PALEOZOIC STRATIGRAPHY AND TECTONICS, RIPOGENUS GORGE AND NEARBY AREAS, MAINE

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REGIONAL GEOLOGY

The main purpose of the field trip will be to see key rock units that bear on understanding the Acadian orogeny in north-central Maine (fig. 1). The field-trip area lies on the east limb of the Caribou Lake anticline — one segment of the Bronson Hill-Boundary Mountains anticlinorial belt. North-central Maine plays a particularly important role in the study of Acadian tectonics because Silurian and Devonian strata in the area are at least sparsely fossiliferous and are amenable to sedimentological analysis. In contrast, equivalent rocks along strike in New Hampshire and Massachusetts were so strongly deformed and (or) metamorphosed that few sedimentological details have survived the Acadian orogeny.

The highlight of the trip will be a fairly rugged traverse through Ripogenus Gorge, which Boston University geology field camp students map every year as part of their training and coursework. A geologic map of the area will be passed out during the trip, rather than being included in this paper as a published map.

The oldest rock unit in the field-trip area (fig. 2) is a Cambrian melange — the Hurricane Mountain Formation (Stop 1). Melange rocks of the Hurricane Mountain Formation have been described in an exhaustive treatise by Boone and others, (1989). It formed during the Cambrian (Boone and Boudette, 1989; Boone and others, 1989), within the Iapetus ocean, prior to the Taconic collision.

Ordovician basalts (Stops 2 and 3) that crop out along the anticlinorial belt are generally attributed to magmatism along an island arc that collided with North America during the Taconic orogeny. Angular unconformities separate the Ordovician volcanics from underlying and overlying rocks.

Silurian strata along the anticlinorial belt were deposited in relatively shallow water (fig. 2). The Ripogenus Formation (Stops 2, 3, 4, and 6) is probably the best exposed and least tectonized of a series of correlative shallow-marine units (mostly quartzose sandstone, siltstone, and impure carbonate rocks) that were deposited along the anticlinorial belt from Maine to Connecticut. These strata are tectonically significant because they record shallow-marine deposition at slow to moderate subsidence rates along the Taconic-modified margin of North America (Bradley, 1983). This implies, in turn, that subsequent rapid subsidence, which was soon to follow in the Devonian (Stop 9), was more likely due to tectonic loading than to initially thin crust.

Another key feature of the anticlinorial belt is the presence of volcanic rocks representing all four stages of the Silurian and the first three of the Devonian. These volcanic rocks are part of what we have called the Piscataquis magmatic belt (Hanson and Bradley, 1989), which includes Silurian as well as Devonian volcanic rocks, plus related plutonic rocks. The name "Piscataquis volcanic belt" was originally applied by Rankin (1968), in a much more restricted sense, to only the Early Devonian volcanic rocks along an 80-km-long segment of what is now known to be a much more extensive and longer-lived belt. We have attributed the volcanism to a magmatic arc that formed during northwest-directed subduction of the Kearsarge-Central Maine basin that eventually resulted in Acadian collision (Bradley, 1983; Hanson and Bradley, 1990). Stop 5 will feature outcrops of a Silurian volcanic rock unit, the West Branch Volcanics. The end of volcanism in the Silurian is marked by deposition of red and gray shales and siltstones of the Frost Pond Shale (Stop 7). The Emsian Traveler Rhyolite, which crops out just north of the field trip area on Soubunge Mountain, is part of the youngest extrusive episode along the Piscataquis belt.

