on woods road to shore at Twing Point ... The contact between garnet-biotite-muscovite-quartz schist of the Cape Elizabeth Formation and feldspathic metatuff (Nehumkeag Pond member of the Cushing) is exposed here. Approximately 50' east of the contact there is a 200' thick section of amphibolite containing plagioclase, hornblende altered to chlorite plus epidote and minor sphene, apatite, and magnetite.</td>
</tr>
</tbody>
</table>
Narrow quartz "stripes" are seen in outcrop in the amphibolite. In thin section these appear as cross-cutting, sub-parallel zones of strained quartz grains with mosaic texture and are interpreted as representing silica introduced along shear planes during faulting. The amphibolite is presumed to be the same slightly discordant (?) unit that outcrops to the north at Carney Point (see stop #1) ... Approximately 100' west of the contact there is a 20' wide zone of silicified breccia within the meta-tuff ... retrace path to main road.

13.2 route #128 ... turn left and continue north. There are numerous large exposures of the Cape Elizabeth Formation on both sides of the road.

14.2 County line, entering Town of Dresden.

14.7 private road to Carney Point (stop #1) on left ... continue north.

19.1 intersection of route #197 ... turn left

20.2 intersection of routes #197 and #24 ... turn left.

20.7 intersection of routes #24 and #197 ... continue south on route #24 through town ... (highway marker: 5070), left again at stop sign, and then immediately right onto a dirt road.

21.1 turn left, continue to shoreline of the Kennebec River opposite Swan Island.

21.3 a structurally complex outcrop of amphibolite containing plagioclase and hornblende ... This apparently discordant unit is well exposed to the east on Swan Island. On the northeast part of the island it "enters" the Kennebec River and is apparently truncated by a fault located in the River ... retrace path to intersection of route #24 and #197.

21.7 turn left and continue west on route #197 to start of trip.

25.4 park on the west side of the I-95 overpass and walk south on the entrance ramp to I-95 southbound ... The large roadcut here is in the Mt. Ararat member of the Cushing Formation. Granulites of variable lithology are folded into a series of small structures which have axial surfaces oriented 290°, 40° N. These are interpreted as late folds. Chloritization and/or slickensiding of biotite rich composition surfaces may be due to interlayer slip during folding. Pegmatities, genetically related to Acadian plutons (and perhaps the Sebago pluton) both cut, and are folded by, these structures. Moench and Zartman (1976, p. 219) have noted a similar close temporal relationship between pluton emplacement and the development of northwest trending cross folds in north-western Maine ... return to vehicles and continue west on route #197.

intersection of U.S. route #201 and #197 at Richmond Corner ... continue through intersection and west on route #197.
54

STOP    MILES
28.5    intersection of Upper Pond Road ... bear left.
29.2    outcrops of the Richmond Corner member of the Cushing Formation on left (south) side of the road. The Cushing Formation is interpreted to be in thrust contact with the Vassalboro Formation just west of this exposure.
29.8    turn right on dirt road (highway marker on stop sign: 6044) and continue north ... Exposures along the road are calc-silicate rich metasiltstones of the Vassalboro Formation.
30.6    Maine Turnpike overpass.
30.9    intersection ... turn left ... In Potters Brook to the north there are exposures of metapelite of the Waterville formation in the nose of a north plunging syncline (see Figure 1.)
31.9    Litchfield Fairgrounds on the right.
32.1    intersection ... turn right on Hallowell Road.
34.6    intersection of route #9, 126 ... turn left and proceed west.
36.5    the roadcut exposes the trace of the axial surface of an upright isoclinal, south-west plunging F-2 synform. Graded beds, if they exist at all in the Vassalboro rocks, are very difficult to read at high metamorphic grade. The rocks here are at least at sillimanite grade. However, on the north side of the road there is some suggestion that the stratigraphy "youns" away from the axial trace in both limbs of the structure. Regionally there is neither definitive paleontologic nor primary structural evidence bearing on the relative ages of the Vassalboro and Waterville formations. Interpretation of map patterns by several workers favors a younger age for the Waterville rocks ... turn around, continue east for a few hundred feet, and turn left (north) on Whippoorwill Road.
41.3    Litchfield (Purgatory) ... turn left at intersection.
41.7    turn right and continue down private road to True Cove, Cobbosseecontee Lake.
42.1    this stop is on the northwest limb of a southwest plunging F-2 antiform. The marble member of the Waterville formation is exposed along the lakeshore. To the east, in the direction of the axis of the antiform, there are exposures of the thick-bedded, garnet-sillimanite bearing metapelite which stratigraphically overlies the marble ... retrace path to the tar road and turn left.
43.1    Litchfield (Purgatory) ... turn right and continue south on Hallowell Road.
44.9    turn left on route #9, 126 and proceed east.
48.1    Spears Corner ... continue east.
51.0    I-95 overpass.
bear right onto "old" route #9, 126 (We will stop at the store located here where those who wish may purchase "fixins" for lunch. The store specializes in kippers and sardines but peanut butter and jelly are also available.)

intersection ... turn right on Pond Road.

bridge over Cobbossee Stream.

turn left on cottage access road called Military Lane and proceed slowly to the west shore of Pleasant Pond.

outcrops of impure marble and metapelite occur along the shore. Osberg (1980) considers these rocks to be part of the Vassalboro Formation. There seems little justification for this for two reasons. First, in other areas where the Vassalboro is well exposed at similar metamorphic grade, rubbly weathering impure marbles with the assemblage garnet-diopside-hornblende-calcite are not observed. In addition, where thin metapelitic intervals are seen elsewhere in the Vassalboro they are invariably sulfidic containing pyrite or pyrrhotite. Such outcrops are rusty weathering. Second, the lithologies and assemblages seen here are recognized in the Waterville Formation. For these reasons these rocks are considered to be Waterville. Exposure is insufficient to establish a map pattern for either the marble or the metapelite. However, they are tentatively considered to be part of a north plunging F-2 syncline which is truncated by a late fault whose trace parallels the axis of Pleasant Pond ... return to Pond Road and turn left.

turn left and continue east

intersection ... turn left on U.S. route #201

I-95 overpass ... to the left on both sides of I-95 there are good exposures of calc-silicate and biotite granulites of the Vassalboro Formation. To the right are low, rusty weathering, intensely sheared outcrops of garnet-sillimanite bearing metapelite. This lithology has previously been mapped as the Iron Mine Hill member of the Cushing Formation, but is here considered to be a unit in the Vassalboro Formation. Outcrops farther south on I-95 are granulitic gneisses of the Mt. Ararat member of the Cushing Formation.

turn right on dirt road ... access to gravel pit ... continue slowly and park under power line and walk along woods road up hill to the north ... Pavement outcrops under power line and in field. The rock is metapelite with several small (up to 1') rafts of amphibolite which are interpreted as Cushing lithologies tectonically emplaced within the metapelitic unit of the Vassalboro. It is uncertain whether the younger Vassalboro has been thrust eastward over the older Cushing Formation rocks (as shown on Fig. 1), or whether the Cushing has been thrust westward over the Vassalboro. If the structure southeast of Stop 6 (Fig. 1) is a north plunging syncline, as outcrop evidence suggests, then the former interpretation is correct. The unit observed here would then sole
the thrust over much of its exposed length ... return to route 201 and turn right.

66.2 outcrop to left is Vassalboro, sheared and mineralized with sulfides along the trace of a late fault.

67.2 Park, City of Gardiner, continue clockwise around park.

67.2 bear left continue down hill ... continue north through two traffic lights and across new bridge over the Kennebec River, following signs for route 9 and route 126.

68.0 turn right onto route 27 and continue south.

68.2 intersection of route 226 ... turn left

69.5 bear right at Cole's lunch and continue east

8 69.9 park cars on road and walk down dirt road to small gravel pit. ... exposures of impure marble in the bed of Togus Stream. These exposures are surrounded by calc-silicate and biotite granulites and metapelites of the Vassalboro Formation. The marble is considered to belong to the Cushing Formation ... consequently the exposures in Togus Stream represent a small "tectonic window" ... return to vehicles and continue east

71.3 Stony Meadow Brook on the left ... follows the trace of the Dearborn Brook Fault

71.5 intersection ... turn left onto route 126

74.5 Trainor Corner ... turn right

77.6 intersection ... turn left onto route 194 and continue east through Village of East Pittston

77.9 intersection ... bear right onto route 194

79.2 on left ... outcrops of amphibolite, just west of Cushing/Cape Elizabeth contact

80.5 Whitefield Post Office

80.7 turn right onto route 194 east

81.5 turn left onto Jewett Road ... outcrops of garnet-biotite-muscovite-quartz schist with some intervals of hornblende bearing calc-silicate granulite ... Cape Elizabeth Formation.

9 82.3 "T" intersection ... turn left and proceed slowly along private road to the west shore of Weary Pond ... a mylonitized zone in the Cape Elizabeth Formation. ... Thin sections show fragmented garnet porphyroblasts, partially retrograded to chlorite, and anastomosing zones of very fine-grained, granulated mica and opaque minerals crosscut with minor offset along a series of close spaced late fractures.

END OF TRIP
Introduction

During the last episode of continental glaciation (Late Wisconsinan), ice advanced across coastal Maine to a terminal position on the continental shelf, well east of the present coastline. Disintegration of the Late Wisconsinan ice sheet began between 17,000 yr. B.P. and 15,000 yr. B.P. Ice had withdrawn to a position parallel to and slightly inland of the present coastline by about 13,200 yr. B.P. Marine submergence was contemporaneous with ice withdrawal, and ice retreat was accomplished, in large part, by calving into the open sea. Withdrawal of the ice across the coastal zone proceeded rapidly, so that ice retreated from the present coast to a position well inland by 12,800 yr. B.P. Isostatic recovery resulted in the emergence that brought the present coastline to sealevel between 12,100 yr. B.P. and 11,400 yr. B.P. The pattern of moraine form and distribution suggests that rates of ice retreat were greater in western Maine — an area mostly above the marine limit, that they were in central and western Maine.

Glacial Stratigraphy

Glacial and glaciomarine deposits of the central Maine coastal zone (Figure 1a) include in ascending stratigraphic order: till, ice-contact stratified drift, subaqueous outwash, and marine silt and clay (Presumpscot Fm.) (see Figure 1b). Till occurs throughout the coastal zone, and its thickness and composition is quite variable. Lodgement and flow tills form the cores of many small moraines, and lodgement till often forms a carapace over the large moraines on the proximal slope. Locally, tills appear waterlain and are interbedded with marine deposits (Presumpscot Fm.).

Ice-contact stratified drift occurs in various forms including: eskers, kames and kame terraces. Below the marine limit, ice-contact stratified drift forms the cores of both large and small end moraines. Above the marine limit, ice-contact stratified drift forms extensive valley fills which are often transitional into broad outwash deltas and fans.

Subaqueous outwash is composed of stratified sand and gravel which often displays distinct fluvial features. These sediments are thought to have been formed by meltwater discharging from the grounding line (or ice front) of the retreating ice sheet. In many cases these sediments display evidence of deformation caused by thrusting of ice-contact deposits upward into outwash.

The Presumpscot Formation is a marine deposit of glacial rock flour. It characteristically occurs as a poorly-sorted silty clay that is gray to blue-gray in color. The average thickness of this unit is about 6-7 meters, although a maximum thickness of 40m. has been noted (Bloom, 1960). The Presumpscot is locally fossiliferous. The faunal assemblage and distribution suggest initial deposition in a cool, deep water environment which was replaced by tidal flat and beach conditions.
Figure 1a. Surficial Geologic Map of Lincoln and Knox Counties, Maine (map generalized from references cited)

- Marine silt and clay (Presumpscot Formation)
- Glaciofluvial sediments - primarily ice-frontal deltas; isolated kames and kame terrace deposits
- Glaciofluvial sediments - eskers
- Glacial till
- Directional indicator of ice movement (includes drumlins, rock drumlins, and stoss-and-lee features)
- End moraines

Figure 1b. Stratigraphy of Late Wisconsinan glacial deposits in central and south coastal Maine
The stratigraphic relationship of the Presumpscot Fm. to glacial sediments below the marine limit is complex. Although it generally overlies till with a sharp contact, thin layers of marine sediments have been observed in waterlain tills. Subaerial outwash sediments both overlie and intertongue with silt and clay of the Presumpscot, while subaqueous outwash generally underlies and intertongues with the marine sediments.

Radiocarbon dates from shells in glaciomarine sediments provide the following general chronology for deglaciation of coastal Maine:

a) Ice had retreated to the position of the present coastline in southwestern Maine by 13,800 yr. B.P., and remained in that general vicinity until 13,200 yr. B.P.

b) Ice retreat west of the Penobscot River was rapid, so that central Maine was ice-free by 12,800 yr. B.P.

c) In eastern Maine, ice retreat was interrupted by the Pineo Ridge readvance. Rapid withdrawal from Pineo Ridge resulted in deglaciation of central eastern Maine by 12,500 yr. B.P.

d) Emergence of central and southern Maine began by at least 12,200 yr. B.P. and reached the position of the present coastline by 11,400 yr. B.P. Emergence of eastern coastal Maine was complete by 12,100 yr. B.P.

