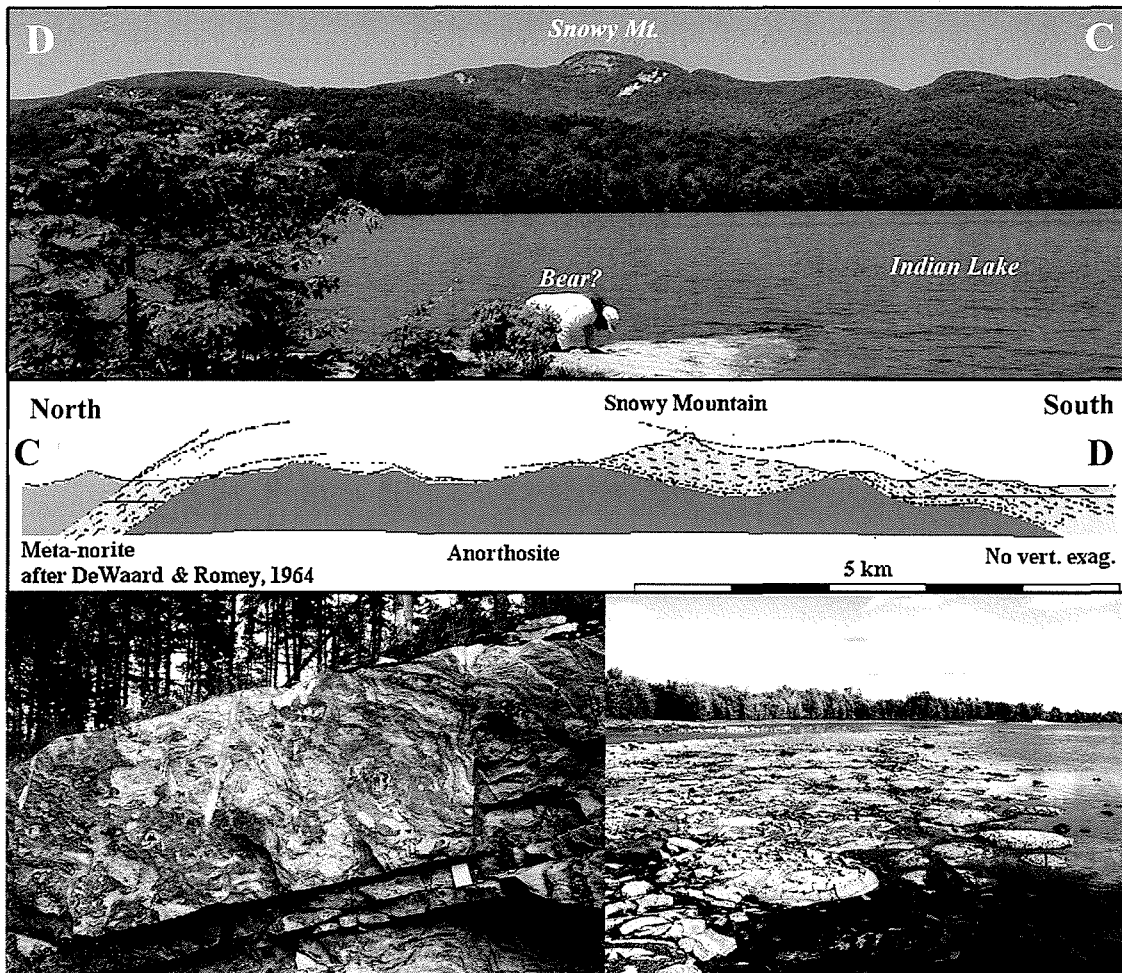


New York State Geological Association

76th Annual Meeting FieldTrip Guidebook



Edited by Robert Badger

Hosted by SUNY Potsdam
September 17-19, 2004

Field Trip Guidebook for the 76th Annual Meeting of the New York State Geological Association

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**Hosted by SUNY Potsdam
Potsdam, New York**



THE STATE UNIVERSITY OF NEW YORK

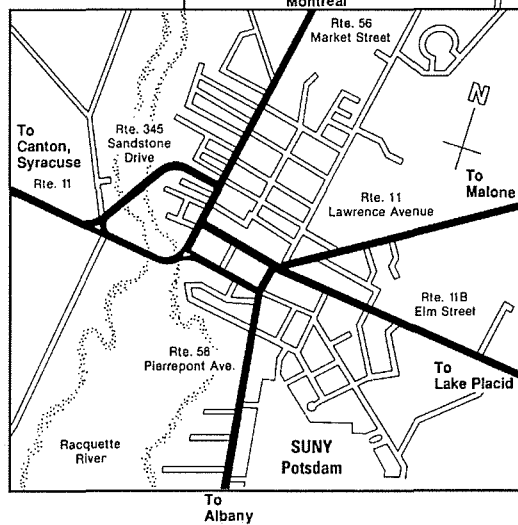
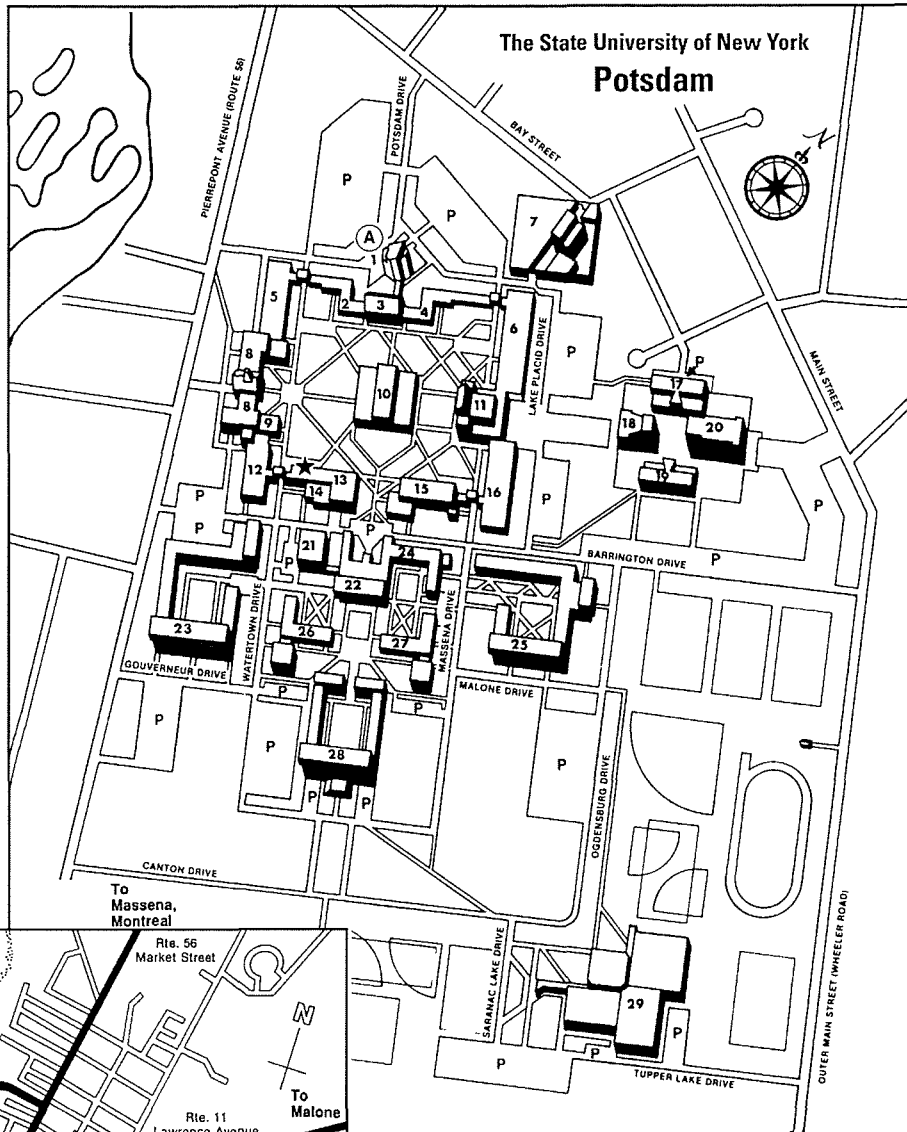
Potsdam

**Edited by
Robert L. Badger**

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Trip F-1

STROMATOLITES AND ASSOCIATED BIOGENIC STRUCTURES IN CAMBRIAN AND ORDOVICIAN STRATA IN AND NEAR OTTAWA, ONTARIO

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INTRODUCTION

This trip will provide an overview of some interesting sedimentary and biosedimentary structures in Cambrian and Ordovician strata of the National Capital Region (Figure 1); stratigraphic relationships (Brand and Rust, 1977; Williams, 1991; Wilson, 1946) will receive only cursory attention (Figures 2 and 3). The main thrust of the trip is to bring attention to the abundance and variety of shallow water environments throughout early Paleozoic time in this part of eastern Canada. Most outcrops to be visited are within the fault-controlled Ottawa-Bonnechere Graben.

During the drives between several stops, the uplifted northern block of the Gatineau Hills is clearly visible. While driving along Carp Road, we will be following a parallel fault along which Precambrian basement of the Carp Ridge has been uplifted relative to the Paleozoic strata to the south. Most of the rich farmland underlain by Paleozoic strata was inundated by the Champlain Sea, which receded from the region less than 12,000 years ago. Some of these clay-rich areas (including substantial volumes of the landslide-prone Leda clay), were buried by sand and gravel initially deposited as outwash during deglaciation, and subsequently by the paleo-Ottawa River.

Although several outcrops containing fossils will be visited, the unusual abundance of stromatolites in strata of eastern Ontario will be emphasized. In places these stromatolites are so abundant that they provide views reminiscent of large tracts of Proterozoic terranes in northern Canada with which both trip leaders are familiar. Such abundance of biofilm-mediated structures, in strata deposited well after the time during which many browsers and grazers had evolved, seems paradoxical. Yet environments suitable for abundant biofilm growth essentially free of predators exist in several parts of the world today. Where such active ecoscapes currently exist, hypersalinity sufficiently high to inhibit proliferation of browsers and grazers is the primary environmental condition that allows biofilm structures to grow in abundance. Such environments are postulated for growth of most of the stromatolitic units to be viewed in Paleozoic strata during this excursion. Although commonly abundant in beds above and below, shelly and trace fossils are essentially absent from the stromatolitic strata; another line of evidence is the common occurrence of associated evaporite pseudomorphs.

A highlight of the trip will be visits to two occurrences of stromatolites and associated biofilm structures in quartz arenite beds. Similar biosedimentary structures have been observed on the other

side of the Frontenac Axis (Dalrymple, pers. com.), and we have seen similar biosedimentary structures in a few localities in New York State. Because such structures can be readily mistaken for dewatering structures when seen in vertical section, re-examination of well-know localities elsewhere is warranted. Because of the prevailing view that stromatolites occur only in carbonate strata, quartz-sand stromatolites may well have been overlooked in other areas of correlative strata (especially in unmetamorphosed Precambrian siliciclastic strata, where such biosedimentary structures should have been abundant under conditions of normal as well as elevated salinity).