Shallow-marine deposition along the anticlinorial belt was succeeded by deeper-water flysch sedimentation during Devonian time. The Devonian succession consists of turbidites (Seboomook Group; Stop 9) and in places, a younger succession of deltaic deposits that prograded over the turbidites (Matagamon Sandstone). The Devonian clastic rocks are interpreted as part of an ancestral Acadian foreland basin. Acadian plate convergence caused this

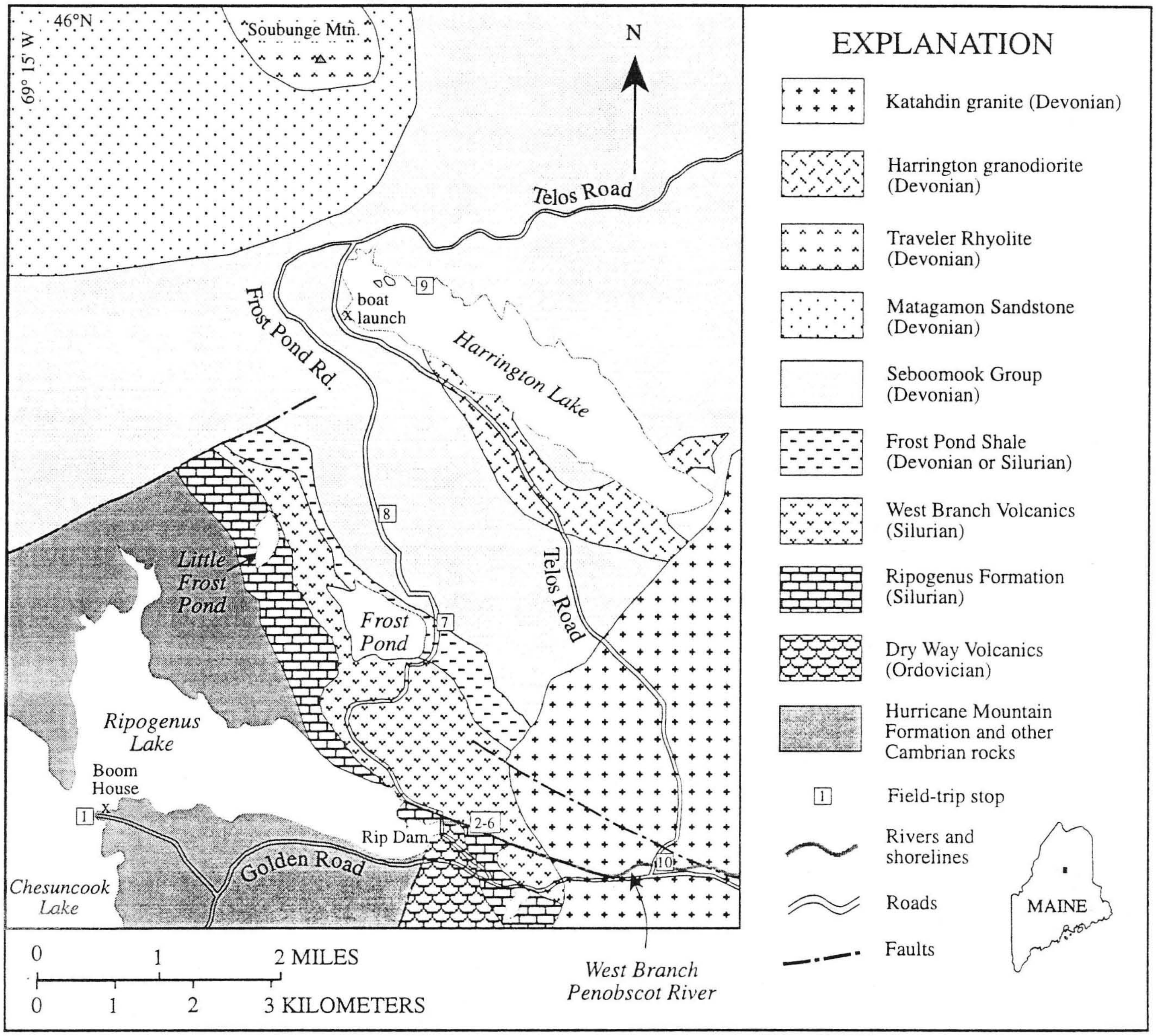

Figure 1. Geologic map of part of the Harrington Lake 15' quadrangle showing locations of field-trip stops. Adapted from Griscom (1976).

