TECTONIC SIGNIFICANCE OF CAMBRO-ORDOVICIAN AND SILURO-DEVONIAN STRATIGRAPHY AND MAGMATISM IN THE CHESUNCOOK LAKE AND RIPOGENUS GORGE AREA, NORTH-CENTRAL MAINE

by
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INTRODUCTION

This trip will allow participants to see various aspects of the Cambro-Ordovician and Siluro-Devonian geology in the Ripogenus Gorge and surrounding areas (Chesuncook Dome, Figure 1). We include key aspects of the stratigraphic and magmatic relationships in the area. The Ripogenus Gorge and surrounding area was first mapped in detail by Griscom (1976) and there have been several studies that have looked at various aspects of the area since then (Rankin, D.W. 1961; Hynes 1976; 1981; Fitzgerald 1991; Winchester and van Staal 1994; Kusky et al. 1994; Fitzgerald and Hon 1994; Bradley et al. 2000; Schoonmaker et al. 2005; Schoonmaker and Kidd 2006; Schoonmaker et al. 2011). Collectively, a number of these studies have produced a significant database of geochemical analyses from the intrusive and volcanic rocks from the gorge and surrounding areas. In addition, several years of mapping by students in the Department of Earth and Atmospheric Sciences at the University at Albany has resulted in an improved detailed picture of the geology in the Ripogenus Gorge and surrounding area. This has led to conclusions regarding the Cambro-Ordovician and Siluro-Devonian sections by the authors detailed in Schoonmaker and Kidd (2006) and Schoonmaker et al. (2011), respectively. This trip will illustrate and discuss the details of these studies.

The pre-Seboomook geologic history in this area can be broadly divided into Cambro-Ordovician and Siluro-Devonian sections (Figure 2). The first several stops (#1-3B) will concentrate on the older rocks, while the subsequent stops (#3B-6) will examine the younger Siluro-Devonian rocks. In the Cambro-Ordovician section we concentrate on the relationship between mélange and its contact with intrusive/volcanic rocks and the geochemistry of the magmatic rocks to make inferences concerning their likely tectonic setting. In the Siluro-Devonian section, detailed stratigraphic relationships and the geochemistry of related volcanics are examined to place constraints on the early Acadian Orogen.

CAMBRO-ORDOVICIAN GEOLOGY

Stratigraphy

The Cambro-Ordovician geology of the Chesuncook Lake and related areas is summarized in Figures 2 and 3. Griscom (1976) identified three stratigraphic units (unnamed Cambrian? undifferentiated rocks, Chesuncook Dam Formation, and Sawmill Formation). The Chesuncook Dam Formation is not shown in figures 2 or 3, but conformably underlies the Sawmill Formation. Another unit, the Southeast Cove Formation is mainly siltstones and some sandstone and was described by Jarhling (1981, referenced in Boone and Boudette 1989). The Hurricane Mountain mélange occurs to the southwest and is probably related to the Sawmill Formation in this area. The unnamed Cambrian (?) undifferentiated rocks described by Griscom include massive graded and cross-bedded graywacke, siltstone, and shale containing some conglomeratic beds. Some calc-silicate horizons were reported by Griscom (1976) and suggest that originally calcareous beds were also present. The Chesuncook Dam Formation is dominantly purple and green shale or slate and tuffs with occasional siltstone and rare sandstone beds. The next unit, the Sawmill Formation, is in some places a chaotically deformed olistostromal and structural mélange unit composed of graded sandstone, siltstone and shale. Collectively, these rocks (unnamed Cambrian? Undifferentiated rocks, Chesuncook Dam Formation, and Sawmill Formation) suggest continental rise-type deposition and we suggest that they could be grouped together (Boom House Group, new name) based on their general similarity of facies.

The Sawmill Formation, in places, displays olistostromal or structural disruption as evidenced by chaotically disrupted beds; sandstone and quartzite beds are sheared and brecciated, and less competent siltstone and shale beds are squeezed and disrupted between the more competent sandstone beds. Based on this style of deformation and position in the stratigraphic section, it is likely that the Sawmill Formation is the northeastern equivalent to the Hurricane Mountain Mélange further to the south. Mélange formation is typically associated with deformation in fore arc basins of subduction zones, but no associated arc has been identified for this event, although tuffs are reported from the Chesuncook Dam Formation (Griscom 1976). Numerous gabbro intrusions occur within the Sawmill Formation. In some places, these display clear intrusive contact with chill margins, while in other places, the gabbro-country rock contact is cataclastically deformed indicating syn-deformational intrusion with at least some magmatism during the waning stages of mélange development.

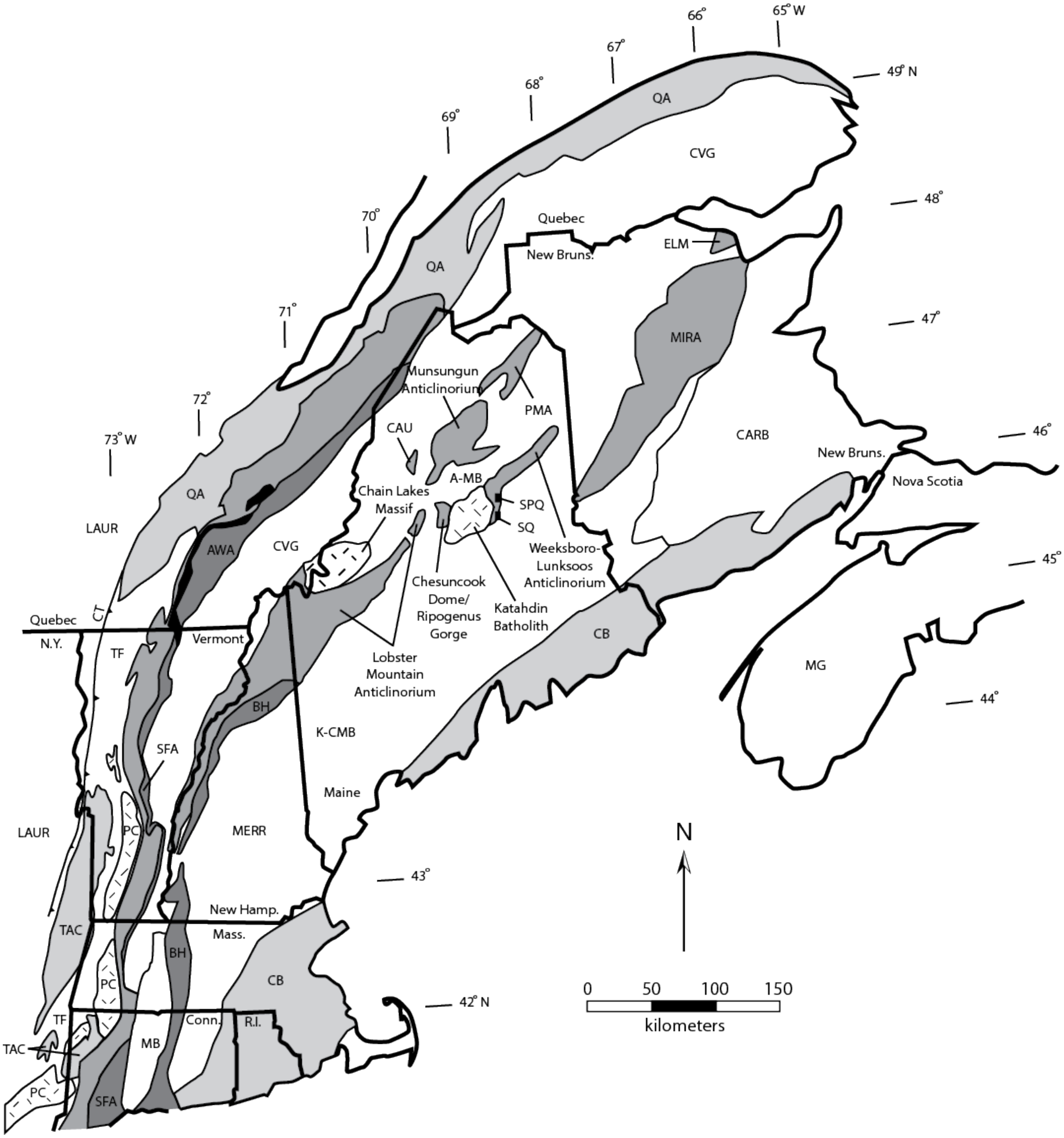


Figure. 1. Generalized geology of the northern Appalachians. Pre-Devonian units are shaded. LAUR=autochthonous Laurentian margin, QA=Quebec Allochthons, TAC=Taconic Allochthons, TF=transported Laurentian margin and basin deposits, PC=Precambrian massifs, SFA-AWA=Shelburne Falls arc, Ascot-Weedon arc, and related oceanic rocks, including ophiolitic fragments (black), MB=Mesozoic basin, CVG=Connecticut Valley Gaspe Synclinorium, BH=Bronson Hill Arc, MERR=Merrimack Synclinorium, CAU=Caucomgomoc inlier, A-MB=Aroostook-Matapedia belt, SPQ=Shin Pond quadrangle, SQ=Stacyville quadrangle, PMA=Pennington Mtn. Anticlinorium, MIRA=Miramichi Highlands, KCMB=Kearsarge-Central Maine belt, ELM=Elmtree-Belledune inlier, CARB=Carboniferous cover rocks, CB=Coastal belt, MEG=Meguma terrane. Adapted from Williams (1978), Osberg et al. (1985), and Robinson et al. (1998) and Schoonmaker et al. (2011).

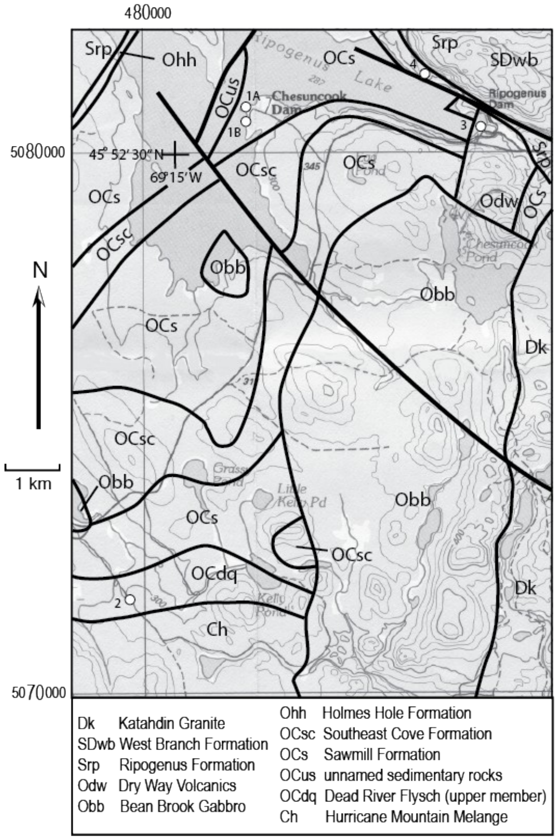


Figure 2. Geologic map of part of the Chesuncook Dome with some sample locations. Modified from Osberg et al. (1985).

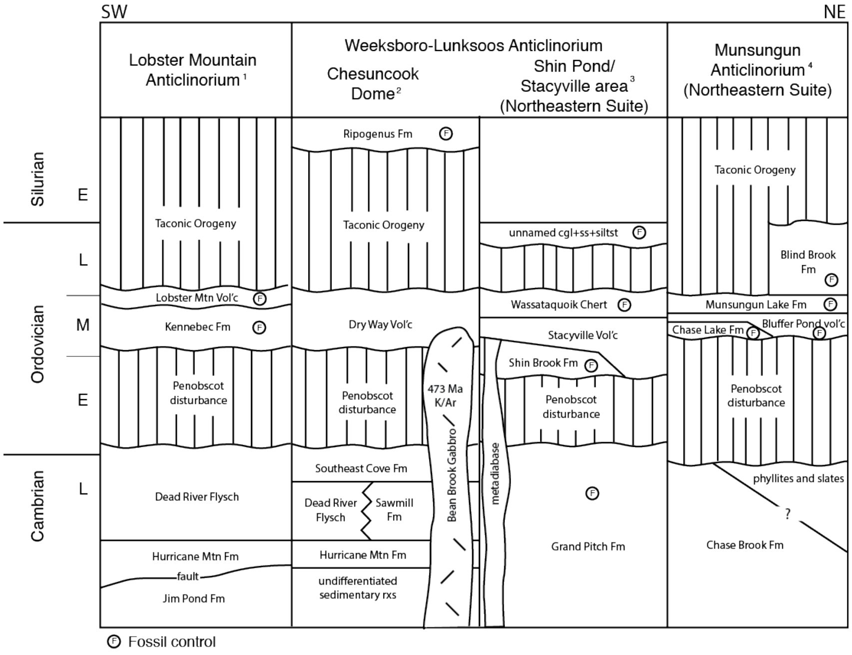


Figure 3. Correlation chart of Silurian and older rocks of north-Central Maine. Compiled from: [1]Boone and Boudette (1989), Boone et al. (1989, Boucot (1969), and Simmons Major (1988); [2]This study, Griscom (1976), Jarhling (1981, cited in Boone and Boudette, 1989), and Osberg et al. (1985); [3]Neuman (1967); [4]Hall (1970). From Schoonmaker and Kidd (2006).