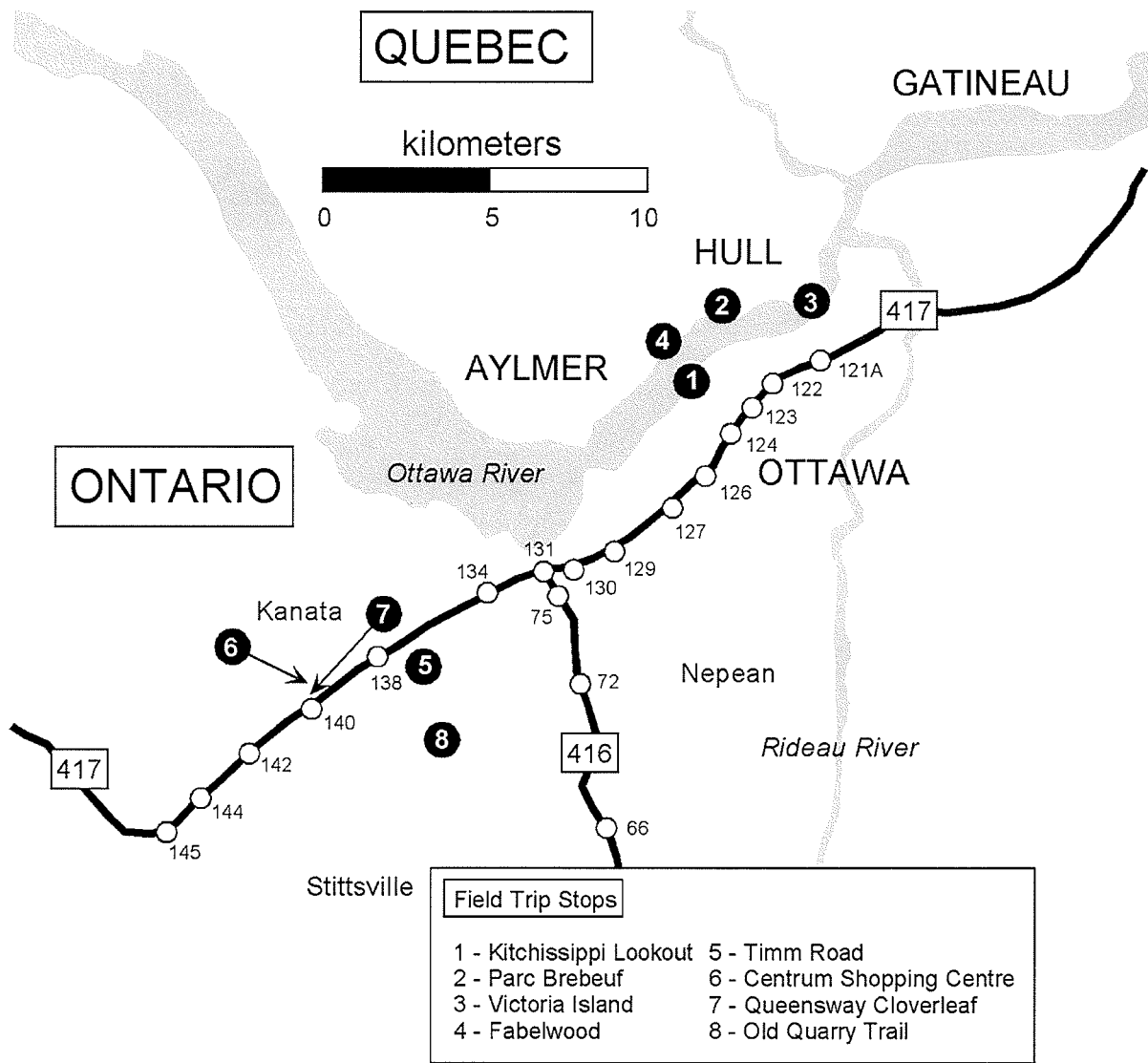


Figure 1. Field trip stop locations. Exit numbers on Highways 417 and 416 are shown for reference. See road log for detailed locations.

Period	Series	Stage	SOUTHEASTERN ONTARIO					NORTHERN NY	
			Williams & Teleford (1986)			Wilson (1946)		Fisher (1977); Cameron & Mangion (1977)	
			Group	Formation	Member	Formation	Faunal Zone	Group	Formation
ORDOVICIAN	Cincinnati	Richmond	Queenston			Queenston		No equivalents	
		Maysville	Carlsbad			Russell			
		Eden	Billings			Billings			
			Lindsay	Upper	Eastview				
				Lower		Coburg			
		Champlainian	Sherman	Verulam			Ottawa		Sherman Fall
	Kirkfield		Bobcaygeon	Upper		Hull			Sugar River
	Rockland			Middle		Rockland			Kings Falls
	Black River			Lower		Leray			Napanne
			Gull River	Upper		Lowville		Black River	Selby
	Chazy		Rockcliffe	Lower		Pamelia			
				Upper					Lowville
	CANADIAN		Beekman-town	Oxford	St. Martin			Chazy	St. Martin
		March		Rockcliffe		Rockcliffe			
		Potsdam	Nepean	Nepean			Keeseville		
	CAMBRIAN	Potsdam	Covey Hill	Nepean			Ausable		

Figure 2. Stratigraphic correlation of Cambro-Ordovician units in the Ottawa area (Southeastern Ontario) with adjacent parts of northern New York (after Williams et al. 1992.)

PERIOD	GROUP	FORMATION	FIELD STOP NUMBER & AGE
ORDOVICIAN	Ottawa	Coburg Sherman Fall Hull Rockland Leray Lowville Pamelia	3 2 4
		St. Martin Rockcliffe	1
	Beekmantown	Oxford March	5
	Potsdam	Nepean Covey Hill	6 7 8
CAMBRIAN			
PRECAMBRIAN ERA	BASEMENT ROCKS OF THE GRENVILLE PROVINCE (Outcrops visible in roadcuts between stops)		

Figure 3. Relative stratigraphic position of units exposed at each of the field trip localities.

ROAD LOG AND STOP DESCRIPTIONS FOR TRIP F-1

Meet at 9:30 am in the Kitchissippi Lookout parking lot, Ottawa.

NOTE 1. Allow at least 1.5 hours to drive from the junction of Hwy. 401 and Hwy. 416 to our rendezvous point (Kitchissippi Lookout parking lot, Ottawa).

NOTE 2. Field Trip F-1 will end around 4 pm, on Eagleson Road south of Kanata. This will allow ample time to return to Potsdam for the NYSGA Registration and Welcoming Reception (6:00-9:00 pm) in Thatcher Hall, SUNY Potsdam.

NOTE 3. Please be sure to have some type of photographic identification at the border. A passport is preferred, especially upon reentry to the U.S..

NOTE 4. Because of the urban setting, this trip will involve some complex driving including entering cul-de-sacs, and frequent turns to reverse direction and obey traffic laws. Thus it is very important to reset your odometer at each locality prior to leaving for the next.

How to get to the starting point from the USA-Canada border:

Follow Hwy 401 to Highway 416; take Hwy 416 north for 75 km to Hwy 417 (known as ‘The Queensway’ within Ottawa). Keep in the lane to enter Queensway East, and drive 3.8 km eastward (past the Richmond Road and Greenbank-Pinecrest exits). Take the next exit at Woodroffe, exiting right on a cloverleaf, and turn left at the stoplights (4.2 km from Hwy 416) to go north over the Queensway just exited. At 5.2 km, Woodroffe takes a 1-block jog to the east on Carling (after turning right on Carling, move quickly into one of the two left two lanes, to be able to turn left in less than 200 m to continue north on Woodroffe; this turn is at the stoplights, just before a shopping centre with a large Sears store). Continue straight, crossing Richmond Road at 6.4 km, proceeding downhill (over a paleo-Ottawa River shoreline) to the point (6.8 km) where Woodroffe merges eastward with the Ottawa River Parkway. Follow the Parkway eastward for 2.5 km, and turn left at the faded black sign (on the far left) marking Kitchissippi Lookout. Be careful not to miss this turn, which lacks stoplights or stop signs; it comes immediately beyond a pedestrian underpass to the same destination. Drive to the west end of the Kitchissippi parking lot, and meet at the kiosk armoured with display panels that provide information about the natural and cultural history of the Ottawa River (Note to subsequent users of this guidebook: on Sundays during the summer months, parts of this parkway, as well as other NCC Parkways in Ottawa, are restricted to use by cyclists and pedestrians only).

STOP 1. LIMESTONE, OTTAWA GROUP (ORDOVICIAN) AT KITCHISSIPPI LOOKOUT, OTTAWA

(Caution: cyclists and skateboarders use the paved path near the river, and patches of poison ivy occur sporadically along the shore beyond it).

The top of a two-metre cliff section along this part of the shore reveals a 20 cm bed of limestone containing laterally linked domal stromatolites with a synoptic relief of 10 cm. The recessively weathered underlying flaggy to slabby beds of limestone contain rare shale interlayers, and are sporadically rich in fossils, including orthocone cephalopods, brachiopods and bryozoa. Some bedding surfaces display desiccation cracks and ripple marks.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		Leave Kitchissippi Lookout (STOP 1), cross Parkway and turn left traveling east on the Ottawa River Parkway.
0.9 (0.6)	0.9 (0.6)	Turn left (north) on Island Park Drive and cross the Ottawa River into Quebec via the Champlain Bridge.
2.5 (1.6)	1.6 (1.0)	Turn right at first stop light past bridge onto Rue Lucerne.
4.3 (2.7)	1.8 (1.1)	Drive east one block past Parc Moussette turning right on Rue Bégin.
4.4 (2.8)	0.1 (0.1)	STOP 2. Park near the intersection of Rue Bourget and Rue Maricourt and; avoid sides of the street with no parking; meet at Brébeuf statue.

STOP 2. LIMESTONE, OTTAWA GROUP (ORDOVICIAN): PARC BRÉBEUF, GATINEAU, QUEBEC

N45°25.067' W075°44.722'

Those arriving early at STOP 2 may wish to check out the tapered base of the Brébeuf statue, which contains at least 500 cobble stones representative of the many rock types within the Grenville Province, sampled during Pleistocene glaciation, and rounded during subglacial transport and fluvial transport during deglaciation (<12000 years ago) . Their clean polished surfaces, reflecting derivation from a gravel pit in Pleistocene outwash, provide an opportunity to study the mineralogy, textures and structures (foliation, lineation, intrusive contacts, folding) typical of Precambrian terrane to the north. Around the base of the statue, metre-square pavement panels have been inset with uniformly sized clasts -- some with well rounded equi-size pebbles of white limestone; others with angular fragments of black basalt.

From the base of the statue, walk directly to the shore of the Ottawa River where gently dipping bedrock platforms of limestone display a variety of fossils: corals, stromatoporoids, cephalopods, gastropods, mollusks, brachiopods, crinoids, bryozoa, trace fossils, and fragments of trilobites. The artistically arranged limestone blocks in the retaining walls display a wide range in grain size, as well as primary structures such as bedding, ripple marks and crossbedding. Secondary structures include joints and stylolites. Note how features are accentuated on weathered surfaces.