AGE (Ma)			THICKNESS (METERS)	ROCK UNIT	NOTES
380	DEVONIAN	Eifelian			
387	DEVONIAN	Eifelian / Emsian	500	TROUT VALLEY FORMATION	Post-orogenic nonmarine sandstone and conglomerate deposited in a local, probably fault-bounded basin
	DEVONIAN	Emsian		angular unconformity	Acadian regional deformation and final emplacement of Katahdin pluton
	DEVONIAN	Emsian	260	TRAVELER RHYOLITE	Calc-alkaline extrusive and hypabyssal rocks, formed in a magmatic arc
394	DEVONIAN	Siegenian	1800	MATAGAMON SANDSTONE	Deltaic sandstones, prograded to the west over prodeltaic turbidites
	DEVONIAN	Siegenian		SEBOOMOOK GROUP	Turbiditic sandstones and slates recording onset of east-derived, syn-Acadian flysch sedimentation
401	DEVONIAN	Gedinnian	200	FROST POND SHALE	Red siltstone and shale
408				?	
	SILURIAN	Pridolian	220	WEST BRANCH VOLCANICS	Subaqueous andesitic lava flows and related sills, interbedded with tuff and siltstone, probably erupted in an island arc.
414 / 421 / 428	SILURIAN	Ludlovian / Wenlockian / Llandoverian	260	RIPOGENUS FORMATION	Mainly calcareous sandstone and siltstone. Also includes limestone, limestone conglomerate, orthoquartzite, and quartz-pebble conglomerate. Corals, stromatoporoids, and wave-formed ripples record shallow marine deposition.
	SILURIAN	Llandoverian		angular unconformity	Erosion following Taconic orogeny, here recorded by a cessation of Ordovician arc magmatism and minor non-penetrative deformation
438	ORDOVICIAN			DRY WAY VOLCANICS	Pillow basalts and allied gabbroic rocks, probably erupted in an island arc
	ORDOVICIAN / CAMBRIAN			angular unconformity	Erosion following Penobscottian orogeny within the Iapetus Ocean, prior to Taconic collision
	CAMBRIAN			HURRICANE MOUNTAIN FORMATION AND OTHER UNITS	Melange and some associated coherent turbidites

LITHOLOGY

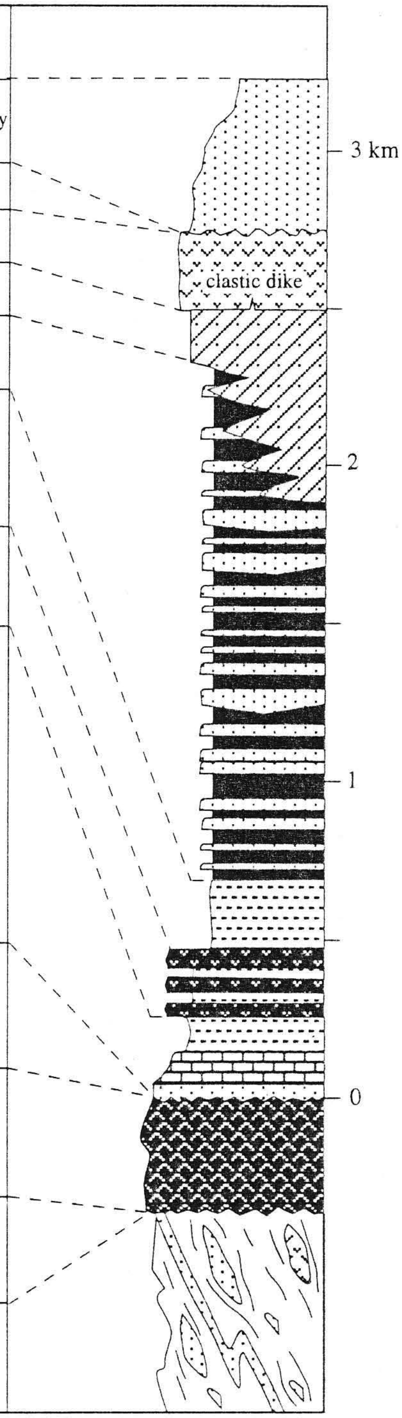

Figure 2. Stratigraphy of the Harrington Lake quadrangle, modified from Griscom (1976).