End Moraines

Occurrence

End moraines and ice frontal features are found throughout the zone of late-glacial marine submergence in Maine (Borns, 1980; Smith, 1981 & in prep.) DeGeer moraines (washboard moraines) occur as regularly spaced linear ridges and are the most abundant ice-frontal feature. Larger stratified moraines and associated ice frontal deltas ("moraine banks") are interspersed between DeGeer moraines. Though these large moraines are optimally developed below the marine limit, evidence suggests that these features can also be traced inland.

DeGeer Moraines

DeGeer moraines occur as short arcuate ridges and are generally found in clusters of 2-3 to 30 or more. These moraines are composed of till, poorly sorted sand and gravel, well sorted fine sand and silt or any combination of these. Sedimentary structures within these stratified moraines suggest fluvial deposition as well as severe deformation. DeGeer moraines occur exclusively below the marine limit and generally are overlain, in sharp contact, by the Presumpscot Fm. or subaqueous outwash sediments. These moraines occur in a variety of shapes and sizes, though generally they range from 6-7 meters in height, 12-18 meters in width, and 1.5 km. in length.

Large Moraines

The form and pattern of the larger moraines closely resemble DeGeer moraines. These moraines occur as linear or arcuate ridges, many of which are "beaded" when viewed along strike. Narrow, sharp crested ridge forms (Stop 1) are generally composed of bouldery till, while the broader, beaded portions are composed of the entire assemblage of recessional sediments. Such moraines generally range in size from 10-20 meters in height, 100-200 meters in width at the base, and 0.5 to 4 km. in length. The basal units of these moraines - ice contact sand and gravel and subaqueous outwash - are severely deformed. Both of these units are overlain by lodgement till and marine sediments, implying a local readvance of ice over the moraine sediments.
Bibliography


__________, 1980, End moraines and the pattern of last ice retreat from central and south coastal Maine, (abs.) Geol. Soc. Am. Abs. with Progs. v.12 no.2 p.84


in prep, End moraines and glaciofluvial deposits of Sagadagoc, Lincoln, and Knox Counties, Maine.


The surficial geology of the quadrangles to be covered on this field trip has been mapped at a scale of 1:24,000. The original mapping by Smith and Anderson (Maine Geological Survey open-file reports) was undertaken during the early phases of the Geological Survey's inventory mapping program. Much of this work is already in need of revision. More detailed study of portions of the Union and Waldoboro East 7.5 minute quadrangles has been completed by Stemen (1979) and Jong (1980). In addition, Thompson (1979) provides a helpful general reference for the superficial geology of the entire coastal zone.

Stop Mileage (measured from junction of Routes 32, 126, and 206)

0 leave Jefferson (junction Routes 32, 126, 206: Jefferson quadrangle), proceeding north on Route 126 (and 206). Route begins in marine clay. After crossing West Branch, notice several (15-20) DeGeer moraines; Fairfield Cemetery on left (west) is located on one of these moraines. Route continues north, rising gradually above the marine clay (150-200 ft. a.s.l.) and crossing till surface.

2.4 enter Knox County

2.6 road turns east, crossing Davis Stream in marine clay, then rises onto flat surface of broad ice-frontal delta. The delta surface is at an elevation of 290+ feet a.s.l., and is the highest marine feature in the immediate area. It represents the limit of late-glacial marine submergence in this part of the coastal zone. the delta was fed by an esker that can be traced northward through low hills to Sheepscot Pond. The surface of the delta is marked by kettleholes that indicate the proximity of ice during delta construction. Distributary levees and channels are clearly visible on the delta surface. Distal delta sediments cover small DeGeer moraines.

S1A 4.6 turn right into large gravel pit. Park on upper pit level.

STOP 1A If exposure permits, we will make a brief stop to examine the delta sediments. Well-defined topset and foreset bedding has been visible in the past. The arrangement of
coarse gravel topsets overlying and truncating finer sand and gravel foresets is typical of most deltas in coastal Maine.

return to cars and Route 126. Continue east to junction with Route 220.

4.8 junction with Route 220. Turn south (right). The delta extends both east and west of the road. The esker described earlier emerges from beneath the delta and parallels Route 17 for approximately 1 mile before turning south to Medomak Pond. Though poorly-exposed south of Medomak Pond, the esker can be traced into the valley of the St. George River, where it underlies the moraines seen at stops 2, 3, and 4.

route continues south, leaving delta sediments and crossing marine clay. DeGeer moraines occur in the area of marine clay immediately north of the Medomak River.

6.2 enter Lincoln County

7.0 cross Medomak River. Route again rises above marine clay to till cover over bedrock. Within a mile or two south of the Medomak River, numerous east-west-trending DeGeer moraines occur in clusters that can be traced southward to the Waldoboro Moraine (Figure 2a).

10.1 leave Jefferson quadrangle, enter Union quadrangle.

S1 11.7 Park along shoulder of road. Be careful in walking along road to Stop 1.

STOP 1 Waldoboro Moraine This moraine was first described by G. Stone in 1899, and has been discussed by several workers since that time. It is one of the larger and more continuous moraines thus far mapped in the coastal region west of Penobscot Bay. The moraine here consists of a single till ridge 10-15 m. high and approximately 150 m. wide at the base. The ridge form is distinctly asymmetrical, with the proximal slope (north) less steep than the distal slope. The occurrence of numerous large boulders along the moraine crest is typical of both the large and small moraines of the coastal zone.

The DeGeer moraines seen both north and south of the Waldoboro Moraine are representative of those found throughout the coastal region. These features
a) occur only below the marine limit
b) tend to concentrate in topographic lows and against the flanks of till uplands
c) are controlled in their orientation by topography
d) are regularly spaced within groups

Spacing of the DeGeer moraines in this area ranges from 35 m. to 100 m., averaging 65-70 m. The moraines range in height from 1-4 m., in width from 6-15 m., and are generally less than 0.5 km. in length. The tonal difference between the moraines and adjacent ground (marine clay) observed at this locality reflects the greater permeability of the sediments
Figure 2a. Map of the Waldoboro Moraine in Lincoln and Knox Counties, Maine, showing distribution of principal moraine ridge and relationship to DeGeer Moraines. Numbers indicate field trip stops.

Figure 2b. Stratigraphy of the Waldoboro Moraine complex between Whitney Corner and White Oak Corner, Knox County, Maine.
comprising the moraines. This tonal distinction is an essential aid in mapping the moraines by use of aerial photographs.

return to cars, and continue south on Route 220.

12.0
leave Union quadrangle, enter Waldoboro East quadrangle.
road crosses thin mantle of till and marine clay over bedrock, and a series of DeGeer moraines. Note the relationship between the locations of houses and cemeteries and the positions of the DeGeer moraines.

13.6
junction with Route 1. Turn east (left) for a distance of 0.9 mi. Turn north (left) on Route 235. Road crosses marine clay then rises to till cover over bedrock.

15.7
leave Waldoboro East quadrangle, enter Union quadrangle.

16.4
Waldoboro Moraine visible to west (left) of road. Height of the distal face of the moraine here is 5-6 m. The road parallels the moraine for a short distance, crosses a small stream in marine clay, then rises onto the moraine crest for a distance of approximately 1 mi. Note the hummocky aspect of the moraine crest and the abundance of large boulders. Route turns northeast, leaving the moraine to the south. After leaving the Waldoboro Moraine, the road crosses marine clay and an area of DeGeer moraines before rising onto the esker/moraine complex at stop 2.

18.7
enter Knox County. Cross Fuller Brook.

S2 19.0
turn left into gravel pit. Park, as space permits, in gravel pit and along shoulder of road.

STOP 2 Whitney Corner Moraine Exposure This exposure is located within the Waldoboro Moraine complex (Figures 2a & 2b), here developed on an esker core. The shallow pit north of the road exposes small (3 m. high) till and gravel ridges overlain by well-sorted and stratified sand. The ridges are DeGeer moraines. The sand comprises an apron of subaqueous outwash that is traceable to the south where it intertongues with silt and clay of the marine Presumpscot Formation. Close examination of the till ridges shows them to be composed of highly deformed waterlain material. An interesting variety of sedimentary structures in the overlying sand also attests to the subaqueous origin of this unit.

Excavations south of the road expose coarse sand and gravel (esker sediments) overlain by subaqueous outwash, fossiliferous marine clay, and beach deposits. The stratigraphy of the marine and beach sediments exposed on the south face of the borrow pit (top to bottom) is as follows:

4-5 m. predominantly sand and pea gravel; cross-beds dip to SW. Basal zone of pebble and cobble gravel. Abrupt basal contact. Beach sediments washed from moraine and esker deposits.
1 m. gray plastic clay and sandy clay.

1 m. black plastic clay; wet. Mytilus zone. Tidal flat. 11,760 ± 105 y. B.P. (DIC-1600).

2 m. gray plastic clay; moist. Abundant fauna, though less so than Mytilus zone (more species, fewer shells). Abundance of shells diminishes with depth. Few thin sand lenses. 11,720 ± 125 (DIC-1599).

2.5 m. barren clay zone. Upper part plastic, becoming less so with depth. Sand lenses common. Basal contact abrupt.

Undet. well-sorted medium-coarse gray brown to brown sand. Subaqueous outwash.

Fauna collected from the marine clay include: Chlamys islandicus, Hiattella arctica, Macoma sp., Mya truncata, Mytilus edulis, Natica clausa, Neptunea sp., Serripes groenlandicus, barnacles, echinoids, bryozoa, and crabs. The radiocarbon dates on shells probably record the rapid influx of fauna during a late phase of marine submergence following ice retreat.

return to cars, and continue northeast for 0.1 mi. on Route 235. Turn southeast (right) on unmarked road. Rise to moraine crest. Shallow excavations on right expose beach deposits seen at stop 2. Road descends distal slope of moraine, crosses marine clay, then rises to next moraine crest.

park along shoulder of road. Be careful crossing to the gravel pit on the east (left) side of the road.

STOP 3 Waldoboro Moraine This is probably the lateral equivalent of the moraine seen at stop 1. Recent excavations both east and west of the road expose the stratigraphy and structure of the moraine, and provide a clear picture of the interrelationships of the moraine sediments. The generalized stratigraphy of these pits is shown in Figure 2b.

In the gravel pit on the east side of the road, till, comprising the proximal slope of the moraine, overlies deformed sand and gravel, considered to be both esker and subaqueous outwash sediments. Immediately to the north of this exposure, marine clay overlies the till. Of particular interest here is the nature of the till, best seen above the east face of the exposure. The till actually consists of a variety of genetic types, including lodgement till and basal melt-out till. Interbedded fine sand and silt within the till suggest that it was deposited, in part, in a subaqueous setting. Small-scale shearing, both within the till and within the washed sediments indicate that ice was active during moraine construction. The till, itself, has been thrust southward over the underlying esker and outwash sediments. These latter sediments display both large- and small-scale shear phenomena as well as collapse structures related to melting ice. It should be noted that the till extends only to the moraine crest, forming a carapace over the
proximal (north) slope of the moraine. The possible mechanisms of moraine formation can be discussed as we examine the deposits at this stop.

Cross road and enter pit on the west side of the road. The till in this pit is not well-exposed. Most of it has been removed as overburden. However, the character of the underlying sedimentary sequence is well-exposed. Sedimentary structures within this sequence indicate chaotic and very rapid deposition of these materials. Again, large- and small-scale shear structures indicate the presence of active ice during moraine formation. An overall decrease in grain size toward the distal (south) face of the moraine has been recorded here. Intertonguing of sand (moraine sediments) and clay (Presumpscot Formation) can be observed along the south face of the exposure.

return to cars and continue southeast for 0.8 mi. to White Oak Corner. Turn sharp left and drive north for 0.3 mi.

turn west (left) into large gravel pit. Park to the side of the main pit access road.

STOP 4 White Oak Corner Esker Exposure Over the years, this pit has provided perhaps the clearest picture of moraine stratigraphy in the immediate area. The pattern of gravel excavation have presented a unique opportunity to view the moraine and the esker in all dimensions. The esker core, exposed in the main pit, is overlain by till and marine sediments. Till fabrics collected from the proximal slope of this moraine average $N35-40^\circ W$, paralleling the younger set of striae on nearby bedrock outcrops. Thrusting of ice-contact (esker) gravel upward into the overlying sand has been observed at several stages in the development of the pit. The upper sand is interbedded with marine clay south of this exposure.

A casual walk through the several coalescing pits will permit a general overview of the stratigraphy seen during the morning, and will provide an opportunity to discuss any particular points of interest or to answer any questions.

return to cars and to the road. Turn north (left).

join Route 235. Much of the route between here and Union skirts the marine clay/till contact. DeGeer moraines can be seen east (right) of the road.