To the east, a large boulder of Precambrian gneiss marking the Voyageurs Portage shows excellent folded foliation in three-dimensions. Immediately north, Rue Bourget has a curb along the south side consisting of two rows of stone paving blocks. Most are Nepean sandstone (set both on edge and parallel to bedding), but a few are granite. Some of the sandstone blocks display Liesegang banding. From the east end of Rue Bourget, walk east along the bike path (look out for speeding cyclists and rollerbladers). In rounding the curve below the transformer station on the left, note the variety of bedding-surface structures in limestone slabs set in the sloping base of the fenced-in transformer area. At its northeast fenced corner, take the last gravel footpath to the east (just before the T- junction in the bike path) out to the south shore of an inlet on the Ottawa River. Excellent views of folds in limestone beds can be seen along the northeastern shore of this inlet.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
		RESET ODOMETER BEFORE LEAVING
0.0 (0.0)		Leave Parc Brébeuf (STOP 2) and drive north on Rue Bégin to Taché Blvd.
0.4 (0.2)	0.4 (0.2)	Turn right and follow Taché Blvd east to Rue Eddy.
2.4 (1.5)	2.0 (1.3)	Turn right at Rue Eddy and travel south on the Chaudieres Bridge
3.1 (1.9)	0.7 (0.4)	Drive part way across the bridge, passing three stoplights, and turn left on Middle Street at the black sign indicating access to Victoria Island
3.4 (2.1)	0.3 (0.2)	Drive past an old generating station, and park in a small raised gravel parking lot on the right side, just past the Ottawa-Hull Navy Association building. Walk downhill towards Cul-de-sac sign. STOP 3.

STOP 3. OTTAWA GROUP LIMESTONE (ORDOVICIAN), VICTORIA ISLAND, OTTAWA RIVER

N45°25.216' W075°42.855'

In this exposure of Ottawa Group limestone, megaripples are recurring bedforms topping coarse clastic flat-lying beds that are intercalated with carbonate mudstones containing abundant trace fossils both perpendicular & parallel to bedding. Fossils in the megarippled units include bryozoa, brachiopods, crinoids and orthocone cephalopods (cf. Wilson, 1956). A distinct alternation is evident between these calcarenite beds rich in shelly fossils (mainly fragmented) and the shaly calcilutite beds rich in trace fossils. This probably represents alternation between quiet-water conditions and episodic storms. This interpretation fits well with the abundance of fine-grained intraclasts in the coarse-grained interbeds. Rare carbonate mudstone surfaces displaying desiccation cracks, reflecting intermittent exposure. The symmetrical megaripples are superposed on crossbedded units, suggesting storm reactivation of originally asymmetric current-deposited subaqueous dunes.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER BEFORE LEAVING Leave Victoria Island (STOP 3) by retracing your entry via Middle Street.
0.3 (0.2)	0.3 (0.2)	Turn left on Booth St. and drive south. Cross over intersection with the Ottawa River Parkway (no turns are allowed, due to construction). Keep right at the OC Transpo sign.
1.0 (0.6)	0.7 (0.4)	Turn right on Scott St. and head west.
4.0 (2.5)	3.0 (1.9)	Turn right (north) on Island Park Drive and re-cross the Champlain Bridge.
6.3 (3.9)	2.0 (1.4)	Turn left at Rue Lucerne (the first stop light after leaving the bridge).
6.6 (4.1)	0.3 (0.2)	Drive west about 200 m from these stoplights, and turn left again into Samuel de Champlain parking lot (6.6 km). Walk a few steps riverward to the bike path along the north shore of the Ottawa River. Turn left on this paved path and walk halfway back toward Champlain Bridge (Caution: speeding cyclists and skateboarders may suddenly appear around the curves, and patches of poison ivy commonly flank both sides of the paved path). The best exposures are in front of Fablewood, a historic yellow frame house with brown trim. STOP 4.

STOP 4. STROMATOLITES IN PAMELIA FORMATION (ORDOVICIAN), FABLEWOOD

N45°24.676' W075°45.980'

Glaciation has cut a near bedding-parallel section (Figure 4) through a single bed less than 40 cm thick that contains a continuous display of closely packed domal stromatolites. Successive degraded biofilm sheets separated by storm-deposited fine-grained carbonate sediments are marked by concentric rings of carbonaceous matter. In some areas, freeze-thaw action has exhumed the original morphologies over many square metres of laterally linked, domal stromatolites. Mapping at 1:25 scale has revealed strong local north-south trends of elongation for the stromatolite heads (Donaldson et al., 2002). In many places two or more are coalesced in parallel, strings oriented in the same (north-south) direction. By analogy with modern stromatolites in Hamelin Pool, Shark Bay, Western Australia, these trends are readily attributed to the action of tides and onshore-wind-driven waves (Playford, pers. com.). Some small stromatolites are elongate perpendicular to the prominent north-south trend; because several inter-stromatolite patches of small-scale asymmetric ripples indicate easterly currents, elongation of the orthogonally oriented small stromatolites is attributed to longshore currents. Intermittent exposure is reflected by micro-desiccation patterns on the tops of a few large stromatolites. Also by analogy with the modern stromatolites of Shark Bay, a hypersaline environment in which biofilm predators (Garrett, 1970) could not survive is inferred. This is supported by the observation that, whereas the underlying stromatolite-free beds of carbonate are fossiliferous (with gastropods and vermiform trace fossils particularly abundant), the stromatolite unit is free of megafossils. Only conodonts have been observed, and those extracted from the stromatolite unit are compatible with a hypersaline environment (Von Bitter, pers. com.).

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
		RESET ODOMETER BEFORE LEAVING
0.0 (0.0)		Leave (STOP 4) by retracing your entry via Samuel de Champlain parking lot drive.
0.1 (0.1)	0.1 (0.1)	Turn right on Rue Lucerne.
0.3 (0.2)	0.2 (0.1)	Turn right (south) at stop light re-crossing the Champlain Bridge.
1.6 (1.0)	1.3 (0.8)	Turn right on the Ottawa River Parkway and drive west.
7.6 (4.7)	6.0 (3.7)	At 7.6 km keep right to exit heading west on the Queensway (HWY. 417).
13.3 (8.2)	5.7 (3.5)	Drive west and move right to access the Moodies Drive exit.
13.5 (8.3)	0.2 (0.1)	Turn left at Moodies Drive and proceed south.
14.9 (9.2)	1.4 (0.9)	Turn right at Timm Drive, just beyond the railway overpass and proceed west.
18.1 (11.2)	3.2 (2.0)	Drive 3.2 km west on Timm Drive. Park as far over on the crushed stone shoulder as possible. (Caution: some patches of poison ivy, mainly near the fence). STOP 5.



Figure 4. Plan-view photograph of stromatolite exposures in Gatineau, Quebec (STOP 4).

STOP 5. MARCH FORMATION: DOLOSTONE AND DOLOMITIC QUARTZ ARENITE (ORDOVICIAN), TIMM DRIVE

N45°24.676' W075°45.980'

This section is only a few metres above the top of the Nepean formation. The carbonate beds contain abundant burrows, including several varieties that are bedding-parallel. Despite the extensive bioturbation, wispy biofilm structures and a few possible dewatering structures can be seen at several stratigraphic levels. Both the siliciclastic and carbonate beds display abundant crossbedding, and carbonate intraclasts are evident in some of the siliciclastic beds. Scattered patches of white to pale pink calcite are inferred to be replacements after evaporite minerals. The strata exposed here are similar to some outcrops showing the Potsdam –Theresa transition in New York State, as described by Selleck (1984).

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER BEFORE LEAVING
0.4 (0.2)	0.4 (0.2)	Leave (STOP 5) by continuing west on Timm Drive.
3.6 (2.2)	3.2 (2.0)	At 0.4 km Timm Drive crosses Eagleson Road at a stoplight and becomes Katimavik Road. Continue straight across.
4.3 (2.7)	0.7 (0.5)	At the intersection of Katimavik and Terry Fox Drive, turn right and head north on Terry Fox Drive.
4.8 (3.0)	0.5 (0.3)	Continue over the Queensway and turn right on Earl Grey Drive (Entrance to Centrum Shopping Plaza).
		Follow this road for 0.3 km to Chapters bookstore. Turn right to pass the Wal-Mart store, and turn left into the parking area along the southeastern side of Wal-Mart (4.8 km). Gather at the vertical section of horizontally bedded strata behind this building. STOP 6.
NOTE	LUNCH HERE	Depending on time, we will have lunch before or after this stop -- lots of restaurants to choose from, most of them east of the Centrum entrance sign.

STOP 6. NEPEAN FORMATION QUARTZ ARENITE (CAMBRO-ORDOVICIAN; POTSDAM EQUIVALENT), CENTURM SHOPPING PLAZA

N45°18.669' W075°54.716'

This 3m section (Figure 5), recently studied in detail (Anderson, 2004; Anderson et al., 2004), has provided significant information about the complex history of cementation in relation to sea level changes for this uppermost part of the Nepean. Additional information for the study was obtained from a longer exposure of equivalent strata (Dobie, 2004), but unfortunately, much of her longer section to the south (subparallel to the Queensway, north side), has been significantly degraded by construction now underway (a reflection of the lack of respect/protection afforded significant geological features not only in Ontario, but in most parts of the world).

The strata exposed in this section have been divided into facies on the basis of bedding thickness and sedimentary structures such as crossbedding and inferred biofilm structures. The diversity of these interdigitated facies is considerably more complex than as described for the principal reference section (Greggs and Bond, 1972). The prominent thick-bedded dune facies consists mainly of subaqueous dune cross-stratified quartz arenite, in places infilling erosionally-based tidal channels. The thin-bedded laminated facies is characterized by biofilm-mediated crenulate laminations (cryptalgal laminations), heavy mineral streaks, cross-laminated asymmetric ripple marks and granule-rich single-grain layers suggestive of lag accumulation. Soft-sediment deformation (convolute lamination) is locally evident at the top of the section, locally capped by a thin layer of domal quartz-sand stromatolites.

Frameworks grains consist almost entirely of fine- to very coarse-grained quartz; minor components are microcline, plagioclase and chert. Extremely well-rounded zircon, tourmaline and

opaque iron oxides form the heavy mineral streaks, but some opaque patches are of post-depositional origin, having clearly been deposited interstitially. Biofilms, now degraded, are inferred to have played a role in accumulation of these trace components (rare semi-opaque brownish-stained patches visible in thin section may be degraded pyrobitumen). Interstitial clay minerals occur as thin discontinuous films around some framework grains in the least-cemented zones. Quartz alone is the cement for well-indurated beds up to 3 cm thick in all facies, and for most crossbedded sandstones in the dune facies; a few beds that stand out as glassy markers display abrupt truncations (Figure 6), suggesting that they may have been penecontemporaneously cemented, and then locally disrupted by erosional undercutting of unconsolidated substrate, localized upward pressure associated with dewatering, or dissolution of patchy zones of intercalated evaporites. Subspherical clusters of quartz sand (almost exclusive to the dune facies) show a distinctive blade-like external morphology comparable to modern desert rose structures, suggesting that they are pseudomorphs after evaporite-cemented rosettes which grew interstitially within the quartz sand before cementation by silica. Some of these subspherical structures, locally coalesced in clusters (as are modern 'desert roses' of gypsum), contain cores of calcite-cemented quartz sand.