flexural depression to migrate cratonward to its final position in New York (the Catskill "delta"), but deformed, earlier incarnations of the Acadian foredeep are still preserved within the orogen throughout New England (Bradley, 1983, 1987). Along the axis of the Piscataquis magmatic belt, foredeep deposits are partly younger than, partly coeval with, and partly older than magmatism. Furthermore, foredeep deposits occur on both sides of the volcanic chain, as well as along its axis. Hence, we believe that the foredeep was superimposed on an active arc, and that subsidence was the result of flexure of the arc resulting from a thrust load that lay farther outboard (southeast). We suggest that the thrust load was the consequence of collision with the forearc of a second arc complex (the Coastal magmatic belt), which was built on the composite Avalon terrane (Bradley, 1983).

Along the anticlinorial belt, the Acadian orogeny was manifested by regional-scale open folding, greenschist-facies metamorphism, cleavage development in suitable rocks, and intrusion and contact metamorphism by two large plutons, the Katahdin and Moxie. Evidence for an Early Devonian age of Acadian deformation will be discussed at Stop 10.

FIELD TRIP LOG

Meet at the Boom House at 8:00 A.M. Road Log begins here.

STOP 1. MELANGE OF THE HURRICANE MOUNTAIN FORMATION AT CHESUNCOOK BOOM HOUSE. As exposed along the shores of Chesuncook Lake, the Cambrian Hurricane Mountain Formation is a tectonic melange consisting of a chaotic mixture of graywacke blocks and dismembered beds, in a rusty-weathering slate matrix. Along the shoreline near the Boom House, the Hurricane Mountain Formation melange consists of blocks of gabbro surrounded by a green slate matrix, with possible tuffaceous layers. Several tectonic contacts between gabbro and slate can be observed (water levels permitting), as well as thinly laminated slates disrupted by layer-parallel extension and a complex minor fault array. Elsewhere in the Chesuncook Lake area, blocks in the Hurricane Mountain Formation include mafic and silicic volcanic rocks, and gabbro.

0.0 *Drive south to Golden Road.*

1.1 *Turn left onto Golden Road.*

3.7 *Turn left (very sharp) at sign for Pray's Store.*

4.05 *Pray's Store on left (we will pull over here for last-minute purchases).*

4.1 *Take right-hand fork. Outcrops of Dry Way Volcanics at intersection.*

4.3 *Park just before crossing the dam. Walk down dirt road to outcrops at foot of dam. Plan on being away from your car for 3 -4 hours (bring lunch). The map showing locations of Stops 2-6 will be given as a handout.*

Please use caution in the gorge below the dam. Some of the outcrops are only exposed at low water, and the floodgates may or may not be open. A siren will sound shortly before they are opened. If the siren sounds, leave immediately.

STOP 2. DRY WAY VOLCANICS AND UNCONFORMITY BELOW RIPOGENUS FORMATION AT RIPOGENUS DAM. The Dry Way Volcanics consists of basalt pillows and massive flows. Griscom (1976) estimated the stratigraphic thickness at greater than 1.5 km. These volcanic rocks, and a related nearby gabbroic pluton (Bean Brook gabbro), are regarded by many workers as part of an arc terrane that collided with North America in mid-Ordovician time, causing the Taconic orogeny.