End of trip. Provisions for lunch can be purchased at the general store in the center of the village.
Post-Acadian Brittle Fracture in the Norumbega Fault Zone,
Brooks Quadrangle, Maine

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Introduction

This field trip is designed to examine a variety of rocks in a small segment of the Norumbega fault zone within the Brooks quadrangle. The stops for this trip have been selected to focus on evidence suggestive of movement along brittle fracture surfaces subsequent to the most recent significant folding episode, the Acadian Orogeny during the Devonian.

Stratigraphy

This section deals with the lithologic character of the rocks in the quadrangle and their regional correlation, but thorough coverage of these topics will not be attempted due to the complexity of the situation. Before discussing the rock units, a few words are in order about the geometric configuration in which they occur. The quadrangle is transected by the Norumbega fault stratigraphic units are separated by faults associated with this zone.

The oldest rocks in the area are located in the southeastern third of the quadrangle. They are thought to be Precambrian in age (see Bickel, 1976 for amplification), and are generally feldspathic schists and gneisses. These rocks belong to the Passagassawaukeag Formation (Bickel, 1976) which was formerly described as the Knox Gneiss by Perkins and Smith (1925), and they are restricted to the crestal portion of the Liberty-Orrington anticline of Osberg (1974). The metamorphic grade of these rocks is sillimanite and higher (Bickel, 1974), and they are highly variable in their lithologic character.

The next unit northwest of the Precambrian age rocks is the Cape Elizabeth Formation. The use of this terminology is after Pankiwskyj (1976) who mapped the Liberty Quadrangle to the southwest. These rocks have previously been assigned to the Hogback Schist (Perkins and Smith, 1925) and they probably correlate with rocks assigned to the Copeland Formation in the Bucksport Quadrangle to the east. The dominant rock type of this formation is a quartz-feldspar-biotite gneiss interlayered with biotite-rich schist. Subordinate lithologies include purple and green calc-silicate gneiss, chlorite-rich schist, and metaquartzite. Outcrops of this formation are locally restricted to the Norumbega fault zone. The age of these rocks is thought to be Cambro-Ordovician based on radiometric dating to the southwest (Brookins and Hussey, 1978), which is in agreement with the earlier conclusions of Bickel (1976).

Occurring further northwest are rocks which Pankiwskyj (1976) correlated with the Cushing Formation, and they are here interpreted to be in fault contact with the Cape Elizabeth Formation. Fine-grained, commonly laminated, quartzofeldspathic biotite gneisses and schists are the dominant lithologies, but the consistent occurrence of rusty, sulfidic schists characterizes this formation. Relic sedimentary structures are rare, except for lithologic layering reflecting bedding. The Cushing Formation is considered by most workers to be Cambro-Ordovician in age and older than the Cape Elizabeth Formation (Newberg, pers. comm.).

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The youngest rocks in the Brooks quadrangle belong to the Vassalboro Formation and are considered to be Silurian in age (Osberg, 1980). Interbedded, slightly calcareous metasediments and massive quartz wackes are the dominant lithologies, and they have been metamorphosed to chorite and biotite grade (Bickel, 1974). These rocks occur both on the northwest side of the NFZ and as fault-bound slices within the zone.

Structure

The Norumbega fault zone trends N50 E across the quadrangle, extending all the way to New Brunswick, Canada in one direction and at least to the Atlantic Ocean in the other direction where it probably continues under water and emerges north of Boston. In the small 15 mile segment with which this report is concerned, the zone is a major tectonic boundary between the Merrimac synclinorium and the Liberty-Orrington anticline, with the Casco Bay Group caught up in the boundary. The current geometric configuration of formational units adjacent to and within the fault zone is thought to be the result of right-lateral, strike-slip movement between two major tectonic blocks, subsequent to the folding of those rocks. Stewart and Wones (1974) report similar movement directions east of Penobscot Bay within this fault zone.

The foliations of the lithologic units trend parallel to the fault zone, but these units tend to terminate along strike. These terminations occur at splays off the primary faults, trending N5-25E with right-lateral movement. Well-developed, small scale Z-folds are particularly abundant near these splays and have their axial planes oriented parallel to the splays. The results of this combination of faults include the repetition of the section across strike and inclusion of Vassalboro rocks within the fault zone. Minor structural features such as drag folds and slickensides have been used to determine movement directions, and these are compatible with the interpretation of the map distribution of formational units and with associated small scale folding.

The recent occurrence of earthquakes within and adjacent to the Norumbega fault zone (see Figure 1) suggests that it continues to be a zone of movement, which has been active for 100's of millions of years.

References


**Perkins, E.H. and Smith, E.S.C.** (1925), *Contributions to the geology of Maine, no. 1; A geologic section from the Kennebec River to Penobscot Bay:* Am. Jour. Sci., v. 9, pp. 204-228.


**Stop** | **Miles** | Description
--- | --- | ---
0.0 | | Starting at the junction of Maine routes 220 and 137 in Knox Corner, head east on route 137.
4.8 | | Turn left toward Ray Corner, heading north.
10 | 7.0 | Park along the right side of the road (after obtaining permission at the nearby farm) and walk south to Marsh Stream where it crosses the Brooks/Knox township line. The Sunny Side fault of Bickel (1976) here separates two members of the Cape Elizabeth (Hogback Schist) Formation. Biotite-muscovite-quartz-garnet schist on the southeastern side of the fault exhibits undulatory fracture cleavage with chattery surfaces suggesting right-lateral movement. On the northwestern side of the fault are purple and green metasandstone "gneiss" and dark gray phyllitic metasiltstone. Deformation in these rocks is multiple and complex, but the youngest fracture set parallels the axial planes of small Z-folds. These fractures trend N16 E, V, and they are common throughout the Norumbega fault zone...Return to the cars and continue north.
8.5 | | Turn left (west) on Maine route 139.
11.9 | | Turn right (north) at Knox Corner.
11 | 12.1 | Park along the roadside. Rusty, sulfidic black schist assigned to the Beaver Ridge Member of the Cushing Formation (after Pankiwskyj, 1976) are exposed along the road along with black mylonite (?). These rocks exhibit small-scale drag folds parallel to the mylonite-schist contact, and the sense of motion is right-lateral. Quartz veins are common in the mylonite. (Exposures back at Knox Corner are of the sulfidic schist with an anastromtizing vertical cleavage trending N35 E, and a notable absence of joints.) Turn around, return to route 139 and turn left (east) toward Brooks.
18.0 | | Continue through Brooks on route 139 (Exposures of the Cape Elizabeth Formation are excellent in Marsh Stream just below
the bridge in Brooks.)

12 21.2* Park along the side of the road (route 139) at Pattee Corner. This outcrop is in a fault-bound slice of rocks thought to be part of the Vassalboro Formation. Other outcrops within this slice are typically well-bedded, fine-grained metasiltstones with bedding parallel to the fault zone, but at this stop the rocks differ from the norm. They are very fine-grained, dark gray, non-foliated cherty rocks with brecciated texture. Mineralized shear surfaces covered with quartz and chlorite are slickensided indicating right-lateral movement within this zone. Continue east on route 139 to Monroe.

25.4 Turn left (north) and drive up the west side of the North Branch of Marsh Stream.

27.1 Bear right across the bridge.

27.6 Sharp turn to the left (west).

13 28.3* Cross Chase Stream.

28.8 Park along the side of the road at the brick farmhouse (obtain permission). Outcrops on the south side of the road are located in the northern margin of a fault-bound slice of the Cape Elizabeth Formation, and are here characterized by being sulfidic. These schists vary in color from light to dark gray as a function of increasing degree of cataclasis. Varying amounts of quartz occur as pods and stringers, and crenulation drag folds parallel the foliation and quartz stringers indicate right-lateral motion. Turn the cars around and retrace your route to Monroe.

14 32.2 Turn left on Maine route 139, drive through Monroe, across the bridge, take your first right and park. Outcrops are exposed in and along Marsh Stream. A variety of rocks of the Cape Elizabeth Formation are exposed here, including migmatitic gneiss, purplish gray metaquartzite (laminated and massive), biotite-muscovite-quartz schist with quartz veins, and a mylonitized felsic sill (?). The beds are very steeply dipping and Z-folds can be seen in the schist. Several faults can be observed. One oriented N55W, 85N shows one foot of apparent right-lateral offset, and this fault surface has subsequently been offset ten inches parallel to the bedding (N40E, 86E).... Turn the cars around and continue east on Maine route 139.

33.8 Drive straight through the four corners, leaving route 139 and heading northeast.

15A 34.1 Park along the side of the main gravel road and walk southeast up the woods road through a field. At the far edge of the field where the road bends to the right, continue southeast up toward the crest of the hill. The set of outcrops located here consist of cataclastically sheared biotite-feldspar gneiss. Fresh surfaces of hand specimens show very angular fragments of feldspar up to 1.5 cm in diameter "swimming" in a schistose matrix of black biotite.
Return to the cars and continue northeast a short distance.

Park along the road across from the only house and obtain permission to walk northwest down their woods road.

Outcrops in this area have been mapped by Griffin (1972) as ultramylonite at the triple point between the Vassalboro Formation on the northwest side of a major fault and the contact between the Knox Gneiss (Passagassawaukeag Fm.) and the Winterport intrusive on the southeast side. This is an exploratory stop.

The woods road takes you down hill about one third of a mile to a pronounced dip with clearly visible silicified quartz breccia exposed on your right on the southeast flank of the small knoll immediately in front of you. This exceptionally well-developed silicified zone in the Cape Elizabeth Formation exhibits repeated brecciation and re-silicification so that in places, no recognizable fragments of the stratigraphic horizon remain. The percent added silica drops off rapidly to the northwest. Stops 15A and 15B are located on opposite sides of a principle trace of the Norumbega fault zone.

Addendum to Field Trip 8

Figure 1 for this trip is combined with Figure 1 for Newberg’s Trip 6. At the time the guide was first printed, three epicenters were included on Figure 1: one near Bath, one near South Windsor, and one near Monroe. Six more epicenter locations have been added to the current edition of the Figure. All epicenter data comes from quarterly publications out of Weston Observatory, the data center for the Northeast U.S. Seismic Net.
FIELD TRIP 9

Plutonism and Post-Acadian Faulting in East-Central Maine

by

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04333

and

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24061

Introduction

This field trip is designed to examine the textural and mineralogical variations of several plutonic rock suites in eastern Maine. In addition, several stops will look at deformation associated with the Norumbega fault zone (NFZ) (stops 1, 4), and the Sunnyside fault (stop 3), and one stop will examine the fault contact between the Ordovician Penobscot formation and the Vassalboro/Bucksport terrane (stop 7). Related field trips that may be of interest include Stewart and Wones (1974), Wones (1974), Ayuso and Wones (1980), Ludman (1981), and Westerman (1981).

Summary of Stratigraphy

Eastern Maine at the latitude of Penobscot Bay can be divided into a series of NE-SW trending lithologic belts. From northwest to southeast these belts consist of: the Vassalboro terrane, an extension of the central Maine stratigraphy defined by Osberg (1968, 1980). Osberg extends this terrane southeast of the Norumbega fault zone to the Ordovician Penobscot formation, hence the designation of Sv(?) for the slightly calcareous siltstones and pelites within and southeast of the NFZ. Stewart and Wones (1974) distinguish two additional fault bounded lithologic belts: the Precambrian(?), Passagassawaukeag gneiss terrane (Bickel, 1971; 1976), coincident in part with the Liberty-Orrington anticline of Osberg (1974), and the belt consisting of the Bucksport formation of Wing (1957). In this interpretation the outcrop areas of Sv(?) south of the Norumbega fault zone belong to the Bucksport formation; slices of Sv(?) within the NFZ may be either Vassalboro formation or Bucksport formation (which is lithologically identical to the Flume Ridge formation of Ruitenberg and Ludman (1978)). The lithologic similarity of the Vassalboro and
Bucksport formations (slightly calcareous quartz-wacke and quartz-mica phyllite and schist) make a lithologic correlation tempting, but the possibility of significant post-Acadian movement along the Norumbega fault zone make the cross-strike correlation uncertain.

The Vassalboro/Bucksport terrane is separated from the Ordovician Penobscot terrane to the southeast by a thrust fault (stop 7). The rusty-weathering schists of the Penobscot formation are probably equivalent to the Cookson formation to the northeast (Ruitenber and Ludman, 1978). The Penobscot block is separated from the Cambro-Ordovician Ellsworth terrane to the southeast by a major strike-slip fault zone, the Turtle Head fault zone (Stewart, 1974).

Regardless of the number of lithologic belts or the significance attached to particular fault zones, it is clear that this portion of eastern Maine is composed of several (3 to 5) discrete fault bounded lithologic blocks probably assembled during a continental collision in the early Paleozoic.