Different cementation styles in the dune facies compared to the bounding thin-bedded facies are attributed to contrasts in permeability and differences in the flux of silica-bearing solutions related to water-table variations. Rosettes in the dune facies probably grew soon after emergence above sea level of the highly permeable dune facies; subsequent precipitation of quartz cement in pore spaces between framework components of this facies resulted in widespread preservation of original grains within overgrowths. Having escaped this early cementation, the beds above and below were more subject to grain-contact solution during subsequent burial compaction, leading to the development of pervasive mosaic textures and abundant stylolites. Grenville basement rocks form a hill a few hundred m to the northeast, immediately beyond Castlefrank Road, (just past the top of the section). Such Precambrian highs may have been islands adjacent to, and ultimately over which, the Paleozoic strata were deposited. If time permits, an extra stop will be made at segments of outcrop not yet covered by concrete along the vertical section south of Earl Grey Drive, parallel to the east side of Terry Fox Drive (marking the western boundary of the Centrum Shopping Centre). Impressive cross-sections of metre-deep channels (Figure 7) filled with dune facies sandstone are exposed behind the Texas Chop House (at N45 18.476' W075 54.255'). Crossbed inclinations indicate that these represent tidal channels.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER AT INTERSECTION OF EARL GREY WITH TERRY FOX DRIVE
0.9 (0.6)	0.9 (0.6)	Leave (STOP 6) by turning left on Terry Fox Drive.
1.3 (0.8)	0.4 (0.2)	Cross over the Queensway and turn left on Katimavik (0.9 km).
2.3 (1.4)	1.0 (0.6)	Take the next left on Davis (1.3 km)
2.7 (1.6)	0.4 (0.2)	Left on McGibbon, left at the second intersection with Rowe (2.1 km), and right on Davis (2.2 km). This complex operation has allowed us to return to Katimavik (2.3 km). Turn right on Katimavik and head west.
3.3 (2.0)	0.6 (0.4)	Turn right on Terry Fox Drive and head north.
3.5 (2.2)	0.2 (0.1)	Cross over the Queensway again, but this time take the cloverleaf road marked 417 West ('To Arnprior').
		Before merging with the Queensway, pull well off on the wide gravel shoulder (3.5 km), far enough back from the merge point to avoid blocking visibility for other motorists entering Hwy 417 West. Proceed to flat glacially polished outcrop to your right. Use the utmost caution leaving and returning to the vehicles because of the high-speed traffic. STOP 7.

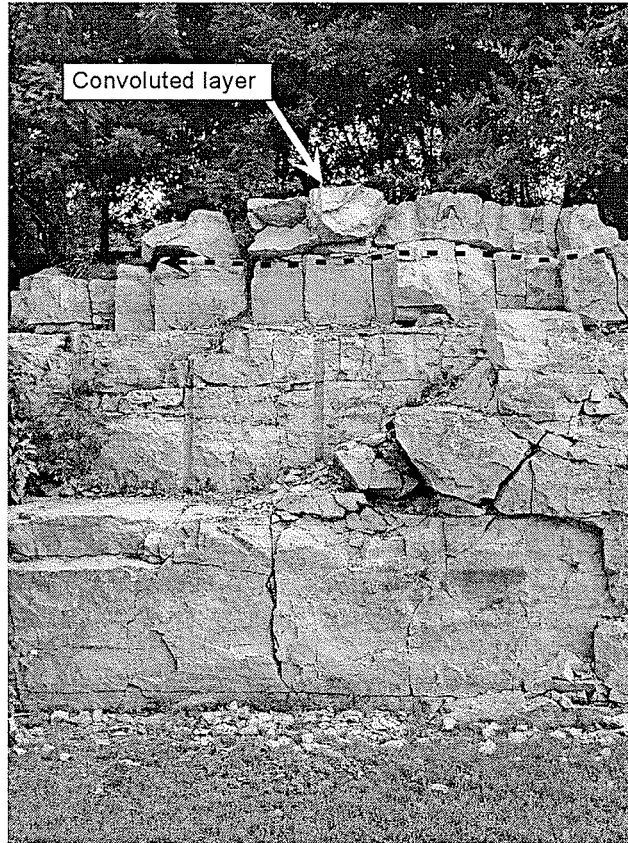


Figure 5. Three-meter-thick exposure of Nepean sandstone behind the Wal-mart in Kanata, Ontario (STOP 6). Note convoluted layer at the top of the outcrop.

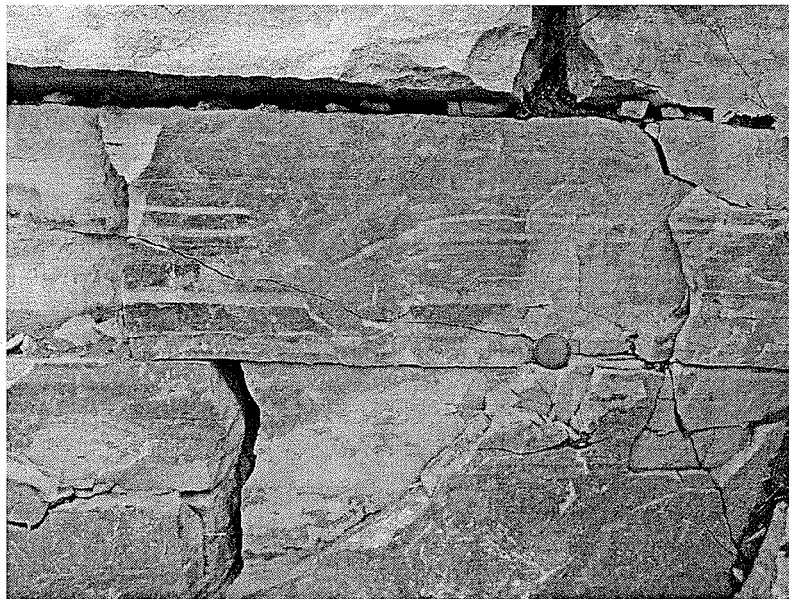


Figure 6. Truncated and silicified layer in the Nepean Sandstone behind the Wal-mart in Kanata, Ontario (STOP 6).



Figure 7. Tidal channels in the Nepean Sandstone, Kanata, Ontario (STOP 6).

STOP 7. NEPEAN FORMATION QUARTZ ARENITE (CAMBRO-ORDOVICIAN), QUEENSWAY CLOVERLEAF

N45°18.410' W075°54.675'

In the top 30 cm of this 2-m section, and in correlative outcrops on the south side of the Queensway, plus the median strip between them, various aspects of distinctive domal stromatolites in quartz arenite are remarkably well displayed. Since their discovery a few years ago, more have been recognized in other Nepean and Potsdam outcrops, but none to compare with these. This locality has been designated as an Ontario ANSI (Area of Natural Scientific Interest) Site, which is supposed to afford protection for significant geoscientific features. The fact that currently planned expansion of the Queensway will mean destruction of a good part of this world-class site clearly indicates the low priority allotted to significant geofeatures in relation highway construction and commercial development.

The glacially polished top of this outcrop of quartz arenite provides numerous cross sections through distinctly laminated domal stromatolites, many showing elaborate crenulate to colloform ornamentation of their laminae (Donaldson et al., 2000). To account for the random tilted arrangement of stromatolites displayed so well here in a flat-lying succession, the model proposed requires early cementation of the stromatolite unit above a still-unlithified substrate of water-charged sand. As a result of a seismic disturbance, the rigid unit of laterally linked silica-cemented stromatolites snapped apart along the thin inter-stromatolite links, allowing the now-separated heads to rotate and founder in random directions into the overpressured sand. Subsequent burial and completion of cementation of the entire unit allowed preservation of the distinctive array that has been so well displayed as a result of fortuitous bedding-parallel slicing through this stromatolite unit during Wisconsinan glaciation.

Local patches displaying overturning of thin sandstone laminae are attributed to synsedimentary rupture of flexible sand-charged biofilm sheets that were subsequently flipped or rolled back (Figure 8) by waves and/or currents (cf. Donaldson, 1967). Dubiofossils described from Potsdam sandstone of New York State (Erickson, 1993) may have had a similar biofilm-mediated origin. The section east of the entry cloverleaf road displays a distinct channel cut into biofilm laminated strata. Thin recessively weathered chips in the lower part of this massive channel-fill unit are inferred to be flakes torn from the truncated biofilm sheets. The base of the channel shows a few load-like protuberances, suggesting rapid deposition, perhaps as a result of bank collapse.

A few small bedding-surface exposures display intact horizontal layers of small, low-amplitude domal stromatolites, some superposed on, or laterally grading to, asymmetric ripple marks. Other bedding surfaces display very small-scale wrinkle patterns capping laminae of quartz sand, similar to interference ripple marks, but significantly under-scaled relative to grain size. These appear to be analogous to small-scale ripples mediated by thin biofilm coatings on siliciclastic tidal flats in modern peritidal sediments (De Boer, 1981; Gerdes et al., 2000; Noffke, 2000.), as well as in other ancient siliciclastic deposits (Hagadorn and Bottjer, 2002; Noffke et al., 2002; Schieber, 1999). In well-sorted layers of silica-cemented sandstone, hemispherical hollows are inferred to represent the molds of gypsum rosettes. Although no evaporite minerals have yet been directly detected, blade-like impressions in the hemispherical cavities suggest early silica cementation of the enclosing sands, followed by subsequent dissolution of the evaporites responsible for the 'sand rose' morphology (Figure 9). In addition, some stromatolites display upward pointed crystal pseudomorphs of probable evaporite minerals (Figure 10). This suggestion of hypersalinity provides an explanation for this rare occurrence of stromatolites in a Phanerozoic setting (Donaldson and Hilowle, 2002) -- just as for the earlier observed lack of gastropods in stromatolite-rich Ordovician carbonates. Probable stromatolites in the Potsdam sandstone on the southwestern side of the Frontenac Axis have also been noted by Dalrymple (pers. com.).

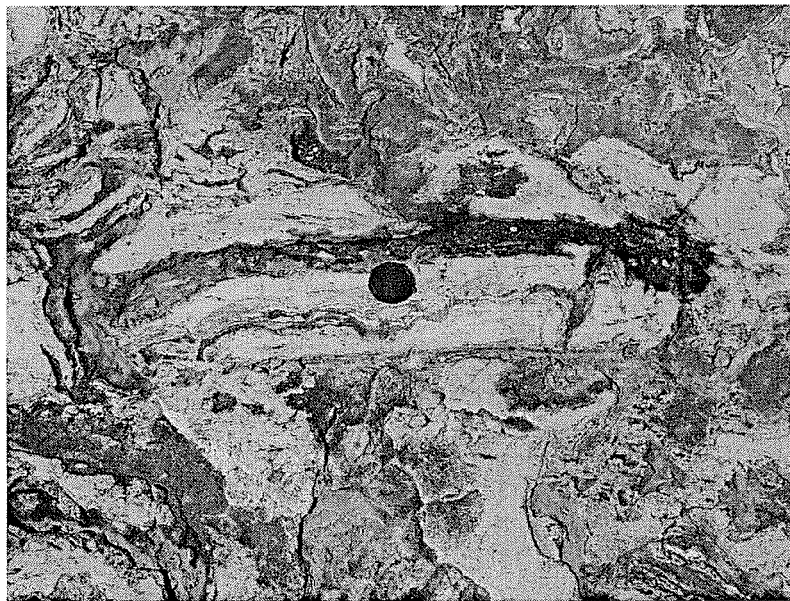


Figure 8. Glacially polished disrupted quartz arenites of the Nepean Sandstone with wrinkly, silicified biofilm layers (STOP 7).