The Dry Way—Ripogenus unconformity is nicely exposed in the bottom of the gorge. Although bedding is hard to find in the Dry Way Volcanics, a fairly convincing angular unconformity can be seen in at least one place. Here, a jasper bed in the Dry Way Volcanics is truncated by the basal quartzose clastics of the Ripogenus Formation, suggesting that this contact is an angular unconformity. Hematite is locally present along the contact, and in thin fissures just below it, suggesting that an interval of subaerial erosion (corresponding to the time of Taconic orogenesis across strike in Quebec) preceded deposition of the Ripogenus (Griscom, 1976). A bed of quartz-pebble conglomerate directly overlies the Dry Way Volcanics. It is overlain by a few meters of quartzose sandstone, followed by approximately 10-15 meters of pitted calcareous sandstone (classic Ripogenus Formation). The latter rocks are best reached by descending from the north end of the dam, which will be Stop 6.

Follow Dry Way (a high-water channel of the West Branch Penobscot River) downstream ~100 m to pool.

STOP 3. DRY WAY VOLCANICS AND LOWER PART OF RIPOGENUS FORMATION ALONG THE "DRY WAY". Basal quartzose clastics (sandstone, pebble conglomerate) of the Ripogenus Formation overlie the Dry Way Volcanics along a sharp contact. The 1- to 3-meter-thick basal clastic unit of the Ripogenus Formation is overlain by several tens of meters of calcareous sandstone. Weathered exposures display conspicuous rows of elliptical pits (typically 10-20 cm thick) at the more calcareous horizons. Shallow marine fossils, which commonly are found within these pits, include tabulate corals, rugose corals, and stromatoporoids. In nearby exposures, two polymict cobble-conglomerate horizons have been identified in the calcareous sandstone member. These cobble conglomerates contain rounded, intraformational clasts of calcareous sandstone, calcareous siltstone, and limestone. In addition, one bed (~5 m thick) of light gray orthoquartzite occurs part way up the calcareous sandstone member. Griscom (1976) estimated the overall thickness of the Ripogenus Formation at about 260 m.

The same rocks are better exposed and more photogenic at Stop 2 than at Stop 3, provided the floodgates are closed. If the unconformity at Stop 2 is accessible on the day of the field trip, we will only spend a short time at Stop 3. Stop 3 can be fairly miserable during black-fly season, according to a number of former B.U. field camp students.

Traverse up section perpendicular to strike through woods for ~100 m to large outcrops along the river.

STOP 4. SILTSTONE MEMBER OF THE RIPOGENUS FORMATION. The upper part of the Ripogenus Formation consists mainly of thin-bedded, green and white, calcareous siltstone. A horizon of pitted calcareous sandstone occurs near the base of the siltstone, suggesting an intertonguing relationship between the siltstone and calcareous sandstone members. Several hundred meters downstream along the south bank, the siltstone is conformably overlain by the West Branch Volcanics. The siltstone has been contact metamorphosed by the Katahdin pluton and (or) sills associated with the overlying West Branch Volcanics.

Go upstream 50-100 m and cross river on stepping stones above large pool. (If water is high, we will retace route to cars without crossing the river, and will get to Stop 5 by crossing the dam.)

STOP 5. WEST BRANCH VOLCANICS. The river here follows a vertical oblique-slip fault with a component of north-side-down displacement. The West Branch Volcanics is exposed on the north bank. It consists of prominent, cliff-forming intermediate volcanic flows and sills, plus less resistant, slope-forming tuff and siltstone. At this stop, two sills sandwich a ~10 m interval of siltstone. Pillows and wave-formed ripple marks in the West Branch Volcanics together indicate shallow-water deposition. The West Branch Volcanics are a calc-alkaline series with "transitional" affinities on various discriminant plots (Fitzgerald, 1991). The West Branch Volcanics form part of the Silurian and Devonian Piscataquis magmatic belt that lies along the northwestern margin of the Kearsarge-Central Maine basin. As mentioned in the introductory text, this magmatic belt is regarded as the product of subduction that led to the Acadian collision.

Scramble uphill to dirt road. Turn left and walk a few hundred meters to Ripogenus Dam. At the north end of the dam, scramble about 100 feet down a path next to sluiceway.