**Plutonic Rocks**

Plutonic rocks examined during this field trip are all post-Acadian in age and cut all of the above mentioned lithologic belts except the Vassalboro terrane (used in the restricted sense). The Lucerne, Lead Mountain, and Cranberry Lake plutons are all cut by and separated from the Vassalboro terrane (restricted) by the Norumbega fault zone.

All three granites are coarse grained, alkali-feldspar rich varieties, with high K and Rb contents, high Rb/Sr ratios, and low K/Rb ratios. In spite of modal and chemical similarities, the granites differ significantly in accessory mineralogy, Sr and O isotopic composition, and probable source material (Loiselle and Ayuso, 1979; Wones, 1982; Loiselle et al., 1981, Wones et al., 1981).

The Lucerne pluton is a biotite granite, and consists of both a coarse grained seriate and porphyritic facies. Post-intrusion faulting (along the E-W Sunnyside fault) and erosion has exposed two levels in the pluton; the northern, or higher, level contains the central porphyritic facies, has slightly greater Fe/(Fe + Mg), and lower total (Fe + Mg). Examination of whole rock and mineral chemistry suggests emplacement and crystallization at between 650° C and 700° C and 1-2 kilobars total pressure. The magma was not saturated with vapor until very late in its crystallization history (Wones, 1980). Major and trace element chemical data combined with Sr and O isotopic data suggest a greywacke source material for the Lucerne magma.
The Lead Mountain pluton is similar to the Lucerne pluton in its coarse grain size and alkali-feldspar rich nature, but amphibole is present as an accessory mafic phase and the late crystallization of biotite indicates a much lower water content for the magma. Sr and O isotopic data indicate a different source material for the magma, possibly an intermediate plutonic rock such as a granodiorite or quartz monzonite.

Very little is known about the Cranberry Lake pluton, partly due to limited exposure. It appears more similar to the Lucerne pluton than the Lead Mountain pluton (no amphibole, relatively early crystallization of biotite).

The alkaline monzonite of Parks Pond cuts the folded sediments of the Vassalboro/Bucksport terrane, and is in turn cut by the Lucerne pluton. Mineral chemical data indicate a very high temperature of intrusion (in excess of 1000°C) under essentially anhydrous conditions. It is extensively mylonitized by the Norumbega fault zone.

The porphyry at Spruce Mountain was first mapped on a reconnaissance basis three years ago, and its relation to the Lead Mountain or Cranberry Lake plutons (if any) is unknown. It appears to be texturally uniform over its outcrop area, and it is not known if it represents the marginal zone of a larger body or is a small, quickly chilled body.

The three alkali-feldspar rich granites are markedly different from the olao-alkaline Center Pond pluton (Scambos and Loiselle, 1979, 1980) and Bottle Lake complex (Ayuso, 1979, 1982; Ayuso and Wones, 1981) north of the Norumbega fault zone. Loiselle and Ayuso (1979), Ayuso et al. (1980), Loiselle et al. (1981), Wones et al. (1981), and Wones (1982) suggest that the Norumbega fault zone is a major crustal fracture at depth, separating two very different source regions for the plutonic rocks exposed northwest and southeast of the NFZ. The juxtaposition of the different source regions may have taken place prior to the Silurian, and the post-Acadian movement along the Norumbega fault zone may be a reactivation of the earlier major crustal suture.

References Cited


et al., and Wones, D. R., 1980, Geology of the Bottle Lake Complex, Maine: NEIGC Guidebook, p. 32-64


Ludman, Allan, 1981, Stratigraphy, structure, and progressive metamorphism of Lower Paleozoic rocks in the Calais area, southeastern Maine: NEIGC guidebook, p. 78-101


Addendum to Field Trip 10

Two modifications must be made to the field trip text and road log. The first of these deals with the stratigraphic summary presented in the text; Osberg (personal communication) has revised the central Maine stratigraphy and no longer argues strongly for the correlation of sedimentary rocks north and south of the NFZ. By this he does not imply that significant post-Acadian faulting has juxtaposed radically different Siluro-Devonian terranes, but the term Bucksport formation will remain in use.

Secondly, while it was mentioned in the text and road log that the Cranberry Lake granite differed from the Lead Mountain granite and was more similar to the Lucerne granite in texture and mineralogy, further field and petrographic investigations have shown that the Cranberry Lake granite is actually very similar to the Lead Mountain granite, and ground magnetometer traverses have indicated that the two bodies may be connected along their southern contact. The Lead Mountain granite was originally termed the Deblois granite by Gilman (1961); in view of the textural and petrographic similarities and the precedence of this name (Deblois), we suggest that both bodies (formerly the Lead Mountain pluton and the Cranberry Lake pluton) revert to the name Deblois.

Road Log

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Assembly Point: Sampson's Supermarket, Rt. 15, Brewer, just south of the junction of Rts. 1-A, 15, and 9. Turn right (south) on Rt. 15.

Outcrops of Sv (Vassalboro formation) on left (east) side of Rt. 15.

Orrington town line.

RR crossing. Outcrops of Sv(?) on the left (east) side of Rt. 15. These outcrops are in a northern slice of the Norumbega Fault Zone, and show considerably more evidence of brittle deformation than exposures of Vassalboro formation in the Brewer and Bangor area.

At this location the rocks consist of calcareous silts interbedded with rusty-weathering pelites. Compositional boundaries were probably sedimentary originally, but are now slip-cleavage surfaces striking N55°E, dipping NW. A set of kink bands striking N20°W are also present (Stewart and Wones, 1974).

Outcrops of Sv(?) on right (west) side of Rt. 15.

Exposures of OCc (Copeland formation - possibly equivalent to the Cape Elizabeth formation and/or Appleton Ridge formation) are present near the river in the town of Orrington.

STOP 1: Exposure of Passagassawakeag gneiss of Bickel (1971, 1976). Most of this gneiss is a quartz-feldspar-biotite augen gneiss, metamorphosed to sillimanite or second-sillimanite grade. Evidence elsewhere in the Bucksport quadrangle indicates intrusion of the gneiss first by a mafic-rich, foliated granodiorite (the Winterport 'granite'), followed by intrusion by non-foliated pegmatitic material (material equivalent to the Stricklen Ridge pluton). Zircons from the Winterport and Stricklen Ridge yield an upper intercept
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Concordia age of 412 +/- 14 m.y. (Zartman and Gallego, 1979). This outcrop shows extensive evidence of mylonitization produced by a branch of the Norumbega fault zone (approximately 0.1 miles to the north). Here vertical mylonites strike N55°E. These mylonites appear vitric because of the extremely fine grain size of the crushed fragments (pseudotachylites).

Make a U-turn and return to the junction of Rts. 15 and 1-A.

Junction of Rt 1-A and Rt. 15. Turn right (east) on Rt. 1-A towards Ellsworth.

Outcrops of biotite grade Sv(?) on the right (south). Biotite grade metamorphism here was caused by the intrusion of the Lucerne pluton.

Large outcrop of biotite grade Sv(?) on the left (north) opposite Stonehenge. A number of major and minor structural features associated with Acadian folding can be observed here.

Junction of Rt. 1-A and Rt. 46; continue east on Rt. 1-A.

STOP 2: Contact of the Lucerne granite with the Vassalboro(?) formation. Close to the contact the Vassalboro(?) becomes strongly foliated. The Lucerne granite is a coarse grained, seriate, two-feldspar, biotite bearing body. Zartman and Gallego (1979) report a Pb/Pb age from a zircon separate of 380 +/- 4 m.y. Several features to note in the Lucerne include: the coarse grain size right up to the contact (this is true in rare dikes as well); the scarcity of dikes or veins of Lucerne granite in the country rock; and the limited number of inclusions of country rock in the granite. These are features which are characteristic of the Lucerne pluton as a whole.

Continue east on Rt. 1-A.
Outcrops of massive Lucerne granite on the left (north).

Turn left (north) onto a dirt road opposite the volunteer fire station. Drive as straight as possible approximately 0.15 mile past several driveways to a large pavement outcrop of Lucerne granite.

STOP 3: Pavements of Lucerne granite showing sub-solidus deformation of quartz and feldspar. The west-central portion of the Lucerne south of the Sunnyside fault shows a pervasive deformation expressed in ductile deformation of quartz and brittle deformation of feldspar rather than mylonitization. This contrasting behavior of quartz and feldspar suggests this deformation occurred below 500°C (Tullis and Yund, 1977). These left-lateral NW trending fractures are conjugate to the right-lateral Sunnyside fault to the north. Kink-banding of biotite and deformation of secondary sphene suggest the deformation also post-dates sub-solidus alteration. Contrast the appearance of these pavements with the massive Lucerne of the last outcrops.

Return to Rt. 1-A.

Rt. 1-A. Turn right (west) back towards East Holden.

Junction of Rt. 1-A and Rt. 46. Turn right (north) on Rt. 46.

Eddington town line.

Junction of Rt. 9 and Rt. 46. Turn right (east) on Rt. 9.

Junction of Rt. 9 and Rt. 180; continue east on Rt. 9.

Outcrops of biotite grade Sv(?) on left (north) side of Rt. 9.

Outcrops of biotite grade Sv(?) on left (north) side of Rt. 9.
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<td>Park the cars and walk into logging area on the left (to the northwest).</td>
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<td><strong>STOP 4:</strong> Exposures of the <strong>monzonite</strong> of Parks Pond. The <strong>monzonite</strong> is a green-weathering, two-pyroxene, biotite-bearing rock extensively altered to amphibole and chlorite. It intrudes the Vassalboro(?) formation and is in turn intruded by the Lucerne granite. The petrology and geochemistry of the monzonite is currently being looked at by Dr. Susan Eriksson, VPI &amp; SU. At these exposures NS to N40°E trending mylonites are well developed. Return to Rt. 9.</td>
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<td><strong>STOP 5:</strong> Exposures of porphyritic Lucerne granite. This core of porphyritic material represents a higher level of the Lucerne pluton dropped to this elevation by the east-west trending Sunnyside fault. Phenocryst phases include quartz, plagioclase, alkali feldspar, and biotite; the same phases as found in the groundmass. This implies the liquid was saturated with all four of these phases prior to intrusion and crystallization. From examination of thin sections it appears that biotite was the first phase to crystallize, followed by quartz, plagioclase, and alkali feldspar; however the relations between these three phases are indeterminate. Good examples of early alkali feldspar mantled by plagioclase are present here. The presence of miarolitic cavities indicates vapor saturation of the magma during this phase of crystallization. Continue east on Rt. 9.</td>
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<td>Outcrops of massive Lucerne granite with aplites on left (north) side of Rt. 9.</td>
</tr>
<tr>
<td>43.5</td>
<td>2.5</td>
<td>Outcrops of biotite grade Sv(?) in roadcut.</td>
</tr>
<tr>
<td>44.5</td>
<td>1.0</td>
<td>Junction of Rt. 9 and Rt. 181; continue east on Rt. 9.</td>
</tr>
<tr>
<td>46.0</td>
<td>1.5</td>
<td>Junction of Rt. 9 and Rt. 179. Turn right (south) on Rt. 179.</td>
</tr>
<tr>
<td>46.4</td>
<td>0.4</td>
<td>STOP 6: Cemetery Road on right.</td>
</tr>
</tbody>
</table>

Here and further west (towards the cemetery) are a number of exposures of Lead Mountain granite. It is a coarse grained, massive granite which superficially resembles the Lucerne granite. A major difference is the presence of hornblende as a mafic accessory (present in the outcrops next to Rt. 179); another difference is the late crystallization of the mafic phases, which with few exceptions are interstitial to quartz and the feldspars. This superficial resemblance to the Lucerne is compounded in the north where the Lead Mountain is mylonitized in the Norumbega fault zone. A preliminary Rb/Sr isochron yields an age of $390 \pm 10$ m.y. with an initial ratio of 0.7043 $\pm 0.0012$.

Return to Rt. 9.

| 46.8          | 0.4                   | Junction of Rt. 9 and Rt. 179. Turn right (east) on Rt. 9. |

There are numerous outcrops of Lead Mountain granite on Silsby Hill (to the north) and to the south of Rt. 9.

| 48.3          | 1.5                   | Road to Air Force Recreation Area at Dow Pines; continue east on Rt. 9. |

| 60.3          | 12.0                  | Airline Diner. |

<p>| 60.7          | 0.4                   | Junction of Rt. 9 and Rt. 193; continue east on Rt. 9. |</p>
<table>
<thead>
<tr>
<th>Total Mileage</th>
<th>Mileage Between Stops</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>61.7</td>
<td>1.0</td>
<td>Maine Forest Service office and road north to eastern side of Lead Mountain. Turn left (north) on road 34-00-0.</td>
</tr>
<tr>
<td>62.4</td>
<td>0.7</td>
<td>Bear left continuing on logging road 34-00-0.</td>
</tr>
<tr>
<td>62.5</td>
<td>0.1</td>
<td>Bear left on logging road 30-34-0.</td>
</tr>
<tr>
<td>63.0</td>
<td>0.5</td>
<td>Stop and park cars; walk approximately 2000 feet on a bearing of S 70 W.</td>
</tr>
</tbody>
</table>

**STOP 7:** The fault contact between the Silurian Calc. Ss Vassalboro(?) formation and Ordovician Penobscot formation is exposed on these eastern slopes of Lead Mountain. The contact is marked by extreme brecciation and quartz veining, and small dikes of granitic material which intrude both units. These dikes may be related to the Lead Mountain pluton to the immediate west of Lead Mountain(?). Osberg feels this thrust is a major suture between the Penobscot block and the Vassalboro block (central Maine stratigraphy).