Figure 9. Recessively weathering pockets within the Nepean Sandstone. Note the blade-like morphology in the hemispherical molds, probably produced by the replacement of evaporite rosettes (STOP 7).

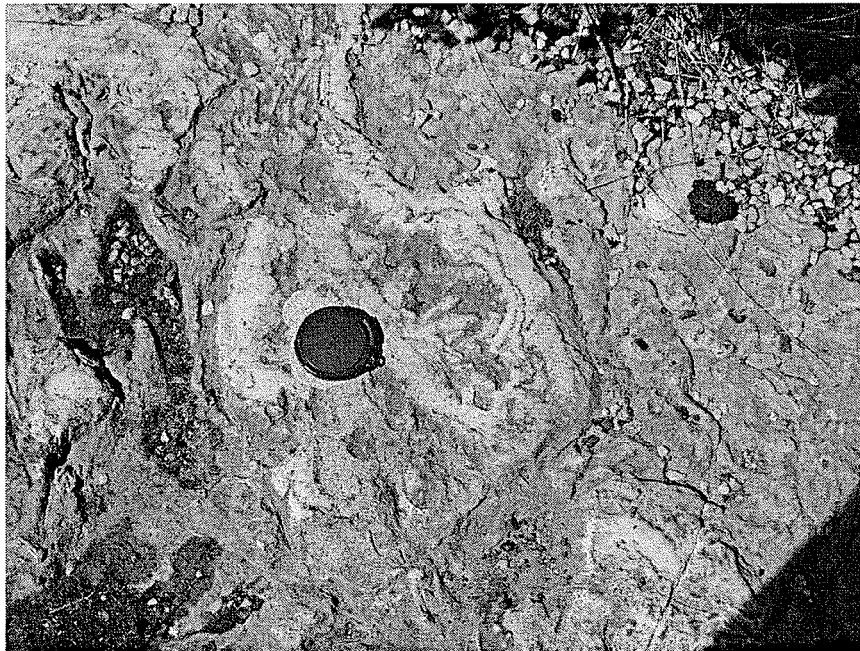


Figure 10. Close up of disrupted quartz arenites showing fine detail of layers and possible evaporite pseudomorphs (right of lens cap) in the Nepean Sandstone (STOP 7).

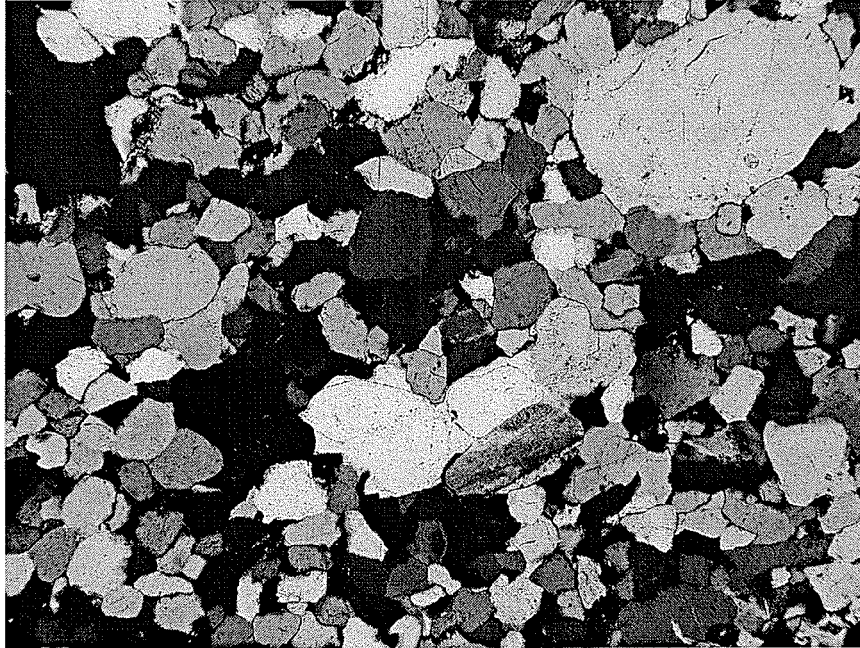


Figure 11. Photomicrograph of the Nepean sandstone from STOP 7. The quartz-rich composition and rounded of quartz grains is apparent. (Cross nicols, field of view 5 cm).

Thin-section and geochemical analysis (Table 1) indicate that the rock composed predominantly of quartz framework grains cemented by silica overgrowths (Figure 11). Geochemical analyses from this location indicate the rock is composed of >98% silica (Table 1) and relatively little else. Locally copper oxide and yellow carnotite(?) staining is evident. Some zones weather recessively indicating carbonate cement. The relative abundance of zirconium indicates that zircon is likely the dominant heavy mineral.

Table 1. Whole rock ICP-MS analysis of the Nepean Sandstone at Stop 7. Concentrations of major and select trace elements are given.

Major Element	Percentage	Trace Element	Parts per million
SiO ₂	98.29	As	0.5
Al ₂ O ₃	0.40	Ba	11
Fe ₂ O ₃	0.36	Cd	<0.1
MgO	0.15	Co	0.6
CaO	0.09	Cu	13.8
Na ₂ O	0.03	Hf	4.4
K ₂ O	0.04	Hg	<0.01
TiO ₂	0.08	Ni	3.2
P ₂ O ₅	<0.01	Rb	1.5
MnO	0.01	Pb	2.1
Cr ₂ O ₃	<0.001	Sr	9.4
LOI	0.5	U	0.1
Total C	0.02	V	<5
Total S	0.02	Zn	4
Sum	99.95	Zr	203.8

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER
2.0 (1.2)	2.0 (1.2)	Leave (STOP 7) by merging onto Queensway and drive west.
2.9 (1.8)	0.9 (0.6)	Exit Queensway at Palladium Drive (Exit 142). Keep in the left lane to turn left to pass over the highway.
8.5 (5.3)	5.6 (3.5)	Move right to enter the cloverleaf entrance to return eastward on Hwy 417.
10.4 (6.4)	1.9 (1.2)	Exit at Eagleson Road, turning right to drive south.
		Cross Robertson-Hazeldean Road. Keep left after this intersection, to allow a left turn, at the blue OP ₅ sign less than 200 m beyond, into the Old Quarry Trail parking lot.
ON	FOOT	From the southeast corner of this lot, follow the crushed-stone footpath southeast for 200 m. Just beneath the power line, walk 10 m to the right through the grass to a flat outcrop with two vertical joint faces that intersect at right angles. STOP 8.
END OF TRIP	RETURN DIRECTIONS	Retrace your entry into the parking lot and head north on Eagleson Road. Enter the Queensway and head east. Exit at the exit for Hwy. 416 and drive south towards the Prescott-Ogdensburg Bridge and Potsdam.

STOP 8. NEPEAN FORMATION (CAMBRO-ORDOVICIAN), OLD QUARRY TRAIL

N45°12.103' W075°52.482'

This siliciclastic outcrop is correlative with the outcrop at STOP 7. Convolute folds in a 1 m-thick unit below a thin unit of foundered 'half-moons and bananas' formed by disruption of an early-cemented layer of stromatolites above still-unconsolidated sand. Overpressure by interstitial water due to closer packing of well-rounded framework grains, aided by an almost complete lack of matrix, resulted in the creation of convolute folds (note lack of deformation in the underlying quartz arenite beds, and progressive attenuation in the upper limbs of antiforms in the metre-thick unit showing convolute lamination). Side views show several foundered 'half-moon' stromatolites within the synformal cores (Figure 12). The three-dimensional morphology of the apparent 'folds' is envisioned as linked bowls (somewhat like half an egg carton, with the egg-pocket openings facing concave-up). Subparallel alignment of the foundered and rotated stromatolites, as seen on the upper surface, suggests possible slope control, with probable condensation of the discrete stromatolite 'clasts' due to downslope sliding. Areas in the Nepean/Potsdam succession elsewhere showing evidence of synsedimentary brecciation (e.g. Selleck, 1978), suggesting that such areas warrant re-examination for evidence of early cementation of beachrock-like carapaces developed over unconsolidated sand layers due to biofilm mediation -- an association likely to rupture easily during seismic disturbances.

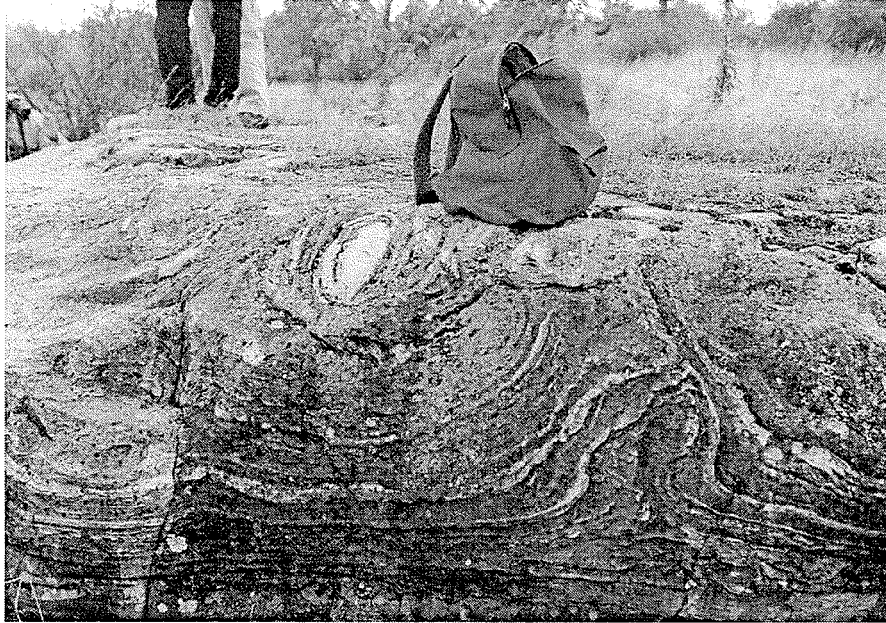


Figure 12. Convoluted layer in Nepean Sandstone at STOP 8. Note the banana-shaped clast next to the backpack and broad synformal warps between a tight antiform.



Figure 13. Plane view of Nepean Sandstone outcrop at STOP 8. Note the elongate cross-sectional shapes formed by foundering of domal structures.

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Workshop W-1

(repeated as Workshop W-4 on Sunday)

GEOPHYSICAL METHODS OF PROSPECTING

Frank Revetta
SUNY Potsdam
Friday, September 17, 2004
Timerman Hall, Room 120
1:00 – 5:00 p.m.