Southwest of the Chesuncook Dam area are phyllites and schists metamorphosed from finely interbedded sandstones and shales (Stop 2). They display a strong, isoclinally folded compositional foliation that is in turn deformed by chevron folds that may be Acadian in age, based on relationships seen in the Caucomgomoc Lake area. The degree of deformation and metamorphism in these rocks is greater than rocks seen along the shores of Chesuncook Lake and these may be part of the Hurricane Mountain Mélange. They fall within the area shown as the upper member of the Dead River Flysch but may also be laterally equivalent to the Sawmill Formation or other rocks in the Boom House Group, based on lithology. However, the metamorphic and structural contrast with those rocks seen at Chesuncook Lake suggests a fault contact exists between the two areas.

The deformed schists at Stop 2 (Dead River Flysch?) are intruded by medium-grained dolerite dikes and dike contacts display a lobate pattern that generally conforms to the orientation of the observed Acadian meso-folds indicating intrusion occurred prior to Acadian orogenesis. A large plutonic body, the Bean Brook Gabbro, occurs directly to the east a few hundred meters away and to which the dikes are likely related. Traversing east towards the main body of gabbro, outcrops become increasingly dominated by dolerite and gabbro until no country rocks are evident at the mapped perimeter of the gabbro. The Bean Book Gabbro was dated at 473 Ma by Faul et al. (1963; K-Ar, no quoted error). Additionally, in the area around Ripogenus Lake and in the upper part of the Ripogenus Gorge are pillowed basalts of the Dry Way Volcanics that unconformably underlie the Ripogenus Formation of Lockhovian age. The Dry Way Volcanics have been correlated with Bluffer Pond Volcanics and the Kennebec Formation that are constrained by fossils to be Middle Ordovician. They are also correlated with the Stacyville Volcanics that underlie the Wassataquoik Chert of late Middle Ordovician age in the Shin Pond area. The trace element geochemistry of the Bean Brook Gabbro, Dry Way Volcanics, and gabbro intrusions in the Sawmill Formation and general coincident timing of the Bean Brook and Dry Way Volcanics indicate they are all genetically related.

Geochemistry of the Bean Brook Gabbro and Dry Way Volcanics

Three previous studies presented geochemical analyses of Bean Brook Gabbros and Dry Way Volcanics (Fitzgerald 1991; Winchester and van Staal 1994; Schoonmaker and Kidd 2006) and are referred to as the Chesuncook Dome Suite. Samples from correlatives in the other pre-Devonian inliers of northern Maine have been reported by other authors and compiled in Schoonmaker and Kidd (2006) and are referred to as the Northeastern Suite. The chemistry of the Northeastern Suite largely resembles those of the Chesuncook Dome as discussed below. Because the mafic igneous rocks have experienced lower greenschist grade metamorphism, our discussion below uses immobile trace element concentrations to discriminate magma source and tectonic setting during magmatism. We follow the conclusions reached in Schoonmaker and Kidd (2006).

The flat pattern shown on the chondrite-normalized diagram (Figure 4A) indicates that the mantle source is likely depleted, although there is slight enrichment similar to E-MORB. However, there is a lack of negative slope usually associated with E-MORB. On the MORB-normalized diagram (Figure 4B), a relatively flat pattern is also evident for most elements, except that there is significant enrichment in Th and Ce, relative to Ta and Nb. This Ta-Nb negative anomaly is generally seen in arc volcanics, although the Ta-Nb negative anomaly seen in these rocks is not as pronounced as in typical arc volcanics.

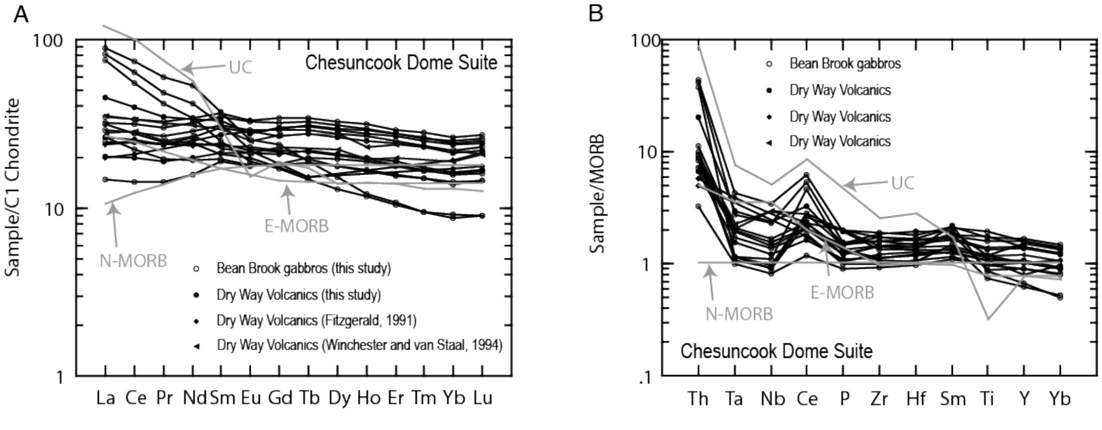
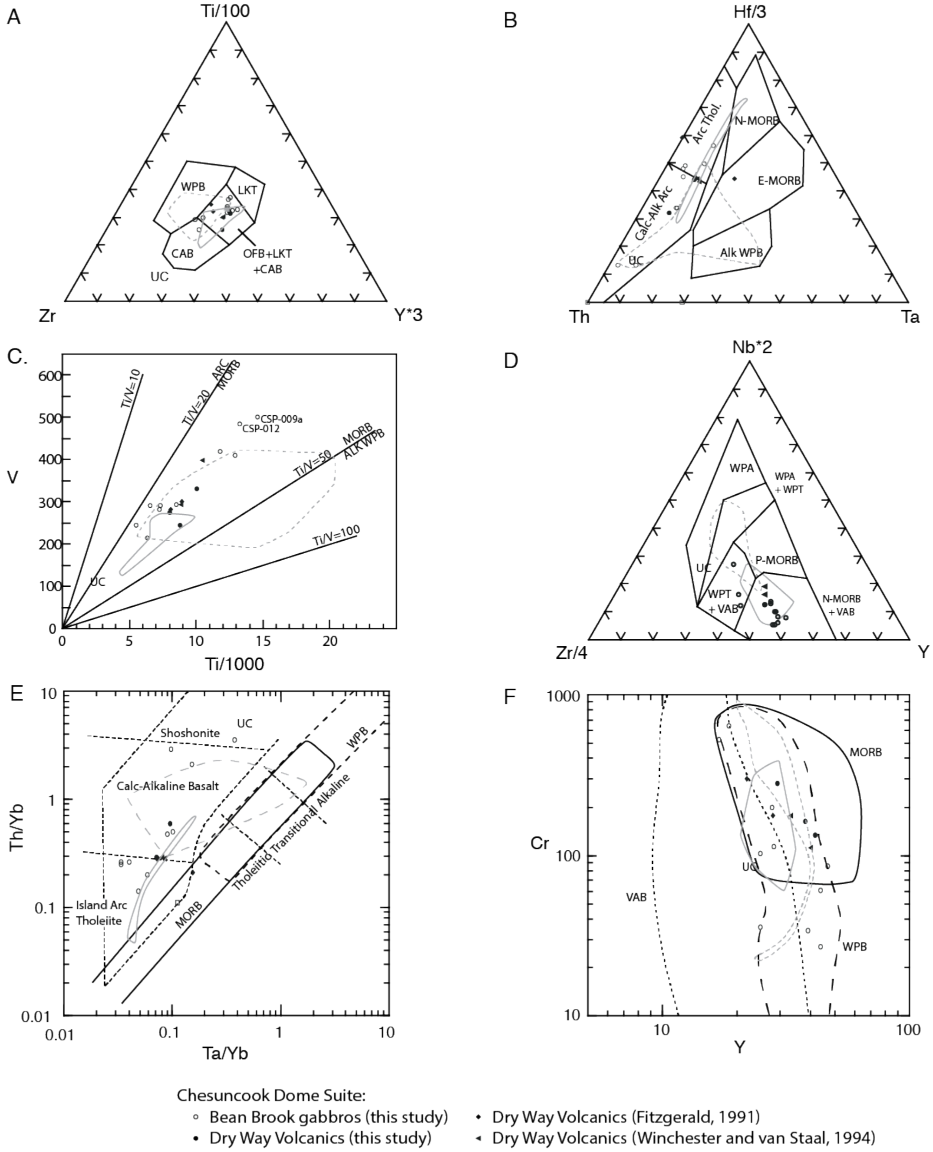


Figure 4. C1-chondrite (REE; A) and MORB (trace element; B) normalized diagrams. UC = upper crustal composition, from McLennan (2001), N-MORB = normal, depleted mantle-derived mid-ocean ridge basalt composition from Sun and McDonough (1989), E-MORB = enriched mid-ocean ridge basalt from Sun and McDonough (1989). Normalization values from Sun and McDonough (1989). Modified from Schoonmaker and Kidd (2006).

On tectonic discrimination diagrams (Figure 5), conflicting conclusions can be drawn. On all Th-based diagrams (Figure 5B and 5E), the enrichment of Th causes the rocks to plot in arc fields. However, on discrimination diagrams not based on Th, a different setting is indicated. On diagrams that do not discriminate between MORB and arc (Figures 5A and 5D), samples plot in the arc-MORB overlap fields. On diagrams that do discriminate between MORB and arc (Figures 5C and 5F), samples plot exclusively in MORB fields.



Chesuncook Dome Suite:
- ◦ Bean Brook gabbros (this study)
- • Dry Way Volcanics (this study)
- • Dry Way Volcanics (Fitzgerald, 1991)
- ◂ Dry Way Volcanics (Winchester and van Staal, 1994)

Figure 5. Tectonic discrimination diagrams. UC = upper continental crust composition from McLennan (2001). Gray solid line = field for Chile margin and Chile Ridge basalts (see Figure 7 caption for sample numbers). Gray dashed line = field for within-plate basalts (see Figure 7 caption for locations and sample numbers) a.) Ti-Zr-Y diagram of Pearce and Cann (1973), WPB = within plate basalts (oceanic and continental), OFB = ocean floor basalts, LKT = low-K tholeiites, CAB = calc-alkaline basalts; b.) Th-Hf-Ta diagram of Wood (1980), Calc-Alk Arc = calc-alkaline volcanic arc basalt, Arc Thol.= volcanic arc tholeiite, N-MORB = normal, depleted mid-ocean ridge basalt, E-MORB = enriched mid-ocean ridge basalt, Alk WPB = alkaline within-plate basalt; c.) Ti-V diagram of Shervais (1982), ARC = volcanic arc basalt, MORB = mid-ocean ridge basalt, ALK WPB = alkaline within-plate basalt; d.) Nb-Zr-Y diagram of Meschede (1986), WPA = within-plate alkaline basalts, WPT = within-plate tholeiites, P-MORB = plume-influenced mid-ocean ridge basalt, N-MORB = normal, mid-ocean ridge basalt, VAB = volcanic arc basalt; e.) Th/Yb-Ta/Yb diagram of Pearce (1982), MORB = mid-ocean ridge basalt, WPB = within-plate basalt; f.) Cr-Y diagram of Pearce (1982), VAB = volcanic arc basalt, MORB = mid-ocean ridge basalt, WPB = within-plate basalt. Modified from Schoonmaker and Kidd (2006).