Return to cars and return to Rt. 9.

| 65.4          | 2.4                   | Rt. 9. Turn left (east) on Rt. 9. |
| 65.6          | 0.2                   | Dirt road on right (south) just across (east of) the Narraguagus River. Turn right (south). |
| 67.0          | 1.4                   | Road to right; continue straight ahead. |
| 67.1          | 0.1                   | Road (65-07-0) to left; continue straight ahead. |
| 67.5          | 0.4                   | Road to right; continue straight ahead. |
Total Mileage

<table>
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<td>87.7</td>
<td>0.1</td>
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</table>

STOP 8: Exposures of Spruce Mountain granite.

A porphyritic granite with a fine grained, grey groundmass and phenocrysts of quartz, feldspars, and biotite. Very little is known about the body; more additional work has been done by a graduate student at VPI & SU (John Hogan).

Continue along the road for approximately 0.2 miles to road 65-10-0 and turn around; return to Rt. 9.

Rt. 9. Turn left (east) on Rt. 9.

Outcrops of SOp (Penobscot formation) on left (north) side of Rt. 9. [NOTE: The course of Rt. 9 shown on the USGS Lead Mountain 15' quadrangle is the old Rt. 9; the new road cuts the southern toe of Pleasant Mountain at approximately the 600' contour.]

Outcrops (?) of SOp on left (north) side of Rt. 9.

St. Regis Paper Company road 52-00-0 on the left (north). Turn left (north) on 52-00-0.

Junction with St. Regis road 50-00-0; continue on 52-00-0 (bear to the right).

STOP 9: Pavements of Cranberry Lake granite exposed in the stream. A coarse grained, massive, biotite-bearing granite. Similar to both the Lucerne and Lead Mountain in the coarse grain size and presence of mantled alkali feldspar, it appears more similar to the Lucerne in terms of mafic mineralogy and crystallization sequence. Accessory allanite is prominent in many samples. No absolute age has been determined for the body. Mylonites are observed much less frequently in the Cranberry Lake body, but this may be due to the more limited outcrop exposure, a result of topography and glacial cover.

End of field trip.
GENERALIZED BEDROCK GEOLOGY OF THE LUCERNE, LEAD MOUNTAIN, AND CRANBERRY LAKE PLUTONS

EXPLANATION

Dgl - Massive facies of the Lucerne granite
Dglp - Porphyritic facies of the Lucerne granite
Dglm - Lead Mountain granite
Dgsn - Spruce Mountain granite
Dgcl - Cranberry Lake granite
Dgw - Wabassus Lake granite
Dg - Mount Waldo granite
Dp - Unnamed granitic rocks
Pzs - Monzonite of Parks Pond
Pzs - Syenite of Turner Mountain

Cs - Sandstones and conglomerates of uncertain (but post Sv and Sv(?)) age
Dsf - Flume Ridge formation
Dd - Digdeguash formation
Sv - Vassalboro formation
Sv (?) - Rocks similar in lithology to the Vassalboro formation but within and southeast of the Norumbega fault zone
Op - Penobscot formation
Opm - Migmatized Penobscot formation
Oc - Cookson formation
OCcp - Copeland formation
COe - Ellsworth formation
pCp - Passagassawaukeag gneiss

Geology after Nones (1978 and others), with additional information from Gates (1978) and Osberg (pers. comm.). Compiled (with apologies) by M. Loiselle.
INTRODUCTION

The glacial geology of the coastal zone of southeastern Maine has been studied in some detail over the course of the last 20 years. Work in the area, spearheaded by Dr. Harold Borns of the University of Maine, has led to an understanding of a number of previously undescribed features and has provided a number of important radiocarbon dates. These dates bracket the major events of deglaciation of the area quite well and form the chronologic framework to which all regional models must conform.

North of the 10 mile wide belt encompassing the immediate coastal zone lies a large area which has only in the past few years received more than cursory study. During the course of the past two summers the author has mapped the surficial geology of this area and has concluded that the features and stratigraphy found here differ markedly from those described to the south. Because regional hypothesis concerning the glaciation and deglaciation of southeastern Maine must satisfy the constraints of regional observations, it is appropriate to examine the geology of the area north of the Pineo Ridge moraine/delta complex in the light of existing reconstructions. The intent of this excursion is to examine the salient features of this area and to discuss the possible interpretations concerning the "big picture".

BACKGROUND

Following the advance of the last continental ice sheet to its terminal position on the continental shelf (between 17,000 and 20,000 years BP) the climate ameliorated. This initiated a retreat which, by 13,200 years BP placed the ice margin just north of the present coastline of southeastern Maine (Stuiver and Borns, 1975). The glaciomarine silts and clays which now cover much of coastal and central Maine were the result of the flocculation of rock flour entering the "invading" marine waters (Bloom, 1960). These sediments, which Bloom called the Presumpscot Formation, have yielded by far the most abundant dates in Maine. These dates currently fix the period of marine submergence between 13,200 and roughly 12,000 years BP (Stuiver and Borns, 1975; Smith, 1981).

In Southeastern Quebec, field evidence has demonstrated that ice over this region experienced a reversal of flow late in the last glaciation. There is a growing body of data from Northwestern Maine which clearly shows that one of the phases of ice flow there was also to the north. These data, taken with the stratigraphic record in the St. Lawrence Lowland, indicate that late glacial flow reversal south of the St. Lawrence was a result of the cleaving of the Laurentide ice sheet due to ice drawdown into the St. Lawrence Lowland. The drawdown of ice was caused by calving of the margin into the encroaching marine embayment known as the Champlain Sea (Figure 2). The minimum age of the separation of a Maine ice cap is now given by a date from shells in emerged marine sediments in the Ottawa River valley in Ontario. This date indicates that the Champlain Sea had split the Laurentide ice sheet by at least 12,800 ±200 years BP (Richard, 1975). Given
FIGURE 1
Location Map Showing Trip Route And Stops
Scale 1:250,000
FIGURE 2 - Approximate Extent of Champlain Sea Sediments and Presumpscot Formation
the dates which bracket the final ice retreat across the coastal zone, it is an inescapable conclusion that the ice margin which retreated through the field trip area was the southern edge of the residual Maine ice cap and not the margin of the Laurentide ice sheet.

The shape of this ice cap may only be deduced at the time of maximum submergence. Assuming that the upper limit of marine submergence throughout Maine is not time-transgressive and assuming the retreat of the ice and marine incursion were essentially coeval events, the southern margin of the ice cap at maximum submergence would be given by the inland contact for the Presumpscot Formation (Figure 2). The marginal positions for the remainder of the ice cap are rather ambiguous, being fixed as they are by a limited number of radiocarbon dates. Figure 3 shows the approximate shape of the ice cap over Maine and adjacent Quebec and New Brunswick at about 13,000 years BP. The general ice retreat in the coastal zone of Maine was interrupted by hundreds of minor local marginal fluctuations. These fluctuations are recorded geomorphically by the preponderance of DeGeer moraines and stratigraphically by exposures showing ice-shove deformation and till over glaciomarine and glaciofluvial deposits. Borns has postulated a major readvance in eastern Maine which culminated in the sea at the Pineo Ridge moraine line at about 12,700 BP (Borns, 1973). The period of relative equilibrium which followed the readvance resulted in the construction of the Pineo Ridge delta (Figure 1). Because of the angle formed between the ice contact slope of the delta and the DeGeer moraines to the south and west, and because of the presence of southerly striae which in most cases cut across (and are thus younger than) southeasterly striae, the readvance is believed to have been from north to south, in contrast to the southeasterly flow of ice which preceded it.

GENERAL SURFICIAL GEOLOGY OF THE FIELD TRIP AREA

The excursion area may be divided into two broad geomorphic regions. To the south and west, infringing on the coastal zone, lies the lowland belt of large glaciomarine deltas. To the north, above the marine limit, is the upland terrain underlain chiefly by bedrock hills and ice-molded till forms. The major valleys (Narraguagus and Union Rivers) were loci of meltwater stream deposition, and are filled with vast amounts of pro-glacial and ice contact stratified drift.

Much of the land area through which we will be travelling is hilly and was above the marine limit. The features we will see are thus quite different from those in the immediate coastal zone. The most obvious difference is the lack of DeGeer moraines. This is to be expected given that it is well-documented that these moraines were a submarine phenomenon (Lepage and Borns, 1979; Smith, 1982). Other features unique to the area include a large number of Rogen-type moraines (Stop 4), a set of sequentially constructed glaciofluvial deposits (Stop 6), a number of ice-marginal "dump" moraines composed exclusively of till (Stop 5) and large areas of apparent ice stagnation topography (en route to Stops 3, 4 and 5). The three major questions we should keep in mind throughout the trip are:

1. What was the style of deglaciation from the coastal zone to the north?

2. Is the separation of the Laurentide ice over the Boundary Mountains possibly recorded by any of the stratigraphic or morphologic features in the area?

3. Why is there no stratigraphic evidence of the Pineo Ridge Readvance in the area to the north of the Pineo Ridge moraine/delta complex?
FIGURE 3 - Approximate Extent of Maine Ice Cap at approximately 13,000 years BP (from Denton & Hughes, 1981).
References


ITINERARY

MILES

00.0 8:00 a.m. Assemble at the jct. of Rte. 1 and Rte. 187 in Columbia Falls (NB: Rte. 187 is a loop. We will be meeting at the western end of the loop). After we are all together, we will proceed south on 187.

1.4 Turn left into pit.

STOP 1 - Although not in the author's mapping area, this exposure of the Addison Moraine is one of the most impressive examples of the stratigraphy of a stratified moraine and the record left by overriding ice. The crest of the moraine is slightly north of us. Notice the differences in structural style between the eastern and western ends of the pit. After photography and discussion leave pit and turn right (north on 187).

2.8 Junction of 187 and Rte. 1. Turn right (east).

18.0 Machias. Cross bridge, turn left onto 192 (north).

32.1 Notice meltwater channel on right (east) leading to proglacial deposits on left (west).

34.5 Notice kettle on left (west).

36.3 Notice hummocky ground moraine on left (west).

37.7 Park on side of road. Avoid ditch.

STOP 2 - Striation locality. Here we find SO to SW striae cross cut by S-15 to 30E striae. Diligent looking will also show examples of SOE striae cutting S20E striae. Do these relationships signify readvances or do they indicate a minor shifting of ice flow according to local topography? The entire field to the east of the road is underlain by striated pavement. You may wish to examine the exposures for evidence of chattermarks. After a brief stay, continue north on 192.

38.5 Junction of Rte. 9 and 192, Wesley. Turn left (west).

48.6 Cross Machias River.

55.9 Turn left (south) off Rte. 9 onto St. Regis Road 09-61-0.

STOP. Depending on weather and conditions of road, we may wish to join our colleagues with 4-wheel drive vehicles.

56.4 Notice poor exposure of bouldery moraine overlain and surrounded by proglacial sands. Do Not Stop Here. We will see much better moraine exposures soon.

58.3 Bear left at fork (as a landmark, there is a small camp located at the fork).
58.35 Bear right at fork.
59.0 Take right turn.
59.2 Otter Pond on left.
59.9 Pass road entering on right.
60.0 Pass road entering on right.
60.3 Turn left.
60.4 Turn left into pit.

STOP 3 - We have been driving through an assemblage of ice contact landforms (crevasse-fillings, kames, kame deltas). This pit exposes the internal structure and sediment of one such feature. While here, we will take a short walk to the north to see the landforms. They are very well displayed due to sparse vegetation and are text book examples. Notice the large "esker" in the distance.

11:00 Return to vehicles.
60.5 Turn right.
60.6 Turn left.
61.2 Turn left onto Pleasant River Lake Road (unmarked).
61.7 Notice presence of boulders in sand adjacent to large moraine (both sides of road).
61.8 Pass sand pit on left.
62.0 Pass Pleasant River Lake on right.
62.1 Cross Southwest Brook.
62.4 Pass "Rogen" Moraines.
63.4 Take right fork.
64.1 Turn right into pit in moraine.

STOP 4 - This is an exposure of one of the many lumpy "Rogen" type moraines found in this area. Fabric measurements (Figure 4) in the till indicate a very strong preferred orientation to the south, perpendicular to the axis of the moraine. This is a ubiquitous feature of similar moraines exposed further up the road. The strong fabric and the trend of the moraines suggest that we are looking at till deposited by southerly, not southeasterly, flowing ice. Air photos will be available so we can see the photographic expression of the moraines.