Field work will be conducted on Soccer Field

- | | |
|------------------|--|
| 1:00 – 2:30 p.m. | Electrical Resistivity Surveying
(A) Vertical Electrical Sounding (VES) <ol style="list-style-type: none">1. Wenner Method2. Lee Modification of Wenner Method3. Schlumberger Method4. Dipole-Dipole Method5. |
| 2:30 – 4:00 p.m. | Seismic Surveying
(A.) Seismic Refraction Survey <ol style="list-style-type: none">1. Forward and Reverse Shooting (Sledgehammer)2. Shotgun shooting
(B.) Reflection Survey <ol style="list-style-type: none">1. Optimum Offset Method2. |
| 4:00 – 5:00 p.m. | Gravity and Magnetics |

This workshop is repeated on Sunday, September 19 at 8:00 A.M.

EQUIPMENT

Seismic Refraction and Reflection

StrataView 24-Bit Exploration Seismograph
Betsy Seisgun
General Hole Digger
Hammers and Plates

Electrical Resistivity

Abem Terrameter SAS 300C
Electrodes and Cables

Magnetics

Proton Precession Magnetometer Memory G856 Mag
K-2 Magnetic Susceptibility Meter

Gravity

Worden Gravity Meter – Prospector Model
GPS – GeoExplorer

Radioactivity

Portable Gamma Ray Scintillometer

WHAT GEOPHYSICISTS DO

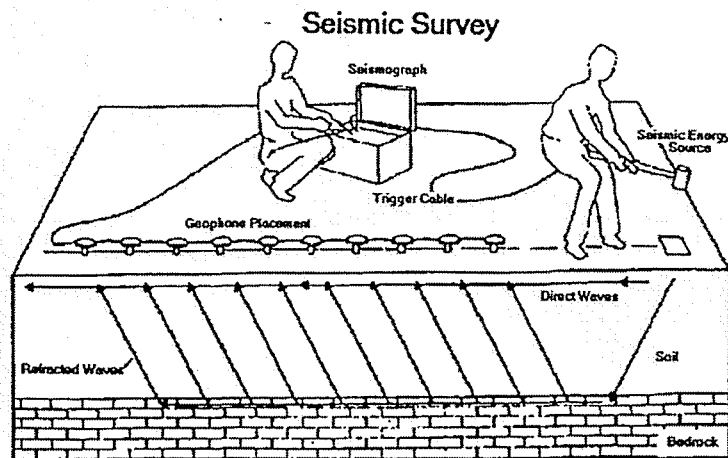
Geophysicists and geophysical engineers are explorers!

- Their target:* the subsurface of the Earth (and other planets)
Their range: the entire globe—all continents, oceans, environments
Target depths: a few meters in environmental applications
hundreds of meters in mineral exploration
up to 8 km in oil exploration
down to the Earth's crust, mantle, outer core and inner core
in studies of Earth processes
- Their methods:* measurement of physical properties of the Earth
its gravity field
its magnetic field
its electromagnetic field
its electrochemical field
its seismic-wave field
- Geophysicists:* hunt for oil and minerals
delineate hydrocarbon and water reservoirs
search for groundwater and geothermal energy sources
seek out contaminant spills and other environmental hazards
search for faults beneath large-scale engineering projects
hunt down hidden land mines
study volcanoes, predict earthquakes
study the Earth and its processes down to its core
- Working with and as geophysicists are:*
geologists, civil engineers, mechanical engineers,
electrical engineers, computer scientists, physicists,
and mathematicians
- Geophysicists work for:*
oil and mining companies
exploration contracting companies
consulting companies
software and hardware companies
state and federal geologic surveys
universities
themselves

SEISMIC REFRACTION METHOD

Applications

The seismic refraction method has many applications in shallow subsurface geologic investigations. The classic application is the determination of depth to bedrock. The method also plays an important role in groundwater investigations since it is possible to determine depth to water table. It is also an excellent tool in engineering and environmental studies since it makes possible the evaluation of dam sites, highways, bridges and landfill sites. Finally it is an excellent method of teaching refraction seismology principles that are used to investigate the crustal structure of the earth. Our seismic refraction survey will be used to determine the depth to bedrock and water table on the Potsdam College Campus.



The basic setup for a seismic survey.

Seismic Equipment

A StrataView, 24 channel Exploration Seismograph is used to conduct the seismic survey. It is ideal for refraction and reflection surveys. It operates from a 12 volt DC battery which is rechargeable. The data is stored in the SEG standard format for processing on personal computers or seismic workstations. The StrataView Exploration Seismograph simplifies seismic surveys. It is excellent for simple refraction surveys and for shallow and deep reflection surveys. Besides the seismograph you will need a power source, geophone cables, geophones and an energy source.

Energy Source

The energy source is the source of seismic energy used to generate the elastic waves. Our survey will involve the use of a sledgehammer and Betsy Shotgun.

The sledgehammer is the most common energy source for shallow surveys. It is popular because it is lightweight (8 lbs.), portable, low cost, efficient, and safe. Its main limitation is its limited depth range. However, the energy from several blows may be stacked to increase depth range. A hammer switch is attached to the sledgehammer to trigger the seismograph.

The Betsy shotgun uses shotgun shells as an energy source. A hole is drilled from 1.5 to 3 feet in depth. The shotgun with shell is placed in the hole and soil is then compacted well to assure the energy penetrates into the earth. This method does produce better records to greater depths. However, conducting the survey requires more work such as drilling and a compaction of soil.

Geophone Cable and Geophones

A standard geophone cable consisting of 12 geophone takeouts at 10 foot intervals is used to acquire the travel times. Two of these cables are used with our 24 channel StrataView. The seismograph is located in the center of the line and the geophone cable (1-12) is connected to one connector and geophone cable (13-24) is connected to the other connector.

A moving coil geophone is the basic vibration sensor (Fig. 1). The coil and its support spring make a pendulum with a natural frequency of 14 Hz. The geophones are less sensitive to vibrations with frequencies lower than their natural frequency. Much noise tends to be low

frequency. For shallow surveys, seismic signals tend to have much higher frequency and a geophone with a natural frequency around 14 Hz is a good compromise for use in refraction surveys.

Display

The liquid-crystal display is easy to see in daylight. A backlight is provided for viewing at night time. Some darkening of the screen may occur in hot weather and bright sunlight caused by thermal heating. An umbrella is useful for shading the display on hot sunny days.

Menus

When the MENU key is pressed the display will show a list of menus shown below.

Geometry Acquisition File Display D_Survey Answers Other

One of the selections will be highlighted in reverse video. Below this line, overlaying the data display, will be a box containing secondary menu selections. The selections will correspond to the highlighted main menu item. There may be a single selection shown, or a long list. Some selections are execution statements, meaning that an action will be performed if ENTER is pressed while the selected item is highlighted.

Other selections will cause another menu to be displayed, or a request for a number to be entered, or suggestions for further action. In operation, the menu system is quite easy to use.

GEOMETRY menus are used to record the locations of the geophones and the energy source.

ACQUISITION menus control the data gathering parameters (such as sample interval, record length, filters).

FILE menus control the saving and reading of data files onto disk.

DISPLAY menus control the way the data is displayed on the screen and plotted.

DO-SURVEY contains the functions normally used to acquire, display, and analyze data in a production mode.

ANSWERS menus are used to run the field quality control software programs to analyze the data.

Seismic Methods

The two types of seismic methods of prospecting are the refraction and reflection methods (Fig. 2). The travel times of critically refracted waves are measured in refraction surveying while the travel-times of reflected waves are measured in reflection surveying. Figure 2 shows the wave paths for each method.

The mechanism for transmission of refracted waves is shown in Figure 3. The wavefront is used to describe the disturbance and a line perpendicular to the wavefront known as ray path. The ray is refracted along the higher velocity layer at the critical angle. The critical angle is given as:

$$i_c = \sin^{-1} \frac{V_1}{V_2}$$

Where V1 and V2 are the upper and lower velocities.

Refraction Method

The travel-times of the first arrivals are measured in the refraction method. These represent the waves that take the minimum travel-time path to reach the geophones and are the waves refracted at the critical angle. Figure 4 shows the refracted wave paths and the travel-time graph drawn from the travel times. This graph shows a three-layer case. The inverse slope of the travel time curves gives the velocity and the crossover distances or intercept times enable depths to be calculated.

Seismic Record

Figure 5 shows a typical seismic refraction record of a forward shot. The horizontal lines are 5 milliseconds time lines and the vertical traces are output from the 24 channels. The numbers above each trace are geophone numbers and gain of each channel. The shotpoint is located at the left side at an offset of 10 feet. The record shows the first arrivals or first breaks that are used to construct the travel-time curve as well as airwaves and ground roll.

Figure 6 shows the seismic record of a reverse shot. Reverse shots should always be done during seismic refraction surveys since they provide additional data and enable dips of the layers to be determined. This record shows the picks of the first breaks which are made by the computer software but usually need to be adjusted. The forward and reverse times are shown in milliseconds beneath the traces.

Figure 7 shows a cross section drawn by the software indicating a 3-layer model of the subsurface geology at the site. The area consists of a low velocity layer about 10 feet thick overlying a higher velocity material extending to a depth of 62 feet. The third layer has the highest velocity around 16000ft/sec. Well logs in the area indicate the 3 layers are a near surface silty sand layer overlying a compact clay. The third layer is the Potsdam sandstone.

Travel-Time Graph

A travel-time graph produced by the computer software is shown in Figure 8. This graph shows three shots were made. Two end shots were made with an offset of 5 feet and one shot located in the center of the spread. The travel time graph shows the times for the refracted waves to travel to the geophones. The graph indicates 3 layers as shown in the model.

Seismic Velocities

Velocities of compressional (P) waves in feet/sec and meters/sec are shown in Table 1. The refraction method requires that the lower layers have a higher velocity than the upper layer, otherwise no critically refracted wave will occur. Fortunately in most areas this is the case. However there may be cases where the upper layer has a higher velocity.

Reflection Method

Figure 9 shows the basic principle of the seismic reflection method. Acoustic energy is produced at the shotpoint which could be a sledgehammer hitting a steel plate or a shotgun shell set off below ground level. Elastic waves travel through the earth and are reflected from boundaries of rocks having a contrast in density and velocity.

Seismic Reflection Method

The StrataView may be used to conduct seismic reflection surveys. The basic idea behind the seismic reflection method is shown in Figure 10. The travel times of the elastic waves to travel down and reflect from a reflector is measured. Several seismic reflection methods exist such as common midpoint, split spread and optimum offset method. We will use the optimum offset method, which measures the reflected time to each geophone while keeping the offset the same (Fig. 10). An offset is chosen that provides the record that shows reflections that arrive at

times that are not the same as other waves such as ground roll, air waves or refracted waves. An optimum offset shallow reflection record is shown in Figure 11.

Figure 1 - Geophone coupled to ground to detect seismic waves.