Tectonic Setting of the Bean Brook Gabbro and Dry Way Volcanics

The apparent conflict in tectonic setting indicated by the geochemistry can best be explained if the Bean Brook Gabbro and Dry Way Volcanics erupted in a ridge subduction setting (Figure 6). Similar geochemical signatures are seen in the modern ridge subduction setting along the Chile Margin. The Taitao Peninsula, where the actively spreading Chile Ridge is currently subducting beneath South America, contains a series of volcanics erupted up through the actively deforming forearc region and whose geochemical makeup is similar to those of the Chesuncook Dome suite (Le Moigne et al. 1996; Figure 7). These have E-MORB-like signatures with anomalous Th-enrichment and apparent arc signatures. Further, the Chile Ridge segments closest to the trench also show similar composition. Klein and Karsten (1995) attributed this to the migration of subduction zone fluids laterally into the upper mantle beneath the spreading ridge.

This conclusion is consistent with the stratigraphic setting of the Bean Brook and Dry Way Volcanics. The Cambro-Ordovician sedimentary rocks were all deposited as deep water sediments adjacent to a continental margin, some while the margin was actively deforming. Tuffs in the Chesuncook Dam Formation may be related to the nearby arc activity. The gabbros in the Boom House Group are shown to be in both intrusive and sheared contact with the surrounding sediments and mélange, indicating that the gabbros intruded into turbiditic sediments, but that some were dismembered from their feeders in the actively deforming forearc.

Ordovician volcanics from other northern Maine inliers have similar contact and stratigraphic relationships as those from the Chesuncook Dome (Stacyville Volcanics, Bluffer Pond Volcanics, Munsungun Fm, Lobster Mountain Volcanics; see Figure 2). Geochemical analyses of these rocks by Winchester and van Staal (1994) show them to be similar in trace element concentration to the Chesuncook Dome suite, indicating that Ordovician-aged magmatism in these areas may also be related to ridge subduction. Recent geochemical analyses and contact relations from the Caucomgomoc Lake inlier are also consistent with this conclusion (see the Saturday Caucomgomoc Lake trip in this guidebook).

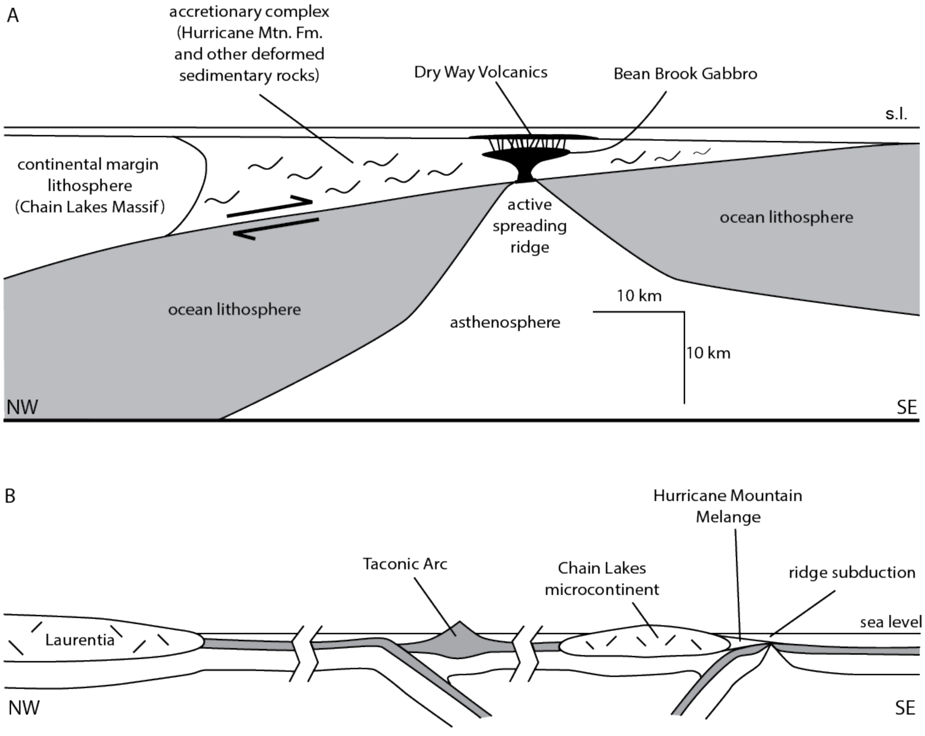


Figure 6. Schematic cartoons of the early to middle Ordovician Taconic ocean illustrating: a.) Ridge subduction beneath Chain Lakes Massif and b.) Relationship of Chain Lakes microcontinent to pre-Taconic Laurentian margin and Taconic arc. From Schoonmaker and Kidd (2006).

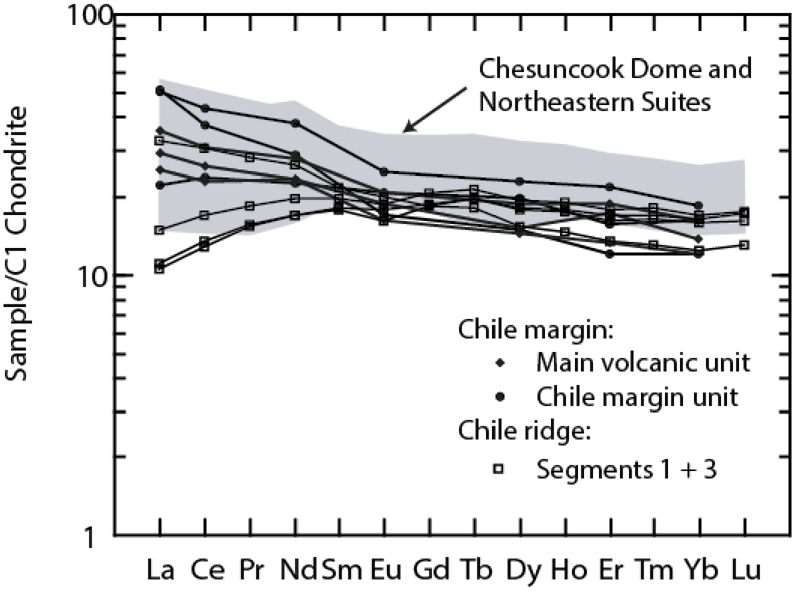


Figure 7. C1-chondite normalized REE diagram of the Chile Margin and near trench Chile ridge segments. Normalization values from Sun and McDonough (1989). Chile margin basalts from Le Moigne et al. (1996); T8g2, T15b, T16b, T26e, T20e, T28b. Chile Ridge segments from Klein and Karsten (1995); D14-9, D20-1, D42-4, D53-2. The gray field encompasses the REE composition of the Chesuncook Dome and correlative rocks from the Munsungun and Lobster Mountain anticlinoria. From Schoonmaker and Kidd (2006).

SILURO-DEVONIAN GEOLOGY

Stratigraphy

In the Ripogenus Gorge there is a well-exposed section of Siluro-Devonian sedimentary and volcanics rocks that unconformable overlie the Ordovician Dry Way volcanics. This includes the Ripogenus Formation and West Branch Volcanics that are almost continuously exposed. These are overlain by the Frost Pond Shale that occurs directly to the north of the gorge, which is in turn conformably overlain by the Seboomook Formation (Griscom 1976; figures 8 and 9). Overall, the stratigraphic section is one of shallow water sedimentary units, overlain by deeper water sedimentary rock interstratified with mafic volcanics, deposited prior to the onset of Acadian flysch deposition (Seboomook Formation) in this area. These rocks record the changing sedimentary and magmatic environment leading up to the Acadian Orogeny and provide insights into the evolution of the Acadian Orogen.

The basal Ripogenus Formation is a coarse-grained arenite containing quartz pebbles along its base. It is observed to unconformably overly the Dry Way Volcanics in the gorge (stops 3A and 3B). It grades into “pitted sandstone” containing differentially-weathered, discontinuous limestone beds. This is overlain by fossiliferous, bedded limestone containing conodonts of Lockhovian age (Bradley et al. 2000). Its contact with the underlying arenites is discontinuously marked by a clean, white orthoquartzite composed of mature quartz grains. The orthoquartzite is discontinuous over relatively short distances (100’s of meters) and probably represents shoreline sediment re-deposited into topographic valleys that were eroded during a short-lived emergence of the sedimentary platform; we interpret the boundary marked by the orthoquartzite to be a disconformity.

The bedded limestone grades quickly up into limestone breccia suggesting that topographic discontinuities (normal fault scarps) were introduced into the section (see discussion of Stop 3). Above the limestone breccia are a series of argillites and siltstones, and then mafic volcanics (West Branch Formation). The siltstones show sedimentary features suggestive of contourite deposition. Outside of the gorge and to the north are exposures of red Frost Pond Shale, a unit that is up to 200 meters thick (Griscom, 1976). This monotonous unit, mainly composed of red and purple shale occasionally interstratified with darker colored siliceous slate and shale, along with the underlying siltstones interstratified with the West Branch Volcanics suggest deep-water, marine sedimentation.

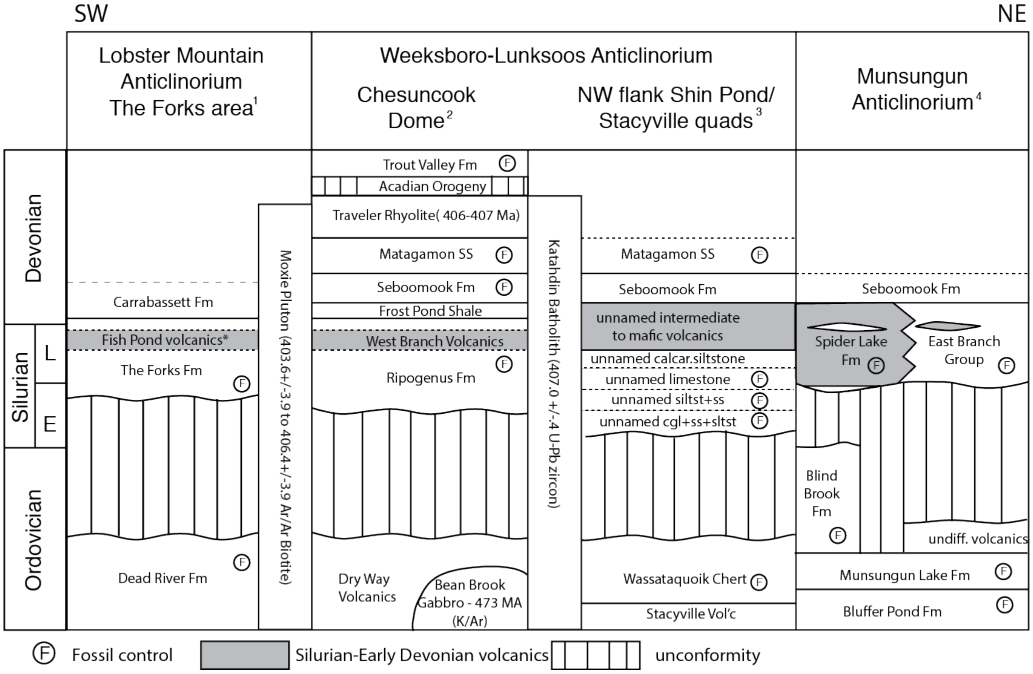


Figure 8. Correlation chart of Ordovician through Devonian rocks of north-Central Maine. Igneous ages from Faul and others 1963; Rankin and Tucker 1995; and Bradley and others 2000. Compiled from: 1Marvinney 1982; 1984; Burroughs and Marvinney 1981; 2Schoonmaker et al. 2011, Griscom (1976), Jarhling (1981, cited in Boone and Boudette, 1989), Osberg and others (1985), and Rankin and Hon (1987); 3Neuman (1967); 4Hall (1970). From Schoonmaker et al. (2011).