The lack of distal fluvial deposits, the presence of strongly oriented stones, and the lack of typical ice marginal asymmetry of the moraines tend to support a subglacial origin. This would be in accordance with
Figure 4

TILL FABRIC - SOUTHWEST POND MORaine
interpreted origins for similar moraines in Scandinavia. The classic Rogen moraines however, show some degree of ice molding or drumlinization which does not seem to be the case with the features we see here. Lundqvist (1969) has proposed that Rogen type moraines have formed under active ice which is dissected with transverse crevasses such as would occur over a bedrock surface which is convex upward. Alternatively, Rogen moraines have been attributed to zones of compression. In this hypothesis, shear planes, formed by imbricate layers of overthrusting ice, are believed to be a conveyor of debris from the base of the ice. The strong "reverse-dip" of stones within the till here is consistent with this idea, as is the constrictive nature of the topography. Return to vehicles and proceed back up the road from whence we came.

67.0 Pass road on right.
69.2 Junction Rte. 9. Turn left (west).
75.5 Cross Narraguagus River
75.65 Take right past "Maine Forest Service Station; Beddington" sign. We are on St. Regis Road 30-00-0.
81.3 Pass "esker" segment (crevasse-filling?).
82.7 Notice boulders on surface of ice contact deposits.
83.1 Turn left on St. Regis Road 30-12-0.
83.6 STOP 5 - Lead Mtn. Moraine. For those wishing to photograph the moraine, this spot is probably the best vantage point. With the Southwest Pond Moraine fresh in our minds, we can examine the morphology and structure of this moraine and compare them. The fabric of the till composing the moraine is given in Figure 5. Notice particularly the dip of the stone axes. This, combined with the asymetry of the moraine (the distal side is much steeper than the proximal side) and the delicate map geometry distinguish it from Rogen type moraine and suggest an ice marginal rather than subglacial origin. One problem we will address: The moraine presumably was associated with active ice. How does this reconcile with the dead ice topography in the Narraguagus Valley?

Before leaving, note the trend of the crest of the moraine (approximately N40E). This is roughly perpendicular to striae which were mapped just up the road a few hundred yards. It is presumed that the moraine is an artifact of the last ice to encroach upon the area. This being so, it would appear that the last ice flowed from northwest to southeast, and not from north to south.

1:30 Return to vehicles.
84.1 Turn right on St. Regis Road 30-00-0.
91.6 Pass Maine Forest Service Station, turn right onto Rte. 9 (west).
92.8 Pass Rte. 193 on left (south).
Figure 5

TILL FABRIC - LEAD MTN. MORaine
93.1 Pass Airline Snackbar on right (north).
94.3 View of Lead Mtn. on right (north).
98.1 Pass till pit on right (north). Notice sandy granitic till.
102.1 Drive onto "Whalesback" esker.
103.9 Crest of Whalesback. Notice kettles and kame plateau on left (south).
105.0 Leave Whalesback.
105.8 Turn right on road to Dow Pines Recreational Area.
106.0 Turn left on access road to Silsby Plain.
106.4 Turn left and stop. We will definitely want to use 4-wheel drive vehicles from here on.

STOP 6 - Silsby Plain Delta. The most striking feature of this location is the esker which rises roughly 45 feet above the delta surface. The esker and the delta could not have been deposited simultaneously - the esker is an ice-contact form, whereas the delta is proglacial. These two landforms are thus separate "morphostratigraphic" units and represent two distinct blocks of time. The esker itself may be traced to the northwest where it is known as the famous "Enfield Horseback", and to the southeast, where it becomes the "Whalesback" over which we recently drove. There are proglacial features (deltas) to the west of Black Cap Mountain (Figure 6) which may also be separated from ice-contact deposits in a similar, albeit less dramatic manner than we see here. These forms likewise comprise morphostratigraphic units. The deltas to the west of Black Cap Mtn. are not spatially linked to the Silsby Plain delta; they are separated by a bedrock floored gap at Morrison Pond (Figure 6) which is at a slightly higher elevation than either of the delta surfaces. The bedrock near Morrison Pond has poorly developed potholes which are more properly on grade with the Silsby Plain delta than with the esker segments. This suggests that at least a portion of the Silsby Plain delta was built by proglacial streams flowing through the gap from the northwest. Meltwater channels curved into the delta surface indicate that the source for most of the fluvial part of the delta was directly north up the Union River valley. There are at least three separate mappable units from the southeast at Silsby Plain to the northwest at Sunkhaze Stream (Figure 6). The identification of such units (generally called morphosequences) can provide a relative chronology for deposits in an area with suitable topography and deglaciation style. In southern New England the existence of sequences is taken as evidence for a style of deglaciation known as stagnation-zone retreat (Koteff, 1974). The concept calls for a progressive retreat of ice with a relatively narrow stagnant margin. Active ice tends to over-ride the stagnant ice creating a succession of relief shear planes along which material is brought from sub or englacial positions to the surface of the ice. Once there, the material is then picked up by supraglacial streams and deposited as the sediment of eskers, kames, deltas and valley trains. The width of the stagnant zone is generally taken as the length of esker segments at the head of a particular sequence.
FIGURE 6 - Glaciofluvial Features in the Silsby Plain Area

LEGEND
Outcrop  Qg  - Ice Contact Deposits
Thin Cover  Qgo  - Proglacial Deposits
Scarp  Qs  - Swamp
    —— Meltwater Channels

SCALE  1:62,500
Does the existence of sequences indicate stagnation-zone retreat here? If it does, it would appear that adjacent basins experienced different styles of deglaciation at quite similar times (recall the Narraguagus valley). If sequences can be adequately explained by other forces however, accepting them as prima facie evidence for stagnation zone retreat would be incorrect.

End of excursion.
FIELD TRIP 11

BEDROCK GEOLOGY OF THE ANDROSCOGGIN LAKE IGNEOUS COMPLEX,
WAYNE AND LEEDS, MAINE

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Department of Geology
Bates College
Lewiston, Maine 04240

PURPOSE

A bimodal suite of mafic/ultramafic and felsic igneous rock occurs around (and beneath) Androscoggin Lake, Wayne and Leeds, Maine. These post-Acadian alkaline plutonic rocks and abundant related mafic dikes are informally termed the Androscoggin Lake igneous complex (FIGURE 1). The purpose of this field trip is to outline the petrogenesis of this complex as presently understood through illustration of lithologies, relative age relations, and intrusive mechanisms. The data presented are an amalgam of thesis research by Bates College seniors and a summary of work in progress.

GENERAL DESCRIPTION

The Androscoggin Lake igneous complex (hereafter termed ALIC) consists of a core of coarse-grained pyroxenite, gabbro, and diorite and marginal bodies of syenite and quartz syenite. These plutonic units intrude metasediments of the Silurian Sangerville Formation and granitoids of Devonian age and produce a contact zone characterized by brecciation and lit-par-lit injection. Regional contact metamorphic and metasomatic effects are not obvious but no systematic study has been made.

The syenite and quartz syenite are consistently younger than the gabbro/pyroxenite core rocks; gabbro is younger than pyroxenite. At least two chemically distinct swarms of alkaline diabase dikes intrude the core rocks; relative age of these dikes is uncertain. The dikes have an average orientation of N24°E, 70°W (n = 281), an average width of 72 cm, and form 12-15% of the width of the core (measured at right angle to strike). Although the dikes do cut syenite exposed at the southern end of the lake (STOP 3), they are generally absent in large exposures of the syenite and quartz syenite to the east (STOP 6, 7) and to the west (Hedgehog Hill) of the core. The dikes are also absent in the older adjacent meta-sediment and granitoid. The average potassium-argon date of biotite and hornblende from two dikes is 290 m.y. -- upper Carboniferous.

SIGNIFICANCE

There are several intriguing and possibly unique aspects of the Androscoggin Lake igneous complex that have broader petrologic and geologic significance.
1. The age with respect to the petroTECTonic evolution of the Northern Appalachians. Further radiometric dating is necessary to establish whether all igneous activity is co-magmatic and confined within a narrow interval of the upper Carboniferous or is spatially associated magmatism spanning a broader interval from say, late Devonian (gabbro/peridotite) to mid-Mesozoic (alkali quartz syenite).

2. The locus of repeated and spatially restricted mantle magmatism. An early magmatic event is represented by pyroxenite (a clinopyroxene cumulate), a second event by hornblende gabbro, and a final event(s) by dike formation.

3. The distinctive chemistry and mineralogy of the mafic rocks. The mafic/ultramafic rocks (TABLE I) are distinctive when compared to similar types from Maine, for example, from the Cape Neddiek complex and the Moxie pluton (TABLE I).

   a) Whole-rock chemistry indicates an alkali basalt parent for the gabbro and certain (Type 2) of the dikes; the other dikes (Type 1) appear transitional in composition between alkali diabase and lamprophyre.

   b) The rocks contain a high proportion of clinopyroxene (titanaugite), hornblende, and oxide minerals and, a relatively low proportion of plagioclase.

   c) Obvious magmatic layering is absent.

4. The bimodal association. The felsic rocks (especially the alkali quartz syenite) are probably not differentiates of alkali basalt magmas and hence genetically unrelated to exposed mafic rocks. Rocks of intermediate composition are lacking.

5. Locally superposed fabric. The foliation observed in syenite and the presence of disrupted dikes suggest deformation processes during and after solidification of these rocks, not flow orientation.

REFERENCES CITED

A. Bates College B.S. and B.A. Theses


# Table 1. Representative Chemical Analyses Androscoggin Lake Igneous Complex

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<td>0.31</td>
<td>0.62</td>
<td>1.21</td>
<td>0.62</td>
<td>0.16</td>
<td>0.45</td>
</tr>
<tr>
<td>TiO₂</td>
<td>4.92</td>
<td>1.36</td>
<td>2.90</td>
<td>2.29</td>
<td>2.6</td>
<td>3.67</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.19</td>
<td>0.17</td>
<td>0.42</td>
<td>0.30</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td>96.90</td>
<td>97.9</td>
<td>97.57</td>
<td>97.68</td>
<td>100.04</td>
<td>99.38</td>
</tr>
</tbody>
</table>

*Total iron recalculated as Fe₂O₃

---

1. Hornblende pyroxenite, Lothrop Island
2. Hornblende gabbro, Lothrop Island
3. Type 1 Alkali diabase dike transitional to alkali lamprophyre, Camp Tekawitha, STOP 3
4. Type 2 Alkali diabase dike, Stinchfield's Point, STOP 5
5. Olivine gabbro (no. 185), Moxie pluton (Espenshade, 1972, p. 15)
6. Average analysis Cortlanditic gabbro, Cape Nedick (Murphy, 1971, p. 30)
Figure 1. Androscoggin Lake igneous complex

Androscoggin Island

Nurses Island

LaGrange Island

Boggs Island

Inlet

Lake

River

North Leeds

Dead River

Leeds

Sino Pond

Wayne

Paul

Pocasset

Sy

Aqs

E

W

N

E

hd

hg

iz

hp

4

3

2

1
TABLE II. EXPLANATION TO FIGURE 1

ALKALI QUARTZ SYENITE: (aqs). Massive homogeneous medium-grained rocks composed chiefly of microperthite; grades from syenite to granite with variation in quartz content; less than 10% mafic minerals (clinopyroxene and ferrohastingsite). These rocks are similar in texture and mineralogy to rocks assigned to the White Mountain Magma Series.

ALKALI DIABASE: Type 1 and Type 2 (see Table I) are fine-grained dark grey rocks composed of subequal amounts of hornblende, pyroxene, oxide minerals, and plagioclase; olivine is absent.

SYENITE: (sy). Medium-grained rock composed of orthoclase and microperthite containing up to 15% of hornblende and biotite; on the east side of complex dark minerals define a planar fabric and cataclastic textures locally developed. The asymmetry of syenite distribution may reflect the dominance of NNW-SSE extensional stress during emplacement.

INJECTION ZONE: (iz). Mixed zone in which metasediments are brecciated or injected in lit-par-lit style by syenite and gabbro.

HORNBLENDE GABBRO: (hg) and HORNBLENDE DIORITE: (hd). Coarse-grained locally pegmatitic rocks with distinctive intergranular texture -- late crystallizing amphibole encases clinopyroxene and fill the angular interstices between euhedral plagioclase; rocks grade from melano- to leucocratic; distinction between gabbro and diorite is based upon plagioclase composition and not apparent in the field. Intrudes pyroxenite: where pyroxenite dominates (as on islands) gabbro has dike-like form; where gabbro dominates, pyroxenite occurs as inclusions.

HORNBLENDE PYROXENITE: (hp). Coarse-grained titanaugite cumulates with minor intercumulus titaniferous amphibole and labradorite; olivine and oxide minerals are present as subordinate cumulus minerals; locally pegmatitic and miarolitic texture with coarse apatite and fluorite.