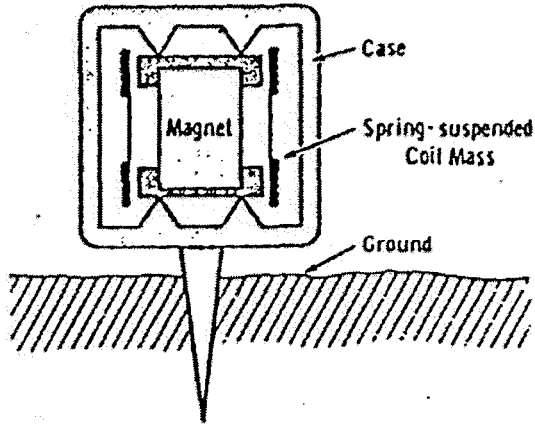


Figure 2 - Seismic wave paths of a reflection and refraction survey.

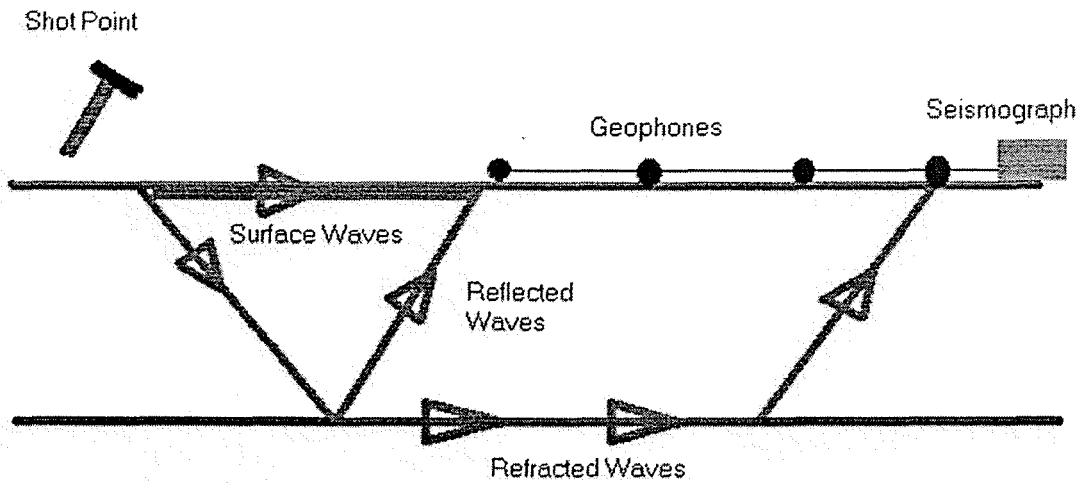
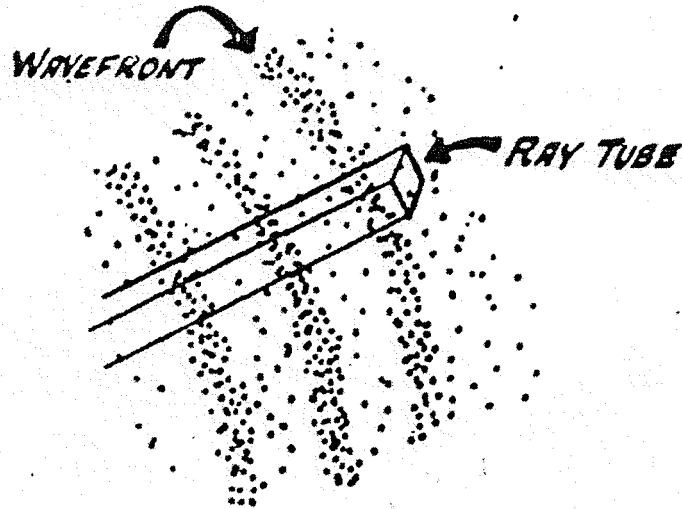


Figure 3 - Mechanism for transmission of seismic waves.

WAVEFRONTS & RAYPATHS



WAVEFRONT - SURFACE OF THE MOST FORWARD POSITION OF A PROGRESSIVE DISTURBANCE AT A PARTICULAR TIME.

WAVEFRONT - SURFACE OVER WHICH THE PHASE OF A TRAVELING WAVE DISTURBANCE IS THE SAME.

RAY PATH - LINE EVERYWHERE PERPENDICULAR TO WAVEFRONT (IN ISOTROPIC MEDIA).

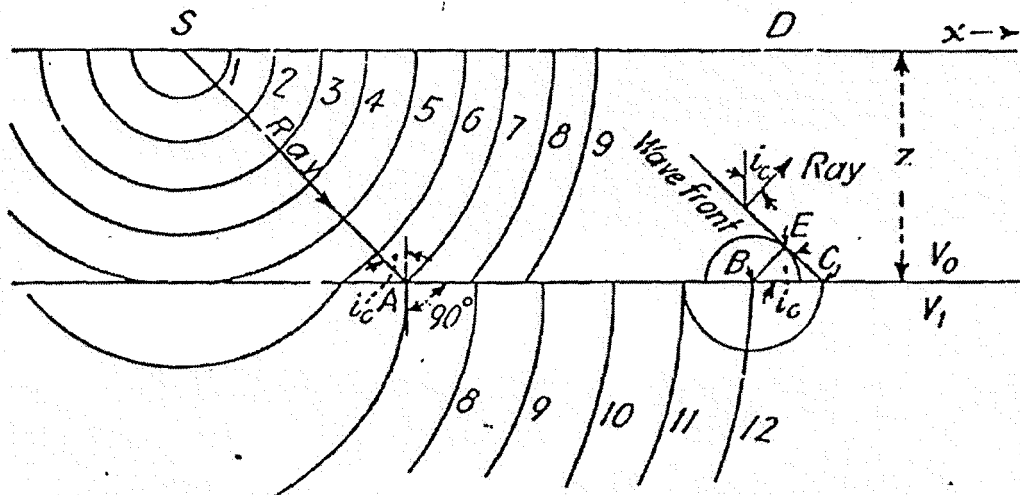


Figure 4 - Travel-time graph, seismic record and wave paths of a seismic refraction survey.

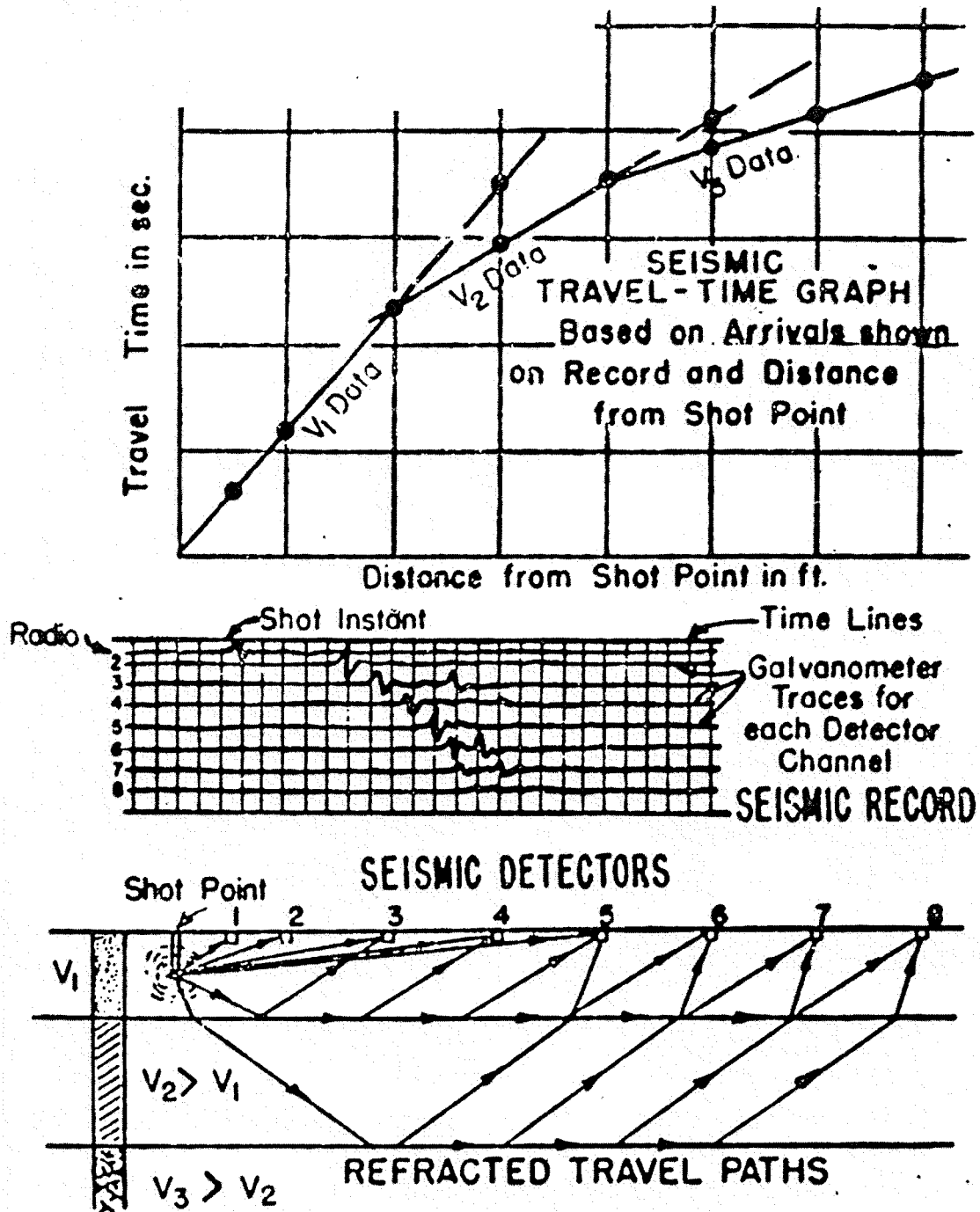
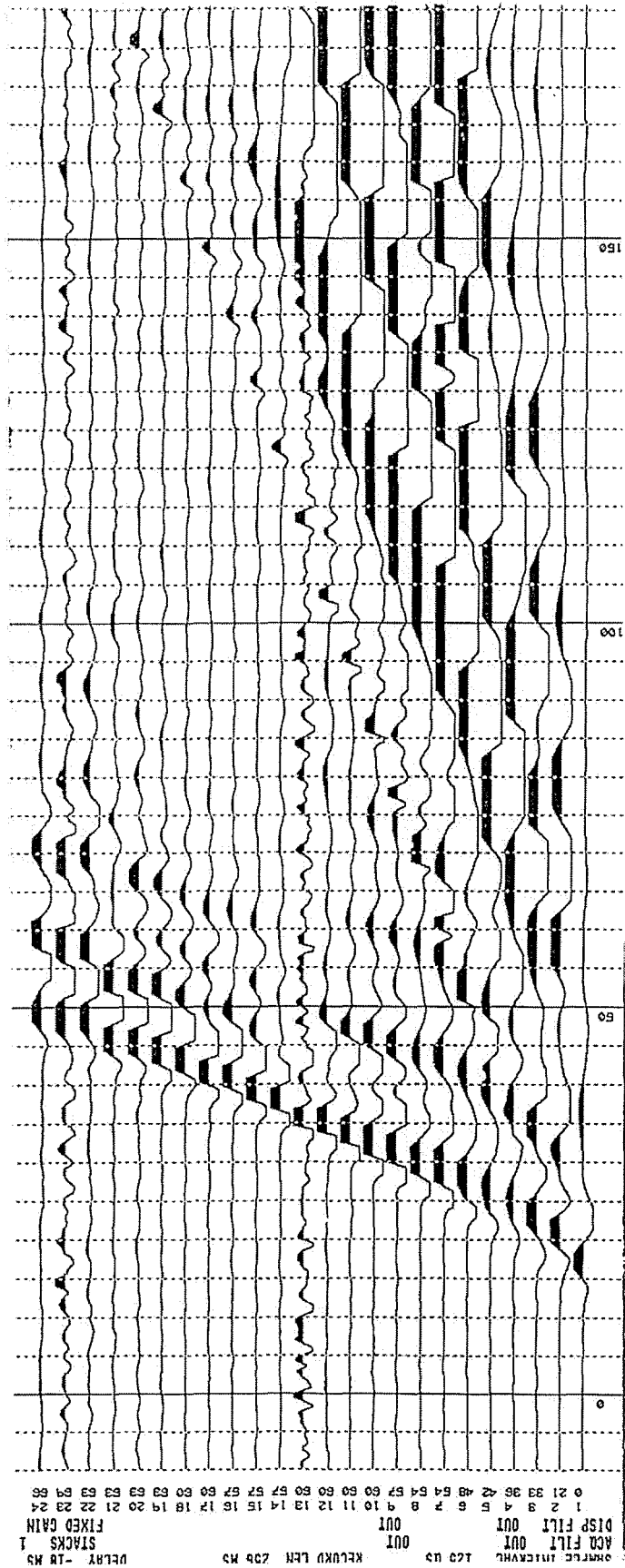