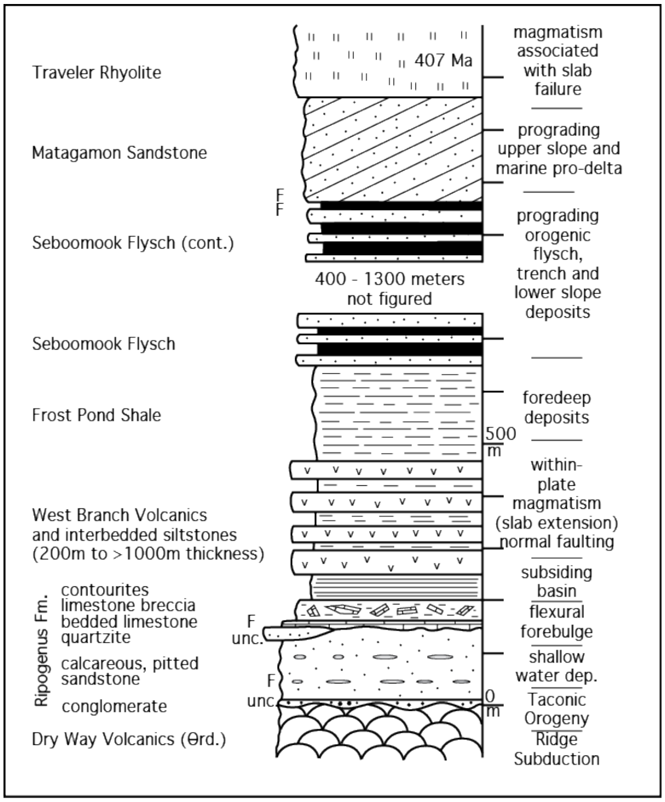


Figure 9. Stratigraphic column of the exposed section in the Ripogenus Gorge and the Chesuncook Dome to the north (from Schoonmaker et al. 2011).

Geochemistry of the West Branch Volcanics

The West Branch Volcanics are a series of mafic to intermediate volcanics (basalts to basalt-andesites) that are interstratified with argillites and siltstones identical to those in the upper part of the Ripogenus Formation. They are in part pillowed flows, although some may be shallow sills. They occur above the orthoquartzite and limestone breccia. Samples were analyzed for trace element and rare earth element (REE) geochemistry and reported in Fitzgerald (1991), and Schoonmaker et al. (2011). Correlative rocks from other northern Maine inliers (Spider Lake Volcanics, Fish Pond Volcanics) have similar geochemical compositions to the West Branch Volcanics, although not shown in the diagrams below. Previous interpretations of tectonic environment for eruption of these rocks have included arc and within-plate settings. The tendency towards andesitic compositions and silicic inclusions tend to indicate an arc environment, but their enriched geochemical compositions favor a within-plate setting. Like the older Dry Way Volcanics, the West Branch Volcanics have experienced lower greenschist grade metamorphism, so only immobile trace element and rare earth element concentrations are used for discrimination purposes.

The West Branch Volcanics are enriched in light rare earth elements (LREE; Figure 10A) indicative of derivation from an enriched mantle source, usually associated with within-plate magmatism. However, on the MORB-normalized diagram (Figure 10B), a significant Ta-Nb negative anomaly is present, typical of arc environments, although the strong LREE-enrichment is evident.

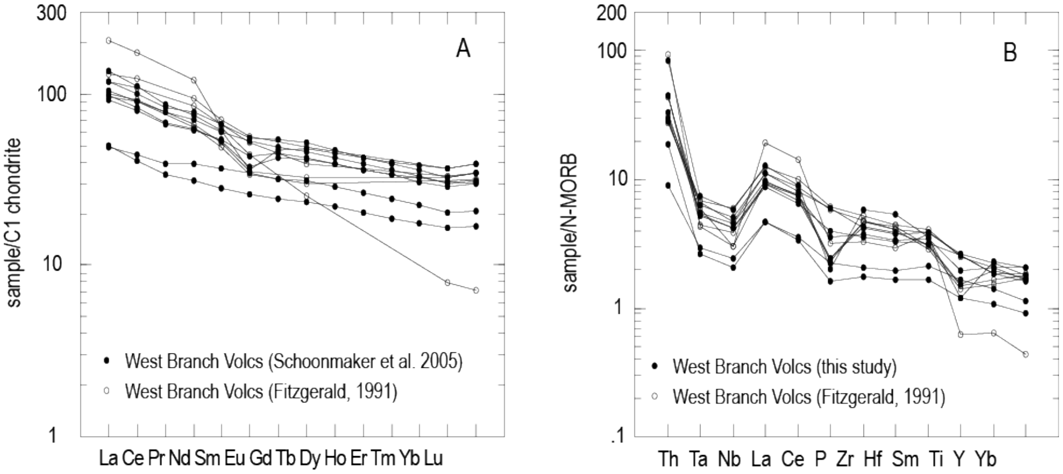


Figure 10. C1 chondrite- and MORB-normalized diagrams of rare earth elements. Normalization values from Sun and McDonough (1989). Modified from Schoonmaker et al. (2011).

Similar, contrasting conclusions can also be made from tectonic discrimination diagrams. On Th-based diagrams (Figure 11), variable Th-enrichment pushes samples into arc tholeiite and calc-alkaline fields. On non-Th-based diagrams that have separate arc and within-plate fields (Figure 12), samples plot in the within-plate fields. On non-Th-based diagrams that do not discriminate between arc and within-plate settings, samples predictably plot in the overlap fields. This behavior was described as “transdiscriminant” by Fitzgerald (1991) and a similar pattern was explained by Dostal et al. (1989) and Keppie and Dostal (1994) for other correlative rocks in Maine and New Brunswick as indicative of derivation from previously-contaminated, subduction-modified, sub-continental mantle, and/or Th-contamination by passage of the magmas through Th-enriched continental crust. This explanation is consistent with the geochemical plots shown here in that in Th-based diagrams that indicate an arc environment (Figure 11), the crustal contamination vector is parallel to the arc vector, and those diagrams that do not rely on Th as a discriminant (Figure 12) indicate a non-arc environment. Further, on the Ce/Nb-Th/Nb diagram of Saunders et al. (1988; Figure 14), the arc and crustal contamination vectors are not parallel; West Brach Samples plot along a trend towards crustal contamination, rather than towards arc.

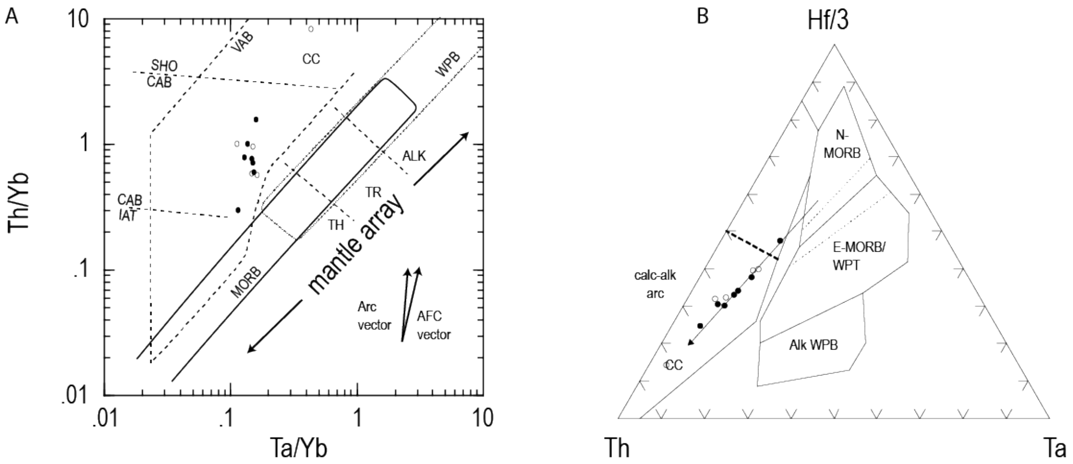


Figure 11. Th-based tectonic discrimination diagrams. A) Th/Yb-Ta/Yb diagram of Pearce (1982). MORB = mid-ocean ridge basalt, WPB = within-plate basalt, TH = tholeiitic basalts, ALK = alkaline basalts, TR = transitional basalts, IAT = island arc tholeiite field, CAB = calc-alkaline basalt field, SHO = shoshinitic basalt field. B) Th-Hf-Ta diagram of Wood (1980). Calc-Alk Arc = calc-alkaline volcanic arc basalt, Arc Thol.= volcanic arc tholeiite, N-MORB = normal, depleted mid-ocean ridge basalt, E-MORB/WPT = enriched mid-ocean ridge basalt and within-plate tholeiite, Alk WPB = alkaline within-plate basalt. The two arc subfields are collectively referred to as the "destructive margin and differentiates" field, separated by the dashed line. CC = average upper continental crust composition (from McLennan (2001). Modified from Schoonmaker et al. (2011).

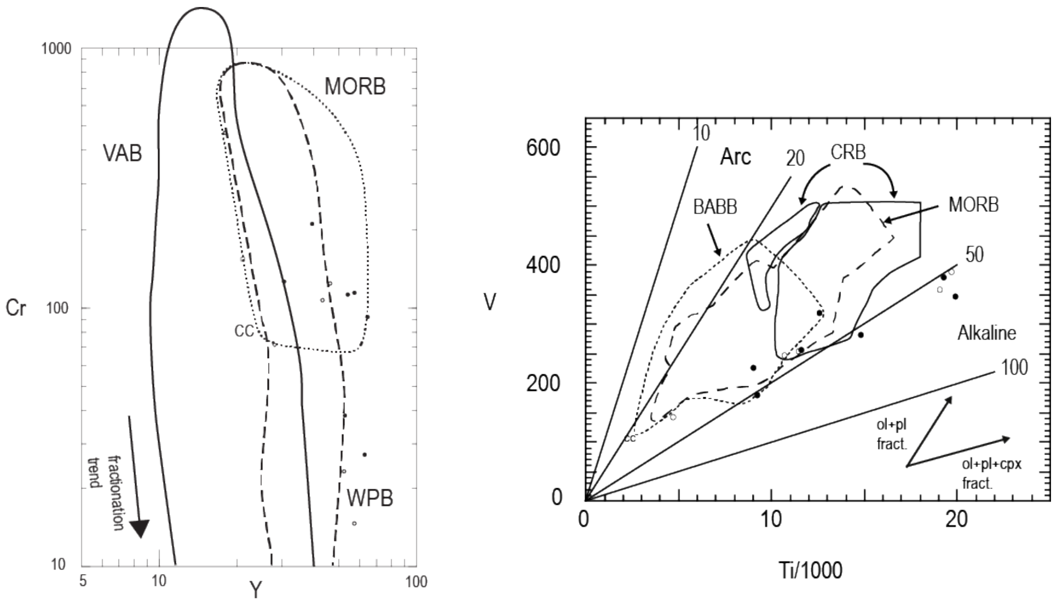


Figure 12. Non-Th-based tectonic discrimination diagrams. Cr-Y diagram of Pearce (1982), VAB = volcanic arc basalt, MORB = mid-ocean ridge basalt, WPB = within-plate basalt. Ti-V diagram of Shervais (1982). ARC = volcanic arc basalt, MORB = mid-ocean ridge basalt, ALK WPB = alkaline within-plate basalt, BABB = back-arc basin basalt field, CRB = Columbia River flood basalt field. CC = average upper continental crust composition (from McLennan (2001). Modified from Schoonmaker et al. (2011).

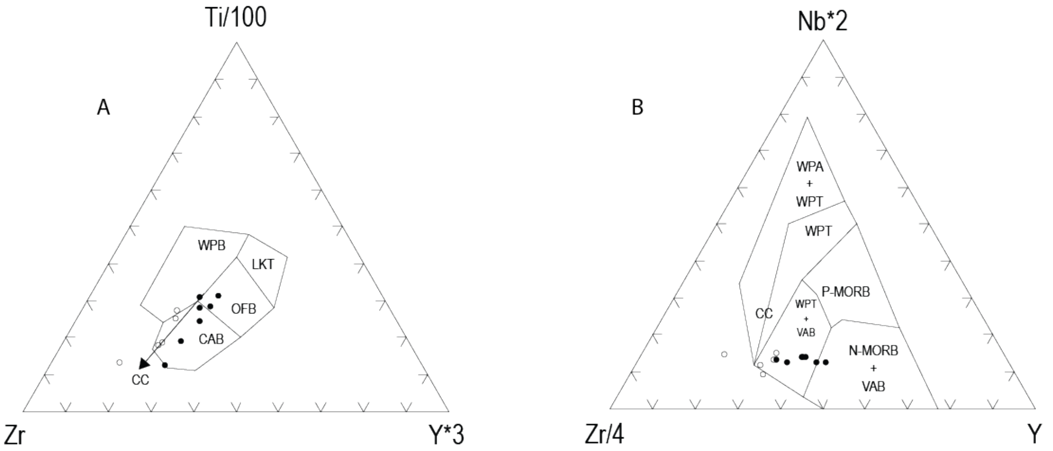


Figure 13. A) Ti-Zr-Y diagram of Pearce and Cann (1973). WPB = within plate basalts (oceanic and continental), OFB = ocean floor basalts, LKT = low-K tholeiites, CAB = calc-alkaline basalts. B) Nb-Zr-Y diagram of Meschede (1986). WPA = within-plate alkaline basalts, WPT = within-plate tholeiites, P-MORB = plume-influenced mid-ocean ridge basalt, N-MORB = normal, mid-ocean ridge basalt, VAB = volcanic arc basalt. CC = average upper continental crust composition (from McLennan (2001). Modified from Schoonmaker et al. (2011).