DEVONIAN GRANITOIDs: (Dg). Foliated two-mica granitoids, garnet-biotite granitoids, and aplite dikes well exposed on Monument Hill at the southwest edge of study area.

SANGERVILLE FORMATION: Main facies (Ss). Foliated garnet-biotite-quartz gneiss with calc-silicate horizons or lenses; best exposed along south and east margins of complex.

Patch Mountain member (Ssp). Finely bedded calc-silicate and biotite or biotite-garnet granofels; best exposed south of Morrison Heights.

\[ \text{Location of Field Trip Stop} \]

\[ \text{Location of Field Trip Traverse} \]


B. Other


FIELD TRIP STOPS
(All stops are in the Wayne 7½' quadrangle and located on Figure 1)

STOP 1. Regional Contact, Route 219, Wayne

This exposure is at the contact of the ALIC and the Sangerville Formation. The very thinly bedded Patch Mountain member (N80°E, vertical dip) is intruded by medium-grained gabbro, syenite, and diabase dikes. It is not clear whether the gabbro is a marginal chill aspect of the coarse hornblende gabbro present south of the outcrop or a large diabase dike. Compare relations here with those at STOP 3.


Access road leads to camp headquarters, park here; walk to left and between double row of cabins towards lake. PLEASE DO NOT USE HAMMERS WITHIN CAMP GROUNDS.
The pavement exposures here illustrate a number of features typical of the mafic/ultramafic core. The coarse-grained hornblende gabbro shows gradational variation in grain size and in plagioclase/hornblende. Note the striking intergranular texture. A few inclusions of pyroxenite are scattered throughout the gabbro. Many diabase dikes crosscut the gabbro and each other; wider dikes have a general NE strike but narrower dikes are more variable in orientation.

STOP 3. Relative Age Relations, Camp Tekawitha, Leeds

Drive through gate and park to right of main building. Traverse is from main building northward between double row of cabins to shore, then east and south along the point of land. PLEASE DO NOT USE HAMMERS.

These exposures well illustrate several contact and intrusive relations of the ALIC. The regional attitude of the Sangerville Formation (N30°E, 60-70°E) is rotated to N80°E, 80°S at the contact with the complex. The Sangerville Formation is intruded by syenite in lit-par-lit fashion and near the main building is cut by medium-grained gabbro/diorite. Is the latter the regional chill aspect of coarser gabbro/diorite present at the shoreline or simply the ubiquitous alkali diabase dikes?

The gabbro/diorite exposed along the shore shows gradational variation in plagioclase/hornblende and is intruded by syenite; both are cut by numerous metre-wide diabase dikes (N20-40°E). Compare the texture of the gabbro/diorite here with that at STOP 2. Of particular interest are dikes that intrude the syenite but are fractured and are intruded by the syenite host. Are these features related to other evidences of post-emplacement shearing seen at STOP 8?

Thin dikes of quartz syenite cut all exposed rock types.

STOP 4. Hornblende Pyroxenite and Gabbro, Norris Island

Landing is best made in the cove on the northwest side of Norris Island at the black sand beach—a rather handsome accumulation of angular hornblende crystals.

Exposures here are of the hornblende pyroxenite which exhibits wide textural variation including pegmatitic and miarolitic features. The traverse follows the shoreline northward across exposures of the pyroxenite and southwestward across a sharp contact with hornblende gabbro. Diabase dikes cut exposures of both rock types. The exposures of gabbro should be compared with those seen at STOP 2. Is this the same unit?

Return to cove by traversing eastward across the island.

STOP 5. Hornblende Gabbro/Diorite and Alkali Diabase, Stinchfield's Point, Wayne

Park in circular driveway of Stinchfield residence and proceed in an easterly direction passing between house and barns to ledgy exposures along shore.

The abundance of diabase dikes is a striking feature of these exposures. Hornblende gabbro/diorite is cut by many dikes of alkali diabase (both Type 1 and Type 2 analyzed from here) and a few thin dikes of syenite.
STOP 6. Syenite, Morrison Heights

There is a turnout at this stop on the east side of the road that can accommodate two small cars; others should park on west side of road. Following this stop we will spot vehicles further south at STOP 7b.

A series of rounded ledges along the east side of the highway persist to the summit of Morrison Heights and are typical of the syenite (sy) of FIGURE 1. The homogeneous outcrops of weakly foliated syenite lack the diabase dikes typical of the core rocks. An isolated outcrop (?) of hornblende gabbro and diabase dikes is located about 100m south of this stop (across from farmhouse) and about 50m east of the road. We will visit this outcrop (?) if time permits. Note the texture of this syenite for later comparison with that of STOP 7.

STOP 7. Alkali Quartz Syenite, West of Morrison Heights

Proceed south along town road to southeast corner of field indicated on FIGURE 1. Park the vehicles here so as not to block driveway of new home. Traverse is approximately one mile in length and involves about 300 feet of relief. The fact that we traverse a recently logged terrain makes this a genuine bushwacke.

The alkali quartz syenite is well exposed at point a and south along the steep east facing slope. Contact with the Sangerville Formation to the east is visible on this slope. In crossing the higher terrain within the alkali quartz syenite, note the gradational variation in quartz content, homogeneous texture, and small milarolitic cavities; compare the blocky texture of these felsic rocks with the syenite on Morrison Heights (STOP 6). The injection zone to the west of this body exposes Patch Mountain member of the Sangerville Formation intruded by the alkali quartz syenite. Continue to point b on the Morrison Heights road using abandoned town road.

STOP 8. Deformational Features in Syenite, the Ledges, Wayne

Proceed along road to camp indicated on FIGURE 1. Walk to shoreline where birchwood sign proclaims this the "LEDGES."

Exposures here are of syenite (sy). Several narrow diabase dikes are offset by a shear zone that has produced a zone of mylonite about 12 inches wide oriented N25°E, 60°S. Is this event responsible for the weak foliation of the syenite and perhaps related to features seen at STOP 3?

Return to vehicles and return to main road, turn right (south) and proceed to T-junction. Turn left (east) at junction, proceed east about .5 mi. to first road on right, turn right (south) here. If you cross causeway you missed turn. Continue south to junction with Route 202. Turn right (south) towards Lewiston.
INTRODUCTION

The purpose of this field trip is to examine the glaciomarine deposits formed at and just below the upper marine limit by the retreating late Wisconsinan ice sheet (Fig. 1). In the region south of Sebago Lake, the marine limit lies at an elevation of just over 300 ft (Thompson et al., 1983).

The evidence for the submergence of the area lies primarily with the fossiliferous marine clays, i.e. the Presumpscot Formation, described by Bloom (1960). Evidence that the ice terminus stood in the marine embayment during deglaciation includes tills interstratified with Presumpscot Formation (Borns, 1980; Smith, in press), and glaciomarine landforms, such as washboard/DeGeer moraines (Smith, 1982, 1983), stratified moraines (Smith, 1983, in press), and glaciomarine deltas (Borns, 1973, 1980; Smith, 1982; Thompson, 1979, 1982).

The period of submergence dates from about 13,800 B.P. to about 11,000 B.P. in this part of Maine (Stuiver and Borns, 1975; Smith, in press). However, the area was rapidly deglaciated; the glacier stood on the coast near Kennebunk at about 13,800 B.P. (Smith, in press), then retreated across the marine embayment and deposited the Gray delta prior to 12,900 B.P. (Jacobsen et al., 1981). The submergence continued in the region until about 11,000 B.P. (Crossen, 1983a). Subsequently, the sea withdrew as the area rebounded and erosion and redeposition of many glacial deposits occurred (Crossen, 1983b).

This trip will focus on glaciomarine deltas. Five major types of deltas are found in the area: 1) ice contact deltas, 2) ridge and kettle deltas, 3) esker deltas, 4) outwash deltas, and 5) combination deltas (combining characteristics of more than one of the other types). Three of these types will be examined, as well as one stratified moraine (to compare it with the deltas).

This area has been previously mapped by Prescott and Thompson (1976), Smith and Thompson (1976), Thompson (1976), and Thompson and Smith (1977).
**ROAD LOG**

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>8:30 A.M. Assemble in parking lot, Bailey Hall, University of Southern Maine, Gorham. Turn right out of parking lot, then turn left on to College Ave.</td>
</tr>
<tr>
<td>0.2</td>
<td>Turn right on to Rte. 114.</td>
</tr>
<tr>
<td>0.3</td>
<td>Junction of Rte. 114 with Rte. 202 and 4. Turn left at stop light.</td>
</tr>
<tr>
<td>0.7</td>
<td>Turn left on Rte. 202 and 4 (towards Gray).</td>
</tr>
<tr>
<td>3.6</td>
<td>Cross Little River.</td>
</tr>
<tr>
<td>4.1</td>
<td>Junction of Rte. 202 and 4 with Rte. 237. Turn left on Rte. 237, Little Falls.</td>
</tr>
<tr>
<td>4.8</td>
<td>Note the large stratified moraine which continues across road and to the right (east). Marine fossils were collected here from clay overlying sand in the Walter Stevens pit, ¼ mi. east of Rte. 237 (Table 1). Note the series of moraines along the road.</td>
</tr>
<tr>
<td>5.5</td>
<td>Turn right into pit owned by Walter Stevens.</td>
</tr>
<tr>
<td></td>
<td><strong>STOP 1 - Pleasant Ridge - stratified moraine</strong></td>
</tr>
</tbody>
</table>

This relatively large, deep pit is fairly typical of the type of stratigraphy found in stratified moraines. Things of interest include: 1) the bedrock outcrop running the length of the pit, 2) the cobble gravel above the outcrop, 3) the difference between the pebbly sand on the north and the finer sand on the south side of the pit, and 4) the dipping sand beds which extend to the surface (especially on the south side of the pit).

This landform has been interpreted as a subaqueous deposit because 1) it exhibits an undulating ridge form (Fig. 2), and 2) it contains dipping beds which extend to the surface. The maximum height of the ridge (about 260 ft.) suggests that the upper marine limit is above this elevation. The coarser deposits found on the north side of the pit suggest that to have been the ice contact side of the ridge. Similar moraines of this type (Fig. 3) show active ice (shove) features, and many have a carapace of till on the top or proximal side of the ridge (Smith, 1983; Borns, 1980; Holland, 1982).
Table 1

Fossils from Walter Stevens pit,
Rte. 237, Little Falls, Maine

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Date</th>
<th>Elevation</th>
<th>Stratigraphy</th>
<th>Species</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI-4747</td>
<td>11,450 ± 90 B.P.</td>
<td>140 ft.</td>
<td>Silty clay over sand</td>
<td>Mytilus edulis, Mya truncata, Serripes groenlandicus</td>
<td>Intertidal</td>
</tr>
</tbody>
</table>

Interpretation:

Although three species were collected here, *Mytilus edulis* was dated as the best intertidal indicator. The date (11,450 ± 90 B.P.) indicates when this elevation was at sea level during the regression of the marine embayment. However, since all shells were disarticulated and fragmented (rather than in upright living position), they may have been redeposited.

Source: Crossen (1983a).
Figure 2 - Topography of a stratified moraine, Pleasant Ridge, Gorham quadrangle (Stop 1).

Figure 3 - Generalized cross section of a stratified moraine. Source: Andersen (1980).
The location of the bedrock ridge within the moraine suggests that during deglaciation the ice was thin enough to be influenced by underlying bedrock topography. The bedrock sill slowed ice retreat for a time, and subaqueous deposition produced an accumulation of sand and gravel which now forms the moraine.

Turn right upon leaving the pit. Proceed north on Rte. 237.

We will cross several small washboard or DeGeer moraines, as well as larger stratified moraines, in the next two miles as we proceed north up the west side of the Presumpscot River valley.

6.5  Cross railroad tracks.

6.7  Fork in road. Stay on Rte. 237.

7.6  Fork in road. Stay on Rte. 237.

For the next 1½ mi. we will be on and off a flat landform which is about 300 ft. a.s.l. It is likely a continuation of the deltaic landform to the west, but no stratigraphic sequences could be located in the area to verify this interpretation.

9.2  Junction of Rte. 237 and Rte. 35. Turn left (west). The Lower Bay of Sebago Lake is on the right (north). Mt. Washington can be seen across the lake on a clear day. This end of the lake is fenced because it provides the public water supply for the city of Portland.

10.2  Cross railroad bridge.

Note kettle (Otter Pond) on left (south). This is the kettled proximal side of the Sebago Lake village delta. Note the steep proximal side of the delta (now the south shore of Sebago Lake) on the right side of the road.

10.5  Turn left (south) into pit owned by White Bros. Construction Co.

**STOP 2 - Sebago Lake village delta**

Typical deltaic stratigraphy is exposed in this pit. Topset beds are composed of 3-5 ft. of cobble gravel and sand with cut-and-fill structures - a typical braided stream deposit. Foreset beds are composed of 10 ft. of sand and pebbly sand dipping 270 towards the SW (azimuth: 230°) - a typical subaqueous deposit. The contact between the topset and foreset beds is an erosional one, formed as the stream channels prograded across the top of the delta. The elevation of the topset-foreset contact measures 309 ft.
The surface of this landform is relatively flat (probably sloping gently from the north to the south), and contains both channels and kettles. This suggests that it was never washed over by rising sea level.