STOP 6. CALCAREOUS SANDSTONE - PITTED LIMESTONE MEMBER OF RIPOGENUS FORMATION AT RIPOGENUS DAM - NO HAMMERS! Time permitting, a photogenic outcrop of the typical pitted calcareous sandstone of the Ripogenus Formation will be examined at this location. These strata directly overlie the basal clastic rocks of the Ripogenus Formation as seen at Stop 2. Here, stromatoporoids are preserved in the carbonate pits, and a few tabulate and rugose corals may be found.

4.3 *Return to cars. Cross dam on Frost Pond Road and follow it to Frost Pond.*

7.1 *Park along roadside opposite the northernmost campsite at Frost Pond Campground.*

STOP 7. FROST POND SHALE AT FROST POND. This small exposure of red shale is the most accessible "rubble-crop" of the distinctive red Frost Pond Shale. The shale consists of 40% quartz, 25% plagioclase, 20 % muscovite, 15% fine-grained hematite, and minor chlorite and calcite (Griscom, 1976). Griscom (1976) estimated the Frost Pond Shale to be 200 meters thick in this area, and suggested a gradational contact with the overlying Seboomook Group. Bedding is marked by a few steeply dipping tan silty horizons, but we are uncertain as to whether or not this outcrop is truly in place.

7.1 *Return to cars. Continue north on Frost Pond Road.*

8.1 *Drive past moss-covered outcrop of gray siltstone and slate on left.*

8.2 *Stop at pavement outcrop on right.*

STOP 8. PENCIL CLEAVAGE IN DEVONIAN SHALE.

At this quick stop we will observe well-developed pencil cleavage in what Griscom (1976) mapped as the lower part of the Seboomook Group (his Seboomook Formation). However, because of the lack of distinctive turbidite sequences in this gray-brown shale-siltstone, which characterize the rest of the Seboomook Group, we feel that these dark shales may best be included as an upper member of the Frost Pond Shale. In either case, the outcrop here preserves a northeast-striking fold hinge, marked by nearly right angles between bedding (subhorizontal) and cleavage (steep). The cleavage - bedding intersection angle forms numerous "pencils", available for collection.

8.2 *Return to cars. Continue north along Frost Pond Road.*

10.5 *Cross Duck Brook.*

10.65 *Slump folds in reddish/buff sandstone in roadway. Overall dip is about 10° toward the southwest.*

11.5 *5-way intersection. On left see Soubunge Mountain (top is Traveler Rhyolite, rest is Matagamon Sandstone). Turn right on Telos Road.*

12.2 *Park in pull-off on right. Walk across road to boat launch area, and ride boats about one-half mile to the north shore of Harrington Lake. The outcrop can be reached during extreme low-water by traversing along shore from the west end of the lake, but at normal water levels, the outcrop becomes an island.*

STOP 9. SEBOOMOOK GROUP AT HARRINGTON LAKE - NO HAMMERS! This stop will involve a short boat trip to a superb exposure of turbidite and slump deposits of the Seboomook Group, part of the Acadian foredeep described in the introductory text. The Seboomook is a name applied throughout most of Maine to a flysch sequence that blanketed the area during Early Devonian time. In the Harrington Lake quadrangle, Griscom (1976) estimated its thickness at about 1500 m. The Seboomook is overlain by prograding deltaic deposits of the Matagamon Sandstone (Hall and others, 1976). Overall sediment transport was toward the west.

Turbidites at this outcrop belong to Facies D of Mutti and Ricci-Lucchi (1972). Foreset cross laminae indicate that paleocurrents were dominantly toward the west (fig. 3). Sedimentary structures are seldom preserved this well in the Acadian orogen of Maine. None of the typical problems that have thwarted paleocurrent analysis in the northern Appalachians are serious here (for example, tilt-correction of steeply plunging folds, correction for strain, 2-D exposures, obliteration by deformation or metamorphism, and poor fossil control).