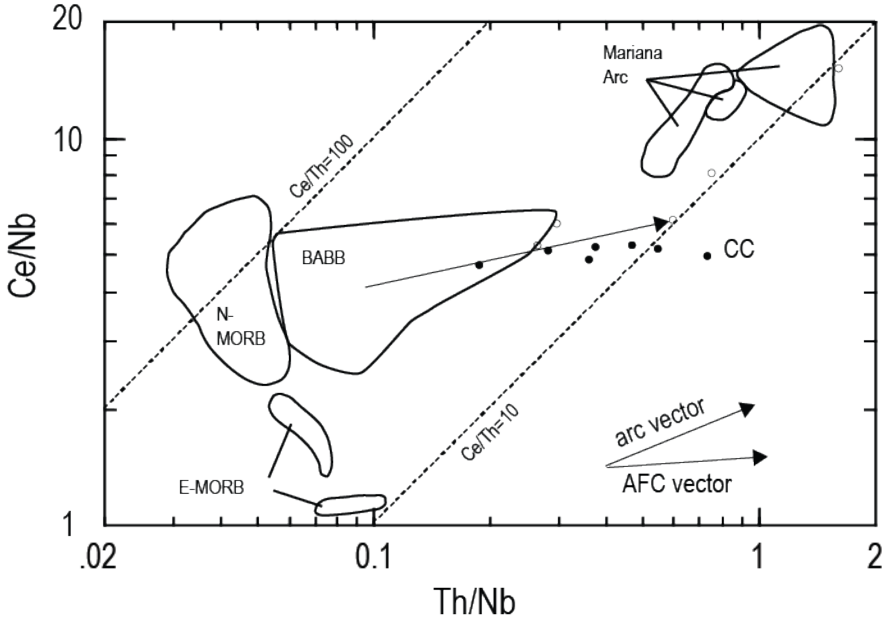


Figure 14. Ce/Nb vs. Th/Nb tectonic discrimination diagram of Saunders and others (1988). N-MORB = depleted mid-ocean ridge basalt field, E-MORB = enriched mid-ocean ridge basalt field, BABB = back-arc basin basalt field. CC = average upper continental crust composition from McLennan (2001). From Schoonmaker et al. (2011).

Samples of West Branch Volcanics analyzed for Nd isotope compositions are shown on the εNd diagram (Figure 15). A 417 Ma model age was used, based on the Lockhovian conodont age from the underlying limestones of the Ripogenus Formation. Samples have εNd values of +2.3 to +3.8 and are similar to arc volcanics and continental flood basalts, and subcontinental lithosphere xenoliths (Rollinson, 1993; Faure and Mensing, 2005).

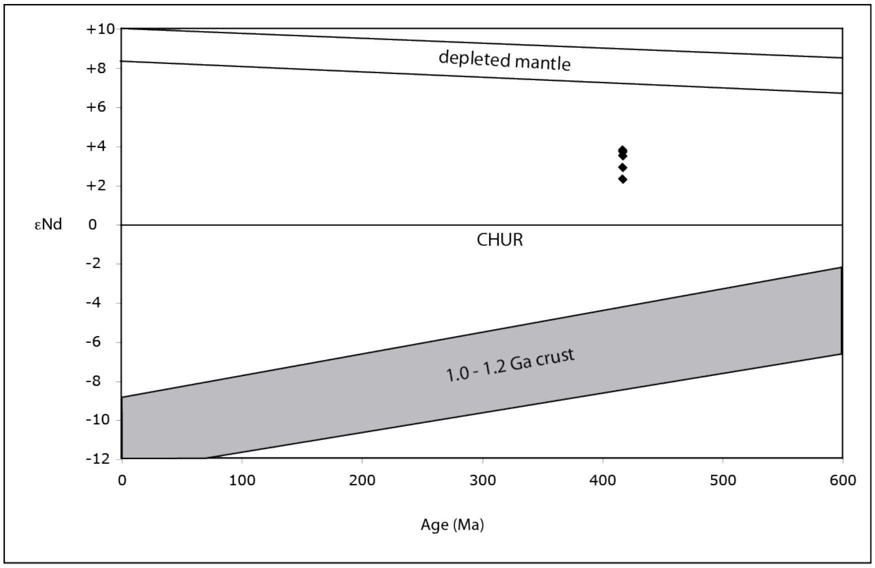


Figure 15. Plot of εNd vs. age for West Branch samples (417 Ma model age). Depleted mantle curve from DePaolo (1981). 1.0 – 2.0 Ga crust curve from Samson and others (2000). From Schoonmaker et al. (2011).

Tectonic Setting of the Siluro-Devonian Section

The apparent termination of shallow marine deposition marked by short-lived uplift, quickly followed by faulting and subsidence to deep water sedimentation can be explained if the continental margin was part of the lower plate during closure as it approached the Acadian subduction zone. The disconformity likely represents the passage of a peripheral bulge, followed by flexural bending and faulting. Deeper water sedimentation occurred as the margin entered the outer trench slope and then was overlain by orogenic flysch of the Seboomook Formation as it neared the active Acadian Orogen.

As the continental margin entered the outer slope region of the subduction zone, lithospheric failure likely resulted in extension of the down-going plate and within-plate magmatism of the West Branch and correlative volcanic rocks through northern Maine and New Brunswick (Schoonmaker et al. 2011). This detachment model of tectonism and other possible scenarios from the literature are shown in Figure 15.

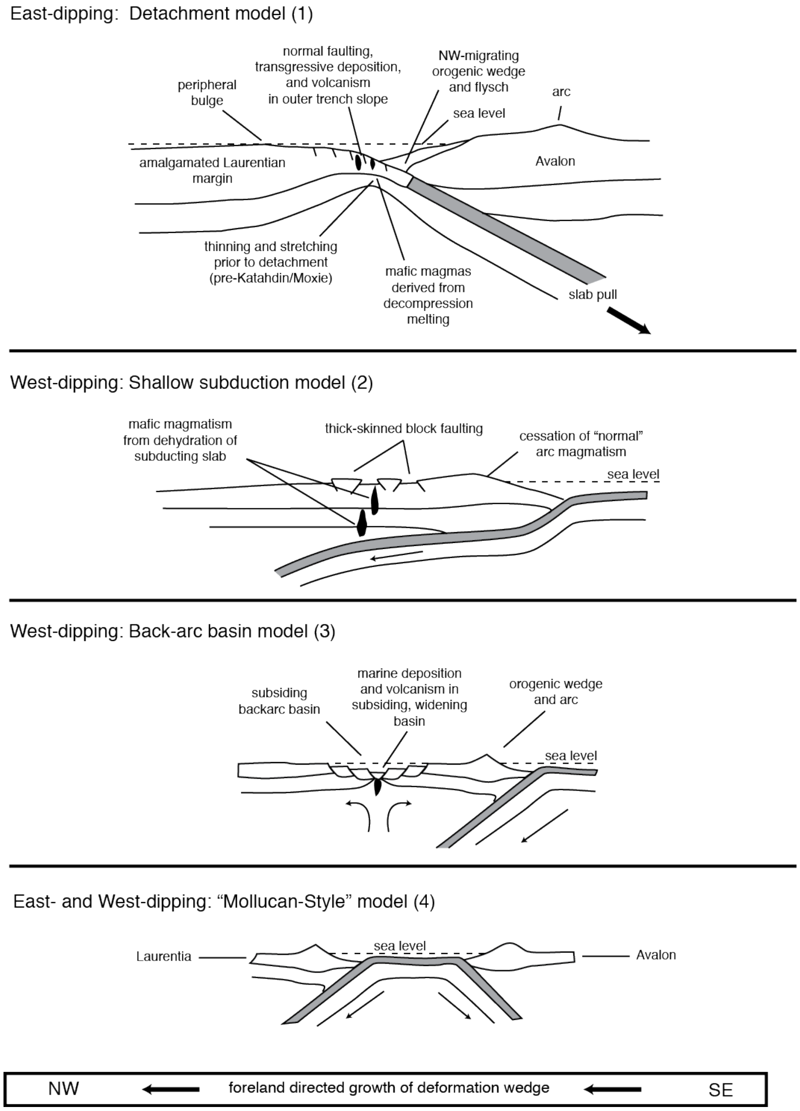


Figure 16. Tectonic scenarios prior to the onset of Acadian Orogeny in northern Maine (Pre-Emsian). 1a.) southwest-directed subduction. 1b.) northwest-directed, "Laramide-style" shallow subduction. 1c.) northwest-directed subduction with embryonic back-arc basin. 1d.) "Mollucan-style" dual subduction. From Schoonmaker et al. (2011).

ROAD LOG AND STOP DESCRIPTIONS

This 66-mile trip takes participants to the relatively remote Chesuncook Lake area via the Golden Road, a privately-owned road used primarily for the transport of timber logs. IMPORTANT: When approached by a logging truck on the Golden Road, pull well over onto the shoulder and let the truck pass. They have the right-of-way and typically drive down the center of the road at what the uninitiated might consider excessive speed. DO NOT EXPECT them to move over to accommodate you; you MUST accommodate them. Take special care when approaching blind curves on the road.

Do not expect cell service anywhere in the area, or food, fuel, or potable water beyond the Abol Bridge Store at mile 9.5. It is recommended that participants fill fuel tanks and obtain food and water the day before the trip in Millinocket. Some supplies (gas, food, water, coffee) may be obtained at the Abol Bridge Store or North Woods Trading Post at Millinocket Lake for a premium, if open. It is best not to count on the trading post or Abol Bridge store to be open, or even have some important items, like gasoline, in stock.

Part of the trip involves descending into the Ripogenus Gorge, a somewhat treacherous river gorge walk, especially if the rocks are wet. Participants should be in good physical health and ability to follow this section of the trip.

Meeting time and place: 8:00 am, Friday, October 11 at the gravel parking lot adjacent to the North Woods Trading Post on the Millinocket Lake/Baxter Park Road between Millinocket (9 miles to the southeast) and Baxter State Park to the northwest. The Twin Pines campground is located nearby, on the shore of Millinocket Lake. The trading post is located on the Baxter Park Road and the Golden Road can be seen running parallel to it about 50 meters to the west [lat/long 45.72954, -68.83810, NAD83].