The proximal side of the delta forms the modern shore of Sebago Lake, suggesting that the ice stood in the lake basin as the delta was deposited to the south. This is one of the two types of ice contact glacimarine deltas; this type has a lake basin on its proximal side.

Turn right upon leaving the pit. Proceed east on Rte. 35.

10.8 Cross railroad bridge.

Otter Pond (kettle) on right.

11.7 Junction of Rte. 35 and Rte. 237. Continue straight on Rte. 35.

For the next four miles, we will be traveling along the landform which dams the southeast side of Sebago Lake. It is composed of morainic and deltaic deposits and is probably underlain by a bedrock ridge (since it is on strike with other bedrock structures in the area).

16.2 Turn right (south) on an unnamed road just before the bridge over the Eel Weir Canal. This canal now drains Sebago Lake and supplies electricity for the S.D. Warren Co. The canal was originally built along the west side of the Presumpscot River to allow barges and boats to travel up the river from the ocean to Sebago Lake and, via Songo Locks, into Long Lake.

17.4 Turn right into pit owned by W. Hatch.

STOP 3 - North Gorham delta - distal side.

This delta is unique because topsets, foresets, and marine clays are all exposed in one pit.

On the west side of the pit, 3-5 ft. of cobble gravel and sand overlie 30-35 ft. of dipping sand and pebbly sand. The foresets dip 14-25° to the east and south (azimuth: 80-170°). This suggests that the delta was being deposited towards the southeast, into the basin which is now the Presumpscot River valley (Fig. 4). The topset-foreset contact measures 307 ft.

On the east side of the pit, a maximum of 10 ft. of silty clay overlies 10-15 ft. of dipping sandy foreset beds. The contact between the sand and silt is transitional. This suggests continuous deposition from the period when the ice contact delta was formed, until the time that the ice retreated and marine silts and clays were deposited. There
Figure 4 - Topography and location of deltas at North Gorham, Windham Hill, and Varney Mills, North Windham quadrangle (stops 3-6).
is no evidence for a period of subaerial exposure between deglaciation and the transgression of the sea as suggested by Bloom (1963).

Within the Presumpscot Formation, the silty clays are interbedded with sands at the base of the stratigraphy, and become more massive towards the top. This suggests that turbidity flows in very brackish water formed the base of the stratigraphy, and as the water became more saline, the clays flocculated to form the upper massive unit (Ashley, pers. comm. 1983). Although no fossils have been found in either the sands or clays this close to the deltas, it has been assumed that these silty clays are continuous with other fossiliferous locales of the Presumpscot Formation which have been dated. Finally, because the Presumpscot Formation is commonly found overlying the topset beds, it is assumed that isostatic rebound was able to keep the deltas above eustatically rising sea level during the period of deglaciation.

Turn right when leaving the pit.

17.9 Junction with North Gorham Road, North Gorham. Turn left (east).

18.0 Cross the Presumpscot River.

18.5 Cross River Road. Proceed straight ahead on Windham Center Road.

Note washboard moraines in fields.

Note steep ice contact (proximal) side of delta straight ahead.

18.8 Turn right into pit owned by town of Windham.

STOP 4 - Windham Hill - proximal side

This pit exposes the stratigraphy in the kettled proximal side of an ice contact glaciomarine delta. Unlike the Sebago Lake delta, this ice contact delta does not impound a lake. Instead, it forms an isolated topographic high surrounded by Presumpscot Formation (Fig. 4).

The stratigraphy here is composed of 10-12 ft. of cobble gravel and sand, overlain in places by up to 5 ft. of silty clay. Many collapse features can be readily observed.

This is interpreted as an ice contact deposit in which the sand and gravel collapsed as a supporting ice face retreated and/or as underlying ice melted. Smith (1983) and Borns (1980) have suggested that the ice was active as it retreated across the marine embayment, and I concur with that interpretation. However, the stratigraphy seen in this pit is not conclusive in either supporting or rejecting that
hypothesis. However, I find no evidence in this area for any regional readvance (Bloom, 1960; Borns, 1973; Borns and Hughes, 1977; Smith, 1981).

Windham Hill is parallel to the strike ridges in this area (Fig. 4). This suggests that the deposition of glacio-marine ice contact deltas in this region was controlled by bedrock ridges underlying the retreating ice front. Similarly, seismic work in New Hampshire (Birch, 1980) shows that bedrock ridges are common features underlying the landward sides of similar landforms there (Fig. 5).

I interpret these data to mean that ice retreat in Maine was slowed by bedrock sills, and sand and gravel was deposited adjacent to the ice front. If the water was deeper and ice retreat rapid, a small deposit would build but remain subaqueous, thus forming a stratified moraine. On the other hand, if the water was shallower and the retreat rate slowed substantially, the subaqueous deposit would build to sea level and form a delta. The processes that formed each type of deposit were the same; only the length of time during which deposition took place was different.

Turn right upon leaving the pit. Continue east on Windham Center Road.

Immediately climb up steep ice contact face of delta.

19.3 Junction of Windham Center Road and Ward Road. Turn left on to Ward Road.

Note the flat surface of the delta. This is a rather small delta (~1/2 mi. wide by 1 1/2 mi. long). We are traveling on the north half of the delta (Fig. 4).

19.9 Turn right into pit owned by Rogers Construction Co.

STOP 5 - Windham Hill - distal side

This pit exposes the distal northeast side of the delta (Fig. 4). The topset beds are poorly exposed, but are composed of 10 ft. of cobble gravel and sand. The elevation of the base of these beds is 300 ft.

The foreset beds are composed of more than 30 ft. of sand, dipping towards the east (azimuth: 65°, 85°, 110°). These beds are overlain by silty clays which interfinger with the sandy sediments.

Note the remarkable change in grain size from one side of this small delta to the other.

Turn right when leaving the pit. Proceed north on Ward Road. Immediately go down off the edge of the delta.
Figure 5 - Generalized cross section of an ice contact glaciomarine delta. Source: Andersen (1980).

Figure 7 - Topography of the East Gray ridge and kettle delta, Gray quadrangle (stops 7 and 8).
20.5 Junction of Ward Road and Rte. 302. Turn right (south) on Rte. 302.

20.9 Junction of Rte. 302 and Varney Mills Road. Turn left (north).

21.4 Begin to climb distal slope of the Varney Mills delta. Note the wave cut scarp on the right (east).

21.6 Turn left into pit owned by C.R. Tandberg Co. Walk back across the road to examine the wave cut scarp along the south side of the road.

STOP 6 - Wave cut scarp - Varney Mills delta

This very straight scarp can be seen both in the field and on aerial photographs. It extends along the distal edge of the delta. The scarp is 16 ft. high, has a slope of 13°, and is at a 285 foot elevation. It is assumed to be a re-bound feature, i.e. eroded by falling sea level as isostatic rebound brought the area above eustatically rising sea level (Fig. 6).

STOP 6 - Varney Mills delta - distal side

The stratigraphy in this pit is as follows: 1-3 ft. of very fine sand, underlain by 10 ft. of cut-and-fill cobble gravel and sand, in turn underlain by 35 ft. of sand dipping 7-24° towards the southeast (azimuth: 92-155°). The sand overlying the gravel is interpreted as fine-grained outwash based on sedimentological analysis (Crossen, 1983a). The topset-foreset contact is at an elevation of 300 ft.

This landform is a large (2 mi. by 2½ mi.) deltaic feature formed along the regional strike, and contains numerous kettle lakes on its surface. Both eskers and outwash feed it from the north. The delta lies at the upper marine limit.

In this field area it is common for the largest deltas to be at the upper marine limit. These large deltas were formed as a consequence of the change in the type and rate of ablation when the glacier retreated from a marine to a terrestrial environment. According to work in Glacier Bay, Alaska (Powell, 1980), while the terminus of the ice remains in the marine embayment, the retreat rate is rapid and most of the ablation is produced by calving. However, when the terminus retreats out of the marine embayment, then ablation changes from calving to melting. Since melting produces a much slower rate of ablation, the terminus remains in one position for a longer time, and a much larger delta can be deposited.

In this area of the marine embayment, small ice contact deltas were formed by the ice when it occupied the marine basin, while large esker and outwash-fed deltas were
Figure 6 - Model for the deposition of a series of glaciomarine deltas.

Top: Formation of small ice contact deltas below the marine limit.

Center: Formation of large esker or outwash deltas at the upper marine limit.

Bottom: Formation of wave cut scarps as rebound uplifts the deltas.

(Later rebound emerges all deltas.)

Source: Crossen (1983a).
formed at the marine limit when the ice retreated from a marine to a terrestrial environment (Fig. 6).

At this stop, Andy Tolman will discuss the aquifer mapping project and its relationship to the deltas.

Turn left after leaving the pit. Proceed northeast on Varney Mills Road.

This road follows the distal edge of the delta for about two miles. Note its flat surface.

23.6
Junction of Varney Mills Road and Rte. 115. Turn right and proceed east on Rte. 115.

This is the eastern edge of the delta where a bedrock/till-covered hill projects above the delta surface.

24.6

For the next two miles, note the flat bench on which the highway is built, the exposed bedrock and eroded boulders on the left (west) side of the road, and the deep valley (100 ft. relief) of the Pleasant River on the right (east) side of the road.

The elevation of this bench is the same as the delta (about 300 ft.). It was hypothesized that this bench could be a beach adjacent to the delta, eroded at the marine limit. However, stratigraphy in the pits on the east side of the highway shows cut-and-fill cobble gravel topsets which overlie pebbly sands dipping east into the valley (foresets). The base of the foreset beds is overlain by silty clay, which also blankets the valley floor. As such, the bench is interpreted as a narrow delta deposited on the side of the strike ridge at the upper marine limit. Similar deposits may be found on the seaward side of many of the former islands in the area of marine submergence.

28.1
Cross the Maine Turnpike.

28.3

28.5
Climb bedrock/till covered hill above the marine limit (elevation about 370 ft.).

29.1
Descend to delta surface at East Gray (elevation about 300 ft.).

Note kettle on the left (north) side of the road.
Junction of Rte. 115 and Mayall Road. Turn left (north) on to Mayall Road.

STOP 7 - McKin site

Bob Gerber will discuss the aquifer and pollution modeling for this site.

Continue north on Mayall Road.

Note distal edge of delta on the right (east). Aerial photos reveal a wave cut scarp along the edge of this delta. Note the meltwater channels which cross the road from west to east.

Junction of Mayall Road and Depot Road. Continue straight (west) on Mayall Road.

Turn left into pit owned by Portland Sand and Gravel.

STOP 8 - East Gray delta and kettle

This is an example of a ridge and kettle delta: a type of glaciomarine delta unique to this area of the marine submergence. These deltas are limited to the area west of Casco Bay, where strike ridges formed islands between long arms of the marine embayment.

This type of delta is characterized by a bedrock/till covered ridge which extends above the marine limit and is adjacent to a delta located on its seaward side. A kettle or kettle lake is located between the ridge and the distal side of the delta (Fig. 7). The ridge has meltwater channels cut across its surface.

This pit is located in what has been described as the largest kettle in Maine (Leavitt and Perkins, 1935). It is about 3/4 mi. long, 1/4 mi. wide, and 100 ft. deep (Fig. 7). Different exposures in this pit show ice contact and collapse features. The east wall of the pit exposes 15 ft. of massive cobble gravel, which overlies 70 ft. of sand and gravel dipping 25° towards the north (azimuth: 200°). The topset beds dip into kettles along this wall of the pit and give evidence that the deltaic beds were deposited over a buried ice block. The topset-foreset contact measures 289 ft. a.s.l. at its highest exposure.

The model for the formation of ridge and kettle deltas incorporates a bedrock ridge along the distal side of the delta which facilitates the retention of a buried ice block within the delta. Gerber's (1983) seismic and well data appear to support this model. The model (Fig. 8) proposes that ridge and kettle deltas begin to form when
Figure 8 - Model for the deposition of ridge and kettle deltas.

Top: A bedrock ridge slows ice retreat and a glaciomarine delta begins to form.

Center: As ice retreat continues, an ice block is detached between two ridges, and becomes buried by continued deposition.

Bottom: Melting of the ice block produces a kettle or kettle lake, located between the ridge and the distal portion of the delta. Rebound produces an emerged landform.

Source: Crossen (1983a).
the retreating ice is slowed by the bedrock ridge. Parallel ridges allow retention and burial of a detached ice block. Meltwater continues to feed the delta via channels cut across the ridge as the ice retreats. This allows deposition of topset and foreset beds over the ice block. When the ice subsequently melts, a kettle or kettle lake is formed.

Return to Gray and the Maine Turnpike via Rte. 115.
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