A spectacular example of a stratabound, contractional slump deposit overlies the coherent turbidites (fig. 3). This slump shows a classic "rumpled rug" fold geometry and therefore is amenable to paleoslope analysis by the "mean-axis" method. The paleoslope is normal to the tilt-corrected strike of axial planes and trend of fold axes, i.e., toward either 075° or 255°. Considering the westerly paleocurrents, 255° is the obvious choice.

12.2 *Return to cars. Continue south on Telos Road.*

18.1 *Park in small parking area immediately before Telos Bridge. Cross road to outcrop.*

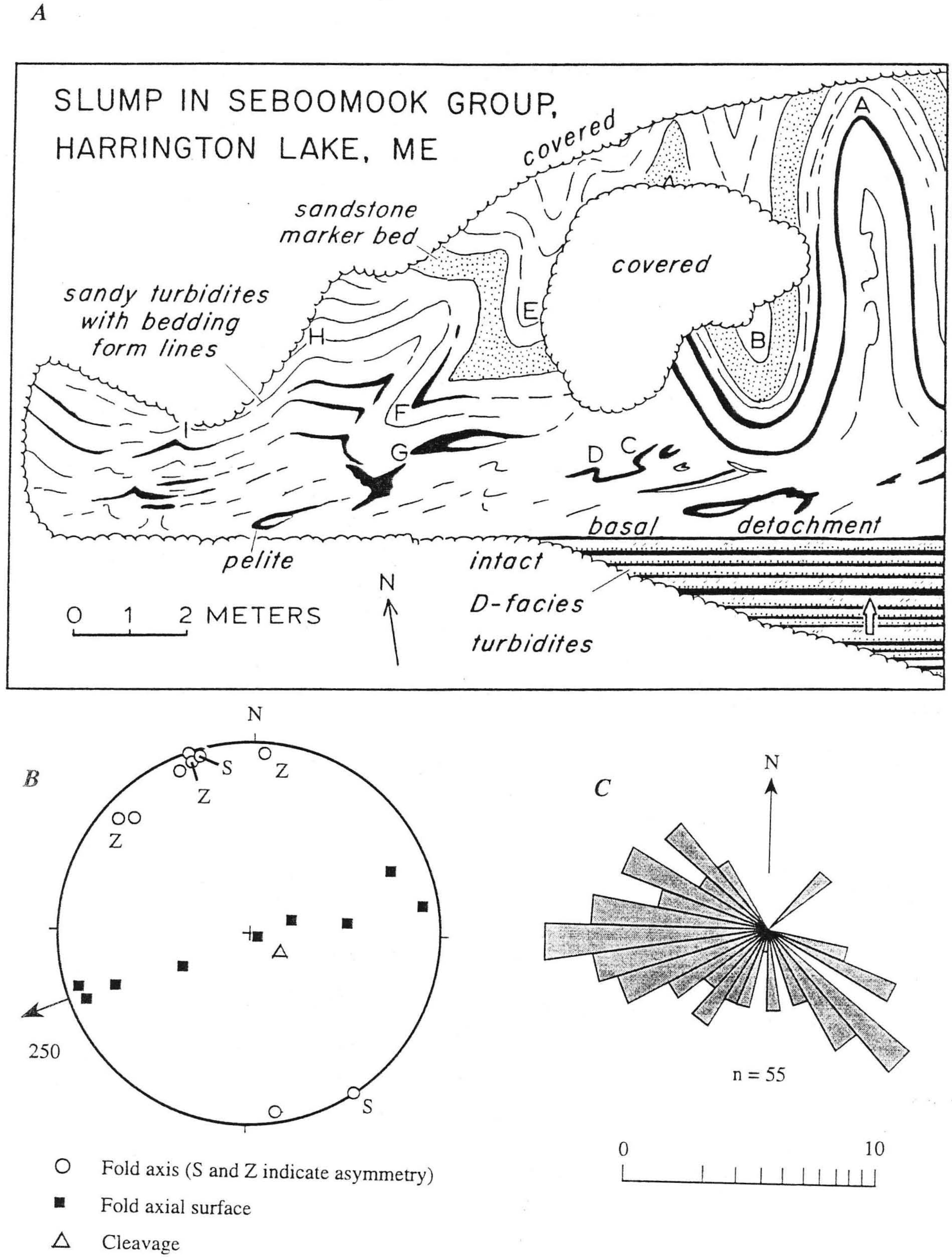

Figure 3. (a) Tape-and-compass map of slump deposit at Stop 9. (b) Lower-hemisphere equal-area projection of structural data from slump folds in a. A paleoslope of about 250° is inferred from the mean strike of fold axial surfaces and the mean trend of fold hinges. (c) Paleocurrent rose for turbidite cross laminae in coherent part of Seboomook Group underlying the slump horizon.

Walk down hiking trail to pavement outcrop containing mafic enclave and joints. Continue to picnic area for discussion of regional tectonics and end of field trip.

STOP 10. KATAHDIN GRANITE AT THE CRIB WORKS (TELOS BRIDGE). The Katahdin pluton consists of granite, which includes 34% quartz, 34% alkali feldspar, 26% plagioclase (An_{25-34}), 5-6% biotite, plus accessory apatite, allanite, tourmaline, zircon, and opaques (Hon, 1980). Accessory allanite is conspicuous here; it is recognized by its dark metallic luster, red halo and radial fractures in surrounding minerals. Between here and our earlier stops in Ripogenus Gorge, several sill-like apophyses of the Katahdin Granite intrude interbedded siltstone and volcanic rocks of the West Branch Volcanics. Here at the Crib Works, the Katahdin pluton is cut by three main sets of joints, including a northeast-striking set, an east-southeast-striking set, and a subhorizontal set. The two steep joint sets control the course of the West Branch of the Penobscot River, with the main river course being parallel to the West Branch fault system (with associated east-southeast joints), and minor bends like that at the cribworks being controlled by the northeast-striking set.