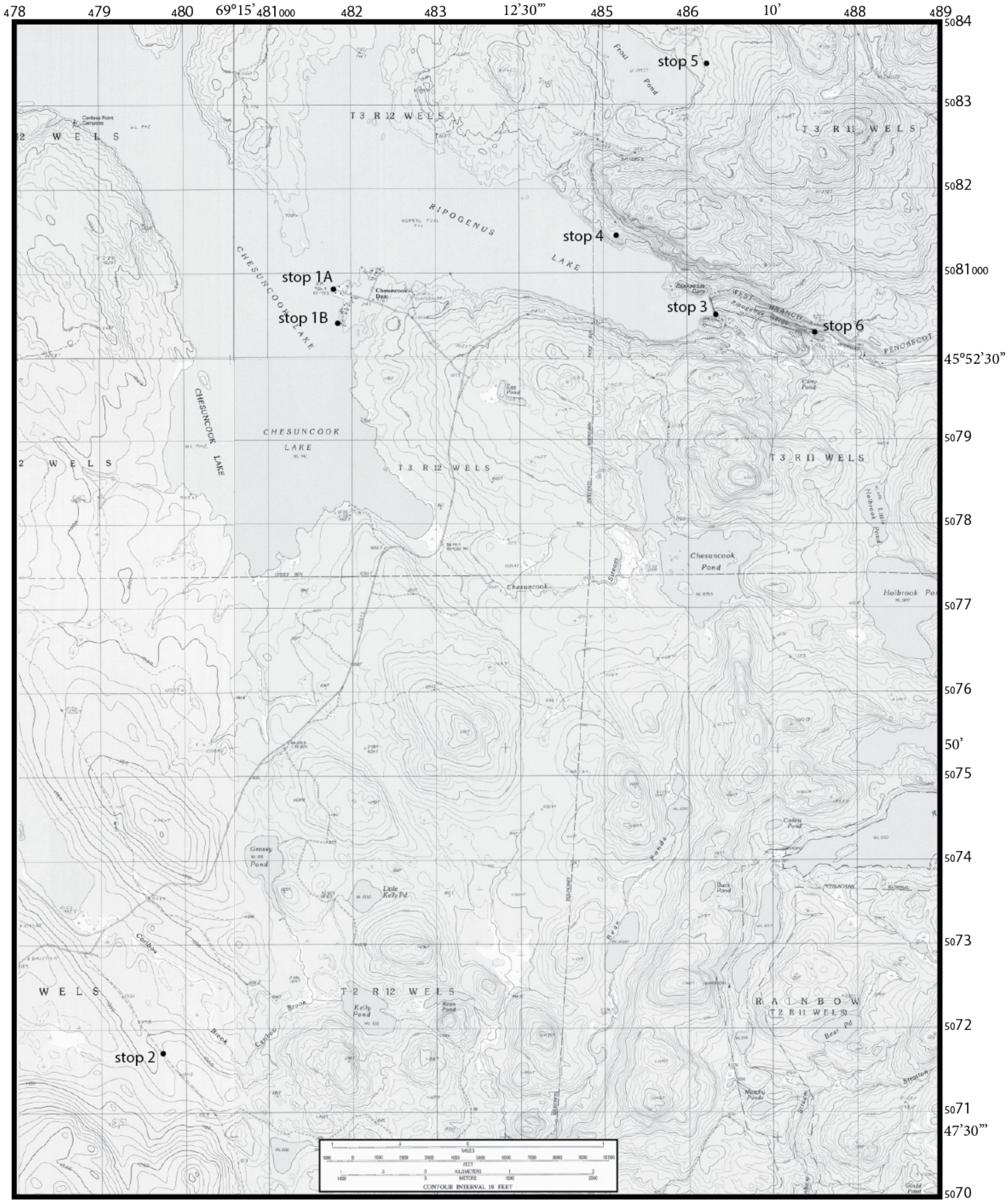


Figure 16. Stop location map. Stop details for the Ripogenus Gorge (Stop 3) shown in Figure 18. Portions of Rainbow Lake West, Harrington Lake, Caribou Lake North and Caribou South 7.5' quadrangles shown.

Mileage

Cum.	Incr.	
0.0	0.0	Proceed 50 meters to the southeast of the Trading Post (back towards Millinocket) and immediately turn right onto the connector between the Baxter Park and Golden road (a right turn if coming from the trading post; a left turn if driving northwest from the direction of Millinocket, or the Twin Pines campground). Turn immediately right (northwest) onto the Golden Road, passing by the low dam and floatplane base at Ambajejus Lake on the left; drive north and west on the Golden Road.
9.5	9.5	Abol Bridge and store [45.83531, -68.96552].
18.3	8.8	Junction with Telos Road to right; continue straight on Golden Road [45.87568, -69.14101].
19.1	0.8	Gravel road on right to McKay hydro power station; continue straight on Golden Road [45.87405, 69.15784].
19.6	0.5	Gravel road on right to Ripogenus Dam and Frost Pond; continue on Golden Road [45.87537, -69.16688].
22.1	2.5	Gravel road on right to Chesuncook Lake and Ranger Station; turn right [45.87335, -69.21445].
23.2	1.1	Park at end of road at Chesuncook Lake [45.88263 -69.23409]. This community of cabins is referred to as Chesuncook Dam.

STOP 1A: BOOM HOUSE AND INTRODUCTION

Here we will provide an introduction to the trip, near the Loggers Memorial and the Chesuncook Boom House. If the lake level is sufficiently low, we may walk along the shoreline to see gabbro/dolerite intruding argillite and arenites in shoreline outcrops of Chesuncook Lake near the Chesuncook Boom House. From the parking place on the driveway, walk down to the shoreline of Chesuncook Lake and go to the right (north) along it to the outcrops. If the water level is high, the same rocks are exposed at stop 1B, visible from here on the shore to the southeast (see stop description below).

Return to vehicles and drive back in the direction of the Golden Road.

Cum.	Incr.	
23.4	0.2	Gravel track on right; turn right [45.88184, -6923094].
23.6	0.2	Go to end of track and park on circle at end.

STOP 1B: DOLERITE/GABBRO INTRUDING SHALES AND ARENITES

Walk to the lakeshore and find outcrops to the north on shoreline; if you are using this trip log independently, please ask permission at the house to cross the property to the shore outcrops.

These show gabbro/dolerite (inferred by us, based on geochemical similarity and intrusive relationship with country rock, to be of the same magmatic episode as the larger Bean Brook Gabbro body, which occurs several miles to the east) and low metamorphic grade cleaved greenish argillites and quartzose arenites identified by Griscom (1976) as the Sawmill Formation of inferred Cambrian and/or early Ordovician age.

The sedimentary rocks show relatively intact bedding here, in contrast to some other localities where the rocks are disrupted to olistostromal and/or structural mélange. The bedding features of the arenites suggest deposition from turbidity currents; no evidence requiring shallow-marine sedimentation has been seen in outcrops of these rocks.

The contacts of the gabbro/dolerite can be shown in places to be intact intrusive surfaces with finer-grained chilled margins typically a few centimeters wide. In other places, there has been displacement on the contact, with the faults removing or obscuring the chilled margin, and evidence of cataclastic strain locally in both the gabbro and the adjoining sedimentary protolith. On a larger scale, the occurrence of the gabbroic bodies in lenticular objects a few meters to tens of meters across suggests boudinage and/or structural slicing of originally more continuous dikes. The gabbro forming the roche moutonnée in front of the Boom House is an example of one of these lenses; when the lake level was exceptionally low in 2002-3, outcrops extending north from the shore by the Boom House showed more of these lenses along structural strike from this outcrop, with evidence of both intrusive origin and later local structural modification of parts of the contacts.

Geochemical analysis of these and similar gabbros in the area show a strong N-MORB character and were likely derived from depleted mantle (Figures 4 and 5). However, they also display some arc characteristics as described in the introduction section of this trip. Because the gabbros intrude turbiditic rocks and mélange of the Sawmill Formation, as can be seen in these outcrops and others (e.g. stop 2), we suggest that this represents part of the deformed fore-arc and inner trench slope region of an early Ordovician arc. An actively spreading mid-ocean ridge subducted beneath the mélange provided the source for this magmatic episode.

23.8	0.2	Return to gravel road intersection; turn right towards the Golden Road.
24.7	0.9	Intersection with the Golden Road; turn right.
29.9	5.2	Intersection with Greenville/Kokadjo Road on left; turn left onto Greenville Road.
30.1	0.2	Gravel track on left; turn left [45.81130, -69.27248].
31.0	0.9	Outcrop in road and in ditch on right [45.79995, -69.25974].

STOP 2: DOLERITE INTRUDING PHYLLITIC SCHISTS

This outcrop consists of a glacially smoothed surface exposed in the roadway and on the south side of the woods road. An intrusive contact between the porphyritic (plagioclase) dolerite fine-grained margin and the layered and foliated metasediments of the Sawmill formation (Griscom 1976) can be found both in both exposures. Figure 17 illustrates similar contact relations a few hundred meters further along the woods road. In the road bed this contact has an intricate lobate geometry but is seen clearly to truncate the main foliation in the phyllitic schist. Tight crenulation-style folds affect the foliation and layering in the schist; it seems possible that this folding has affected the dolerite and its intrusive contact and caused some of its irregular lobate shape. Based on relationships seen in Caucomgomoc Lake, this folding may be of Acadian age, but this is not certain. Given that the event of gabbro/dolerite intrusion is dated as Ordovician (Bean Brook Gabbro, 473 Ma; Faul et al. 1963), the bulk of the strain and the phyllitic metamorphism predates (but perhaps only slightly) this date. The present metamorphic mineralogy appears to be low greenschist facies, although we do not claim to have investigated this intensively. However, the strain expressed by the main foliation and the metamorphic recrystallization accompanying it can be seen to be very significantly more intense than in the rocks at stop 1. Outcrop is poor in this area, as you can observe, and the contact relationship between these phyllitic schists and the bedded sedimentary host rocks to the gabbro at stop 1 has not been found exposed. It seems most likely to us that there is a structural contact between them, but the host rocks at the two sites were not so widely separated at the time of the Bean Brook gabbro/dolerite magmatism for one of them to avoid intrusion. In some places in known younger subduction complexes, foliated metamorphic rocks like these were transported to relatively deeper structural levels and subsequently returned to a shallow crustal level and juxtaposed with slates and other low-grade rocks.

Turn around and return to the Greenville road.

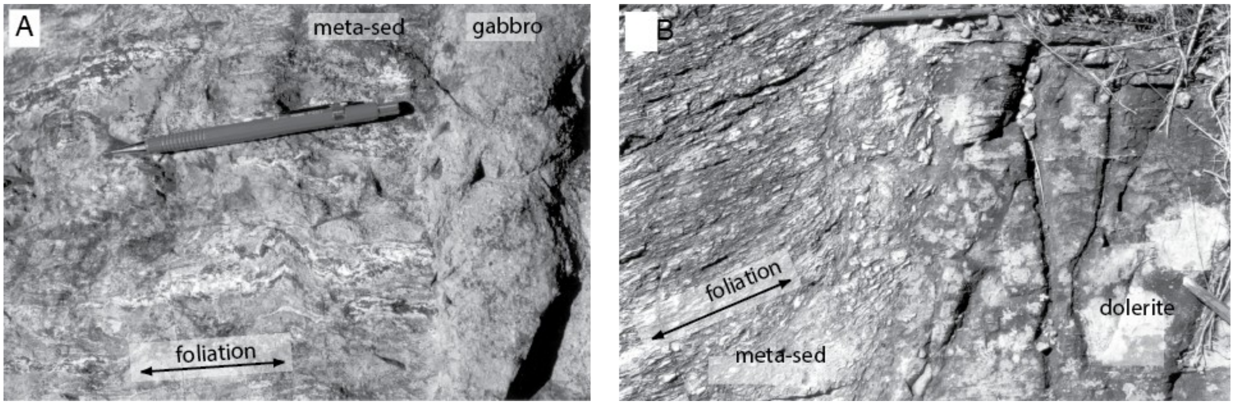


Figure 17. Field relations of Bean Brook Gabbro/dolerite and Cambrian(?) sedimentary rocks. a) gabbro (CSP-010b) and Hurricane Mountain Formation. b) dolerite (CSP-010d) and Hurricane Mountain Formation.

31.9	0.9	Intersection with Greenville Road; turn right
32.1	0.2	Junction with the Golden Road; turn right [45.81384, -69.26933].
39.7	7.6	Gravel road on left to Ripogenus Dam and Frost Pond; turn sharp left
40.0	0.3	Pass abandoned Pray's Store and cabins.
40.1	0.1	T-intersection; turn right [45.87864, -69.17380].
40.2	0.1	South end of Ripogenus Dam [45.87984 -69.17534]; park on right or left of gravel area before dam; do not block road access over dam.

STOP 3: RIPOGENUS GORGE

This series of outcrops exposes a nearly continuous section from the Ordovician Dry Way volcanics through Silurian-early Devonian Ripogenus Formation sedimentary strata to Devonian West Branch Volcanics in the gorge of the West Branch Penobscot River below the Ripogenus Dam (Figure 18 and 19).

Please note it is unlikely, but is possible, that remotely controlled opening of some of the dam sluice gates could occur during your visit. There is supposed to be a warning given prior to such an event through the sirens mounted at places on and near the dam and the powerhouse downstream. If these sound, depart for higher ground immediately! For most locations in the gorge, this will mean moving to the south where the access road will be encountered.

Also, the traverse of the gorge can be treacherous and physically demanding. Care should be exercised while in the gorge, especially when the rocks are wet.

From the parking area next to the south end of the Ripogenus Dam, walk east back along the gravel road about 100 meters to the first bend; then turn left and walk down the track going down the wooded slope to the north. Follow the track to near the base of the dam, then turn north and walk across the rock outcrop to the first prominent elevated part of the rock outcrop nearest the base of the dam [45.881185, -69.175829].

STOP 3A – DRY WAY VOLCANICS AND BASAL RIPOGENUS FORMATION

This prominence and its immediate surroundings expose basaltic pillow lavas of the Dry Way Volcanics. Pillows are well developed in this part of the outcrop, with local yellow-green chert in pillow interstices. One partially preserved bed (a few cm thick) of this chert occurs on the south side and in the rock prominence, and (if water discharge is low) a better preserved and in part purplish chert bed (up to 10cm thick) occurs right next to the concrete base of the dam. Both these interbeds of chert are parallel with each other and near vertical in orientation, showing the depositional horizontal. Pillow shapes are consistent with this orientation and unusually excellent shape asymmetry shows the original way up direction to the east. The Dry Way volcanics are not fossil-dated, nor has any isotopic age been successfully determined. Regional stratigraphic relationships suggest that they are most probably mid-Ordovician (Neuman 1967; Hall 1970). They are observably (this stop 3A and 3B) older than the unconformity at the base of the in-part Silurian Ripogenus Formation.

The geochemical composition of the Dry Way lavas is similar to that of the Bean Brook Gabbro and shows that they are of MORB-type with some arc character, consistent with an origin comagmatic with the Bean Brook Gabbro seen at stops 1 and 2. However, no gabbro bodies have been found in exposures that we have examined in the Dry Way Volcanics. An imperfect exposure of the contact of the Dry Way Volcanics with black slaty mélange with grey arenite blocks in it occurs near the shore of Ripogenus Lake about 300 meters SW of the dam; it appears to be a fault.

If discharge from the dam overflow is not too large it may be possible to visit, for those willing to scramble over locally steep rock faces, the base of the Silurian-early Devonian Ripogenus Formation forming the north part of the outcrop below the dam and south of the concrete spillway where the major discharge overflow from the dam is usually localized. The upper part of this exposure shows prominently pitted sandstones and limestone forming the lower mappable unit of the Ripogenus Formation. The pits result from weathering of the limestone; the original limestone beds have been modified by either differential cementation or differential dissolution of the calcite (or both). The volumetrically dominant rock type is a fine to medium-grained quartz arenite, hence our preferred name of pitted sandstone, rather than limestone. Abundant but disappointingly age-unspecific brachiopod-coral-crinoid-stromatoporoid fossil fragments are easily observed. Bradley et al. (2000) reported a conodont fauna of Earliest Devonian (Lockhovian) age from a nearby locality above this stratigraphic level

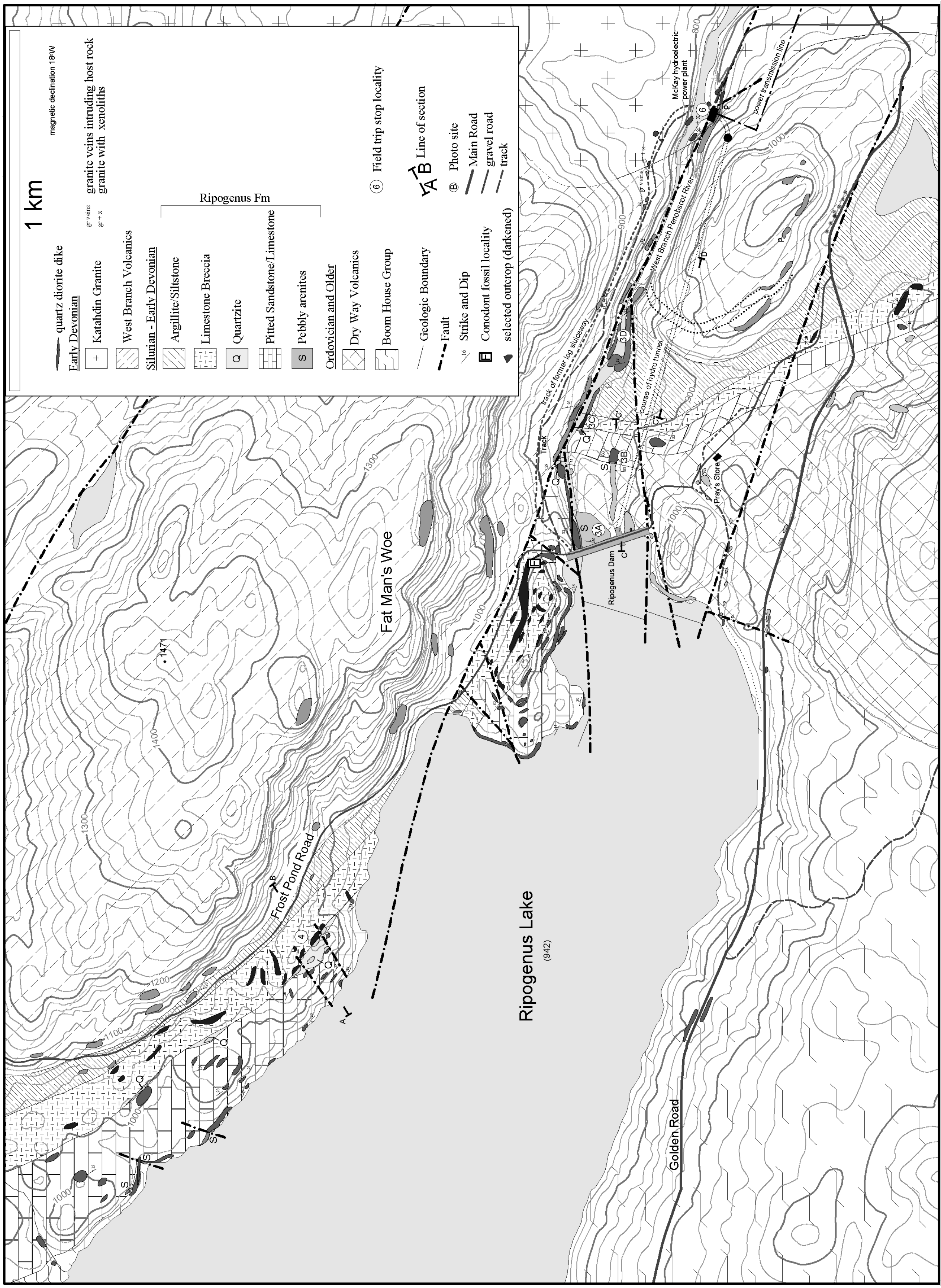


Figure 18. Geologic map of the Ripogenus Gorge and surroundings. Stop #'s within the map area are indicated.

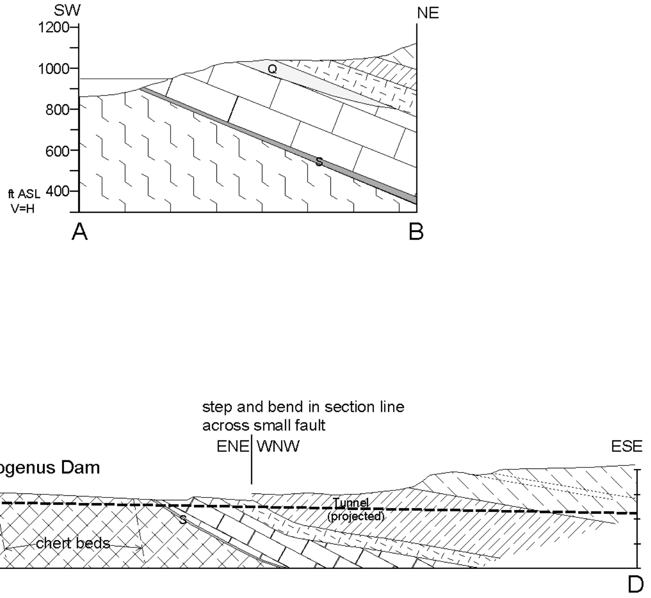


Figure 19. Cross-sections from Figure 18.

in the Ripogenus Formation (see stop 4 description for discussion). Elsewhere in the region, similar arenite-limestone strata at the base of the post-Ordovician succession have been claimed to contain fossil assemblages as old as Llandoverian (Boucout, 1969). In these strata here we have observed small-displacement fault structures showing normal, down-to-E displacement with contemporaneous infill of some of these extensional structures by arenaceous sediment.

Below the pitted arenite/limestone strata, there are a meter or two of limestone-free arenites, in and at the base of which there are local pebbly arenites with vein quartz pebbles. A contact can (at low discharge) be observed here in two places between the basal pebbly arenite and the Dry Way volcanics. The contact here appears not to be significantly faulted (although this could perhaps be disputed), and must mark a significant angular unconformity; this contact is also, and more accessibly exposed at stop 3B (see below).

Walk back to the track; at a point just before it begins to ascend the slope on the south, turn off it to the east through low scrub and in a few ten of meters distance find the outcrop in a dry (or not very wet) stream bed, the Dry Way. Follow this stream bed to the east over more basalts of the Dry Way Volcanics, showing pillow forms in places.

STOP 3B - DRY WAY FORMATION PILLOW LAVAS, CHERT; UNCONFORMITY AT BASE OF RIPOGENUS FM, PEBBLE CONGLOMERATE, PITTED CALCAREOUS SANDSTONES

Where the streambed starts descending and the outcrop widening, a cleft and small cliff face on the north side exposes in section a sub-vertical dark chert bed about 10 cm thick; its orientation is parallel with the chert bed noted at the base of the dam in stop 3A. Here the bed is offset a small distance in a left-lateral sense across the prominent E-W oriented cleft in the exposure. A similar cleft in the south part of the outcrop may also be a similar small fault; jointing in this orientation is also common.

At the place where the bedrock descends east to near the level of the pool of usually permanent standing water, the unconformable contact between the basalt of the Dry Way Volcanics and the prominently pebbly arenites of the base of the Ripogenus Formation can be found in outcrop on both sides of the pool [45.880515, -69.173084]. This contact and the overlying strata are here striking about N-S and dipping east about 30 degrees. At this location, there is no doubt that the unconformity surface is depositional and unfaulted.

Move around the south side of the standing pool of water to the rock face sloping up on the east side. There is one place where it is not too difficult to scramble up the pitted sandstone/limestone, the same strata seen at the dam above the basal, in part pebbly arenites of the lower Ripogenus Formation. At the top of the slope of rock, descend the other side into the forest and then make your way to the NNE going roughly parallel with the course of the streambed from the stop 3B location. When nearing the river bank of the West Branch of the Penobscot River, aim for the top of the prominence located above the confluence of this stream bed and the West Branch river [45.881499, -69.171764].

STOP 3C - QUARTZITE, LIMESTONE BRECCIA, AND HORNFELSED ARGILLITES OF THE RIPOGENUS FORMATION

About 3 meters thickness of white orthoquartzite is exposed here structurally conformable above the uppermost pitted sandstone/limestone exposed at the base of the outcrop. This clean, coarse-grained arenite marks resumption of sedimentation above a significant disconformity, within the Ripogenus Formation as defined by Griscom (1976). The quartzite is mappably discontinuous and variable in thickness over small distances. The sediment likely was derived from a shoreline environment, but the discontinuous and variable distribution we interpret as indicating redeposition into paleotopographic valleys eroded into the underlying pitted sandstones/limestones of the lower Ripogenus Formation. In any case this represents sedimentation onto a formerly subaerial erosion surface, and the beginning of subsidence expressed by increasingly deeper water sedimentation.

On the bank of the West Branch Penobscot River east of this orthoquartzite (scramble down the slope to the east to the waterside outcrop) a section of carbonate breccia is exposed, several tens of meters thick. In most of the area, this is a limestone breccia, but in this outcrop, the influence of the contact metamorphic aureole of the Katahdin Granite is starting to become noticeable, and the carbonate clasts have been recrystallized to a fine-grained marble. There is also some effect of ductile deformation visible in the somewhat flattened shapes of the clasts in parts of this exposure, also a local feature, which we think is connected with the hinge of the large-scale open fold that can be seen on the map affecting the strata of the Ripogenus Formation. This limestone breccia unit of the Ripogenus Formation is continuous throughout the area mapped; more discussion of it and its relationships to the enclosing strata is in the description of stop 4.

Moving east along the outcrop, the breccia is overlain by a unit a few tens of meters thick of mostly homogeneous mudrocks, with uncommon thin nodular calcareous layers, and some uncommon and not very prominent bedding laminations in the mudrocks. All this section has been noticeably affected by contact metamorphism, expressed by the flinty hornfelsed character of the rocks in this exposure. Several kilometers west of this outcrop, farther away from the Katahdin Granite, poor exposures of this mudrock stratigraphic interval of the Ripogenus Formation are dominantly purplish in color; the thermal metamorphism has obscured this original color in the exposures of stop 3C.