The following considerations suggest that magmatism partly predated but largely postdated Acadian deformation: (1) the pluton truncates regional folds that deform rocks as young as the Traveler Rhyolite (Emsian, 394-387 Ma according to the DNAG time scale); (2) the Traveler Rhyolite, however, constitutes the volcanic carapace of the pluton (Hon, 1980); (3) the pluton itself shows no signs of tectonic deformation; (4) deformation within the contact aureole appears to be less intense than outside the aureole, and (5) isotopic ages from the pluton are widely scattered and inconsistent with stratigraphic constraints. Loiselle and others (1983) reported ages of 414±4 Ma ($^{207}Pb/^{206}Pb$ zircon) and 388±5 Ma (Rb/Sr whole rock); Denning and Lux (1989) reported an age of 400±1 Ma ($^{40}Ar/^{39}Ar$ biotite). Geochemistry suggests that this magmatism was the product of subduction (Hon, 1980).

18.1 *Return to cars. Continue 0.1 mile on Telos Road to intersection with Golden Road. Turn right (5.2 miles) to return to Boom House. Alternatively, turn left (approximately 30 miles) to Millinocket.*

22.2 *Turn right off Golden Road*

23.3 END OF FIELD TRIP AT BOOM HOUSE

ACKNOWLEDGMENTS

Research on the Seboomook Group was supported by the National Science Foundation (Grant #EAR87-20915: Lindley Hanson, Principal Investigator; Co-Investigator, Dwight Bradley). We extend our thanks to the numerous Boston University Northern Appalachian geology field camp students who have participated in the mapping of the area.

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1994

NEW ENGLAND INTERCOLLEGIATE
GEOLOGICAL CONFERENCE
85th ANNUAL MEETING

GUIDEBOOK TO FIELD TRIPS IN NORTH-CENTRAL MAINE

SEPTEMBER 23, 24. 25
MILLINOCKET, MAINE

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