Note that there is a significant fault running along the middle of the river here, with volcanics and some interbedded sediments of the West Branch Volcanics exposed on the north bank. This straight, steeply-dipping fault must have significant (100's of meters) north side down displacement and probably also has a component of left-lateral offset.

The outcrop on the south bank is interrupted where the riverbed widens and turns slightly south; walk along the bank to where the outcrop resumes about 80 meters away [45.88047, -69.16971]. It is of course possible that one or more faults occur in this unexposed interval, probably in the E-W orientation of those seen in the Dry Way at stop 3B, and on the map passing through the two ends of the Ripogenus Dam, but we think the displacements, if present, are small (see map figure 18).

STOP 3D - HORNFELSED ARGILLITES AND PINSTRIPE ARENITES OF THE UPPERMOST RIPOGENUS FORMATION; BASALTIC VOLCANICS OF THE WEST BRANCH VOLCANICS

The area of outcrop extending from the south bank of the river across most of its width here (at low water) consists of hornfelsed argillites and abundant thin "pinstriped" fine-grained quartz arenites/siltstones. These form the uppermost unit of the Ripogenus Formation as defined by Griscom (1976). The sedimentary features of the arenite/siltstone beds, namely the consistent fine-grain and excellent sorting, the ubiquitous and laterally persistent thin planar beds, and their laterally-persistent fine-scale internal lamination, the occurrence in places of small-scale cross-lamination and/or small-scale ripples on bed tops, and the absence of coarser or thicker arenite beds are indicative of final sorting and transport to deposition by deep-water contour currents. No evidence is present requiring reworking of the sediment above wave base.

East of the open area, where the river re-enters a narrow gorge, the first of many basaltic flows of the West Branch Volcanics is exposed. There is a fault between the argillites/arenites and the volcanics here, but the map suggests this fault also has small displacement. Most of these flows are massive although some might be shallowly-intruded sills. A few show columnar jointing, and there are flows that are pillowed (we will see one of these at stop 6). Geochemistry of these flows shows that most are basalts; they have the geochemical character of WPB with a whiff of island arc-influence in some; one that we sampled west of Ripogenus Dam has rare crustal-derived, partly resorbed xenoliths in it and this assimilation tends to lead to "andesitic" compositions that have in the past been interpreted to mean that the West Branch Volcanics were a subduction-generated product. We prefer (Schoonmaker et al, 2011) the interpretation that these are basalts of WPB-type with variable contamination both by Ordovician-age subduction modified upper mantle and by local continental crustal assimilation.

The West Branch Volcanics contain intercalations of bedded sedimentary strata up to about ten meters thickness that are identical in their sedimentary properties to the argillites/pinstripe arenites exposed below the first flow in the outcrop of this stop 3D.

Walk back to the west end of stop 3D local outcrop on south bank of river [point 45.88047, -69.16971], then turn and walk SW (bearing 225) through the woods back up to Pray's Cabins [aim for gps point 45.87835, -69.17295]. Turn right to follow gravel road back to parked vehicles.

Drive across Ripogenus Dam; continue on Frost Pond Road

41.2 1.0 Park on right side of road [45.88946, -69.19053]; Walk into woods on south side of road in a direction at a right angle to the road (SSW) for a distance of about 100 meters to the top of a steep slope, [45.88832, -69.19155].

STOP 4: QUARTZITE, LIMESTONE, AND LIMESTONE BRECCIA OF RIPOGENUS FM

Outcrops down this slope are of white orthoquartzite, at the same stratigraphic level seen at Stop 3C, but it is up to 18 meters thick here. Sufficient outcrop can be found in this locality to show that the orthoquartzite is lenticular, and is absent 200 meters along strike to the east, and considerably thinner to the west; if the absence of upstanding outcrop (which usually characterizes the orthoquartzite) is a reliable indicator, it is very thin or absent from about 150 meters west of this location. We think the orthoquartzite here outlines a substantial paleotopographic valley subaerially eroded into the underlying pitted sandstone/limestone of the lower Ripogenus Formation and filled by the redeposition of clean shoreline arenites upon subsidence of this surface below sea level. As at stop 3C, the erosion surface cut into the pitted sandstone/limestone unit of the lower Ripogenus Formation. Outcrops of these strata are present here, but those near the quartzites are not large and well-exposed, and you have to descend to the lake shore to see good exposure (we will not take the time needed for this).

Above the orthoquartzite, a few meters thickness of limestones are exposed. This is the stratigraphic level from which Bradley et al. (2000) obtained the Lockhovian conodont assemblage, from an outcrop close to the Ripogenus Dam. Limestones above the first few meters locally show evidence of brecciation *in situ*, with filling of fractures with brown-weathering arenite that perhaps also formed beds, or may have been introduced (as matrix) with the fully disrupted and transported breccias that overlie the *in situ* limestone. These limestone breccias are the same unit seen at stop 3C, and form a mappable stratigraphic unit typically about 50 meters thick. West of this location, the uppermost part of the breccia unit can be seen to contain multiple pebbly beds on scales of a meter or so, but the lower coarse bouldery breccia may be a thick deposit from a overall single talus-creating event. We think this event was normal faulting, as also expressed by small syn-sedimentary fault structures seen at the Ripogenus Dam (stop 3A). We also think that this normal faulting accompanied significant subsidence, as expressed by the passage from subaerial erosion, through shallow marine sedimentation of the orthoquartzite and limestone, to this submarine talus and the overlying sub-wave base deeper water argillites and contourites of stop 3C and 3D.

If time permits, on return to the road, we may walk west about 50 meters and reenter the woods to see a larger outcrop of the limestone breccia (see Figure 18 for position). Along the road nearby, small outcrops of purplish calcareous argillites occur, equivalent to the hornfelsed argillites and contourite arenites seen in stop 3C and 3D; above these in the steep slopes of Fat Man’s Woe there are many large outcrops of West Branch Volcanics forming a section perhaps 1 km thick overall.

Walk back to vehicles. Continue west and north on Frost Pond Road.

42.4 1.2 Frost Pond camp; continue north on gravel road [45.90140, -69.18261].

42.7 0.3 Campsite pavilion at Frost Pond shore; park vehicles on side of road [45.90363, -69.17867]

STOP 5: RED SHALE/SLATE OF FROST POND FORMATION

At the lakeshore by the stop location, abundant loose fragments of bright red slate can be found in the shallow water, and perhaps onshore (if you don't like leeches, you may wish to avoid going in the water). The bulk of the area of Frost Pond must be underlain by this red argillite, from about the position of the Frost Pond camp buildings, to just beyond the northern shore of the Pond, although outcrops are scarce, and abundant frost-shattered fragments perhaps glacially transported a small distance, like those in the water here, are more common. Griscom (1976) defined this rock unit as the Frost Pond Formation.

The outcrop location for this stop is a small roadcut located about 230 meters north from the parking location along the gravel road, on the east side [45.90550, -69.17719]. In this outcrop, bedding lamination can be seen dipping about 20 degrees NNE in the purplish-red rock, cut by a weak steeply-dipping, slaty cleavage. This bedding orientation is concordant with that in outcrops of basal Seboomook Formation dark slate and thin turbidite siltstones exposed in and near a driveway close to the northwest corner of Frost Pond, and in thicker bedded greywacke turbidites and grey slates of the Seboomook seen in outcrops located about 700-900 meters NNE of the mid-point of the NE shore of Frost Pond. The former outcrops are within a few tens of meters of an outcrop of purplish-red Frost Pond Formation slate, and there seems to us (wielding Occam's largest and bluntest razor) that there is no reason to suppose that the relationship is not conformable.
On the south side of Frost Pond, outcrops of basalt of the West Branch Volcanics are common. The depositional horizontal in those rocks is hard to define, but where elongated pillow shapes are seen, they do not depart grossly from the WNW strike and gentle ~20-30NNE dips seen in the Frost Pond outcrop and the Seboomook Formation nearby, and in the nearest Ripogenus Formation sedimentary strata to the south on the shore of Ripogenus Lake. There is an excellent outcrop of West Branch pillow lavas on the shore of Frost Pond (time will not permit us to visit this, but the gps location is 45.903425, -69.191146 - about 2.4 km round trip walk using the trail near the pond shore) This outcrop has well-developed pillow lavas and interstitial chert, some of which preserves the original red coloration. We think that the red argillites of the Frost Pond Formation conformably overlie the West Branch Volcanics; no exposure of the contact has ever been located, however. Nor has any fossil been found in the Frost Pond Formation.

Griscom (1976) claimed that the red argillites of the Frost Pond Formation were "estuarine" sediments. However, a gradational coarsening-up sequence into the Seboomook turbidites directly above the Frost Pond, and the occurrence of pillow lavas with interstitial red cherts not far below it in the upper part of the West Branch Volcanics, and the occurrence of deep water contourite sediments just below the West Branch Volcanics (stop 3D) make a deep water depositional site for the Frost Pond a more plausible proposition. Red coloration by itself does not preclude a deep water sedimentation site, especially for strata immediately underlying a foreland basin flysch turbidite unit (e.g. Indian River Formation in the Taconic Allochthon - Rowley and Kidd, 1981; basal Shoal Arm Formation in the Exploits Group of central Newfoundland - Bruchert et al. 1994). Also, actual estuarine sediment packages always contain arenaceous lenses showing evidence of sedimentation in shallow marine channels and sandbars with abundant sedimentary structures resulting from vigorous wave and tidal currents; none of these have been seen in the Frost Pond Formation.

Turn around (note that the road is now blocked beyond this point) and return to Golden Road across Ripogenus Dam

45.7	3.0	Intersection with Golden Road; turn left.
46.2	0.5	Gravel road on left to McKay hydro power station; turn left
46.3	0.1	Enter parking area on left and park; walk down gravel road past gates to McKay hydro power station.

STOP 6: DEVONIAN WEST BRANCH VOLCANICS AND CONTACT WITH KATAHDIN GRANITE AT THE MCKAY HYDRO POWER STATION IN THE GORGE OF THE WEST BRANCH PENOBSCOT RIVER

East of the powerhouse [45.87829 -69.16046], in the cut cliff on the south side, there is a sharp contact between Katahdin granite (to the east) and mafic volcanic rock of the West Branch Volcanics. A narrow fault gouge and local brecciation of both rocks along this contact shows it is a fault. The granite nearby in the cliff cut is also rather altered-looking, perhaps from fluids percolating along this fault, compared with fresher rock which can be seen in the roadcut on the north side of the gravel access road. However, as the map shows (Figure 18), there is another fault inferred under the access road, and it is likely that this fault along the granite contact does not have very large displacement since the granite contact continues on the north side of the river without major disturbance. Further, granite veins can be seen in nearby county rock, and country rock xenoliths occur in the granite nearby. Subhorizontal slickensides with left-lateral slip are sparingly developed in the granite outcrop on the north side of the access road.

Walk west from the turning area along the gravel access track between the powerhouse and the cut rock cliff. About half way along the powerhouse wall (and unfortunately now you have to look through the mesh of the protective cage) there is an excellent development of large pillows in the dark basaltic rocks of the West Branch Volcanics.

Continue along the access track to its end, where the rafters launch, and then walk about 30 meters farther along the gravel bench and climb up to the outcrop prominence on the south bank of the river, near the river exit from the tight rock gorge. This exposes Katahdin granite containing numerous xenoliths of the West Branch volcanics and some of the interstratified sedimentary argillites. This outcrop is mapped to the north of the major fault running along the gorge, which must pass between this outcrop and the granite-free volcanics exposed in the cliff of the gorge wall just to the south.

The Katahdin granite cuts cleaved Seboomook Formation slates and greywacke turbidites in outcrops on the shore of Harrington Lake to the north, and elsewhere (Kusky et al. 1994). The Katahdin granite has been dated by U/Pb on zircon at 407+/-1.5 Ma (Bradley and Tucker 2002). Local folding and cleavage shortening strain in this area therefore predates the intrusion of the granite at 407 Ma. Bradley et al (2000) demonstrate that this shortening (and granite plutonism) migrated to the NW across NW Maine and adjacent Quebec over a long interval up into the late Devonian, and perhaps to as late as 360 Ma in the latest Devonian.

Walk back up to vehicle. From the parking lot, return to Golden Road intersection.

46.4 0.1 Golden Road intersection; turn left.

65.5 19.1 Intersection of Golden Road and Millinocket Lake-Baxter Park highway at North Woods Trading Post and Ambajejus Dam.

End of road log. Turn right (southeast) onto Millinocket-Baxter Park highway to return to Millinocket, and I-95.

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