Figure 5 - Seismic record of a shot in one direction (Forward Shot).



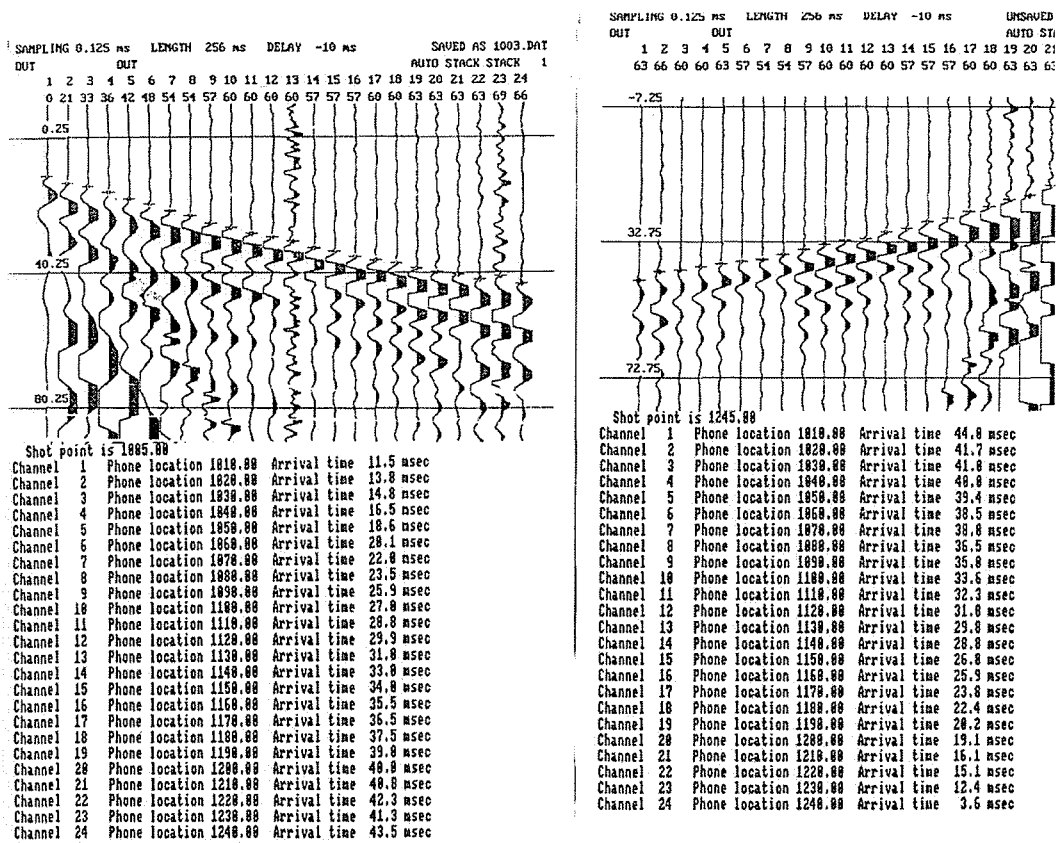


Figure 6 - Seismic record of forward and reverse shot. Picks of first breaks and travel times are shown.

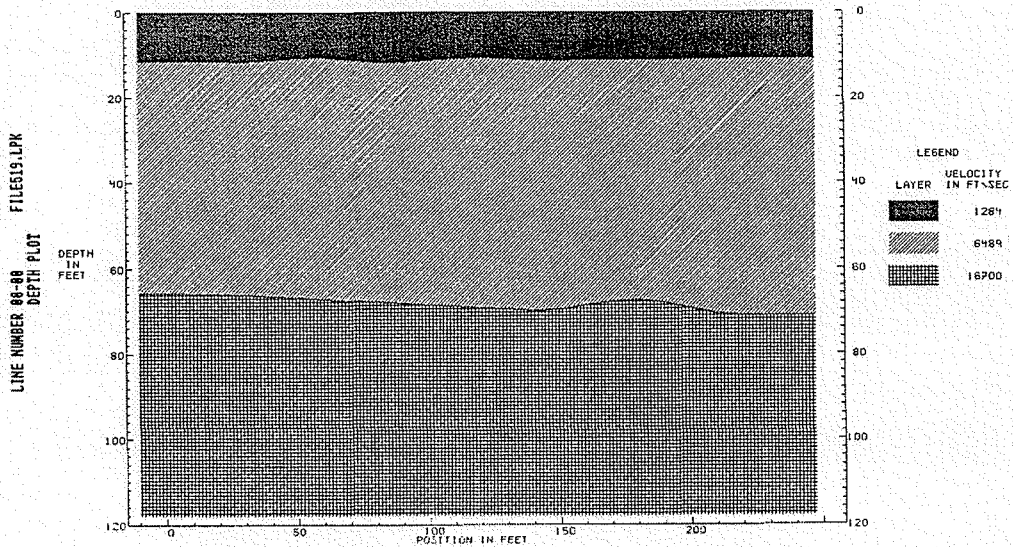
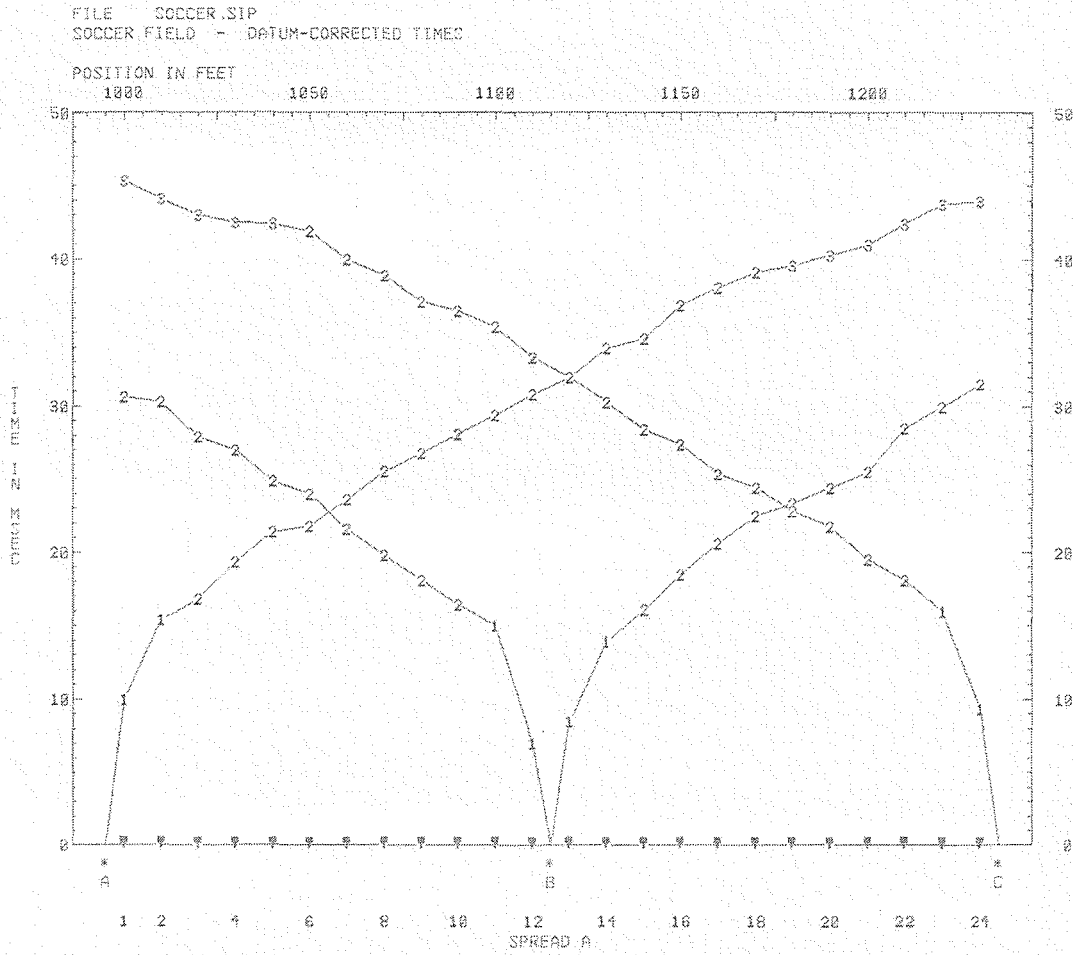


Figure 7 - Geologic cross section showing a 3 layer case based on seismic refraction survey.

Figure 8 - Travel-time curves based on two end shots and a center shot. Graph indicates 3 layers.



TYPICAL COMPRESSION WAVE VELOCITIES (V_p) FOR EARTH MATERIALS

Material	mps	fps
Air	330	1,100
Loam, dry	180 - 300	600 - 900
Loam, wet	300 - 750	1,000 - 2,500
Sand, dry	450 - 900	1,500 - 3,000
Gravel	600 - 800	2,000 - 2,800
Sand, cemented	850 - 1,500	2,800 - 5,000
Sand, loose saturated	1,500	5,000
Water (shallow)	1,450 - 1,600	4,800 - 5,100
Clayey soil, wet	900 - 1,800	3,000 - 6,000
Till, basal/loess	1,700 - 2,300	5,600 - 7,500
Rock, weathered Sedimentary	600 - 3,000	2,000 - 10,000
Rock, weathered Igneous and Metamorphic	450 - 3,700	1,500 - 12,000
Shale	800 - 3,700	2,600 - 12,000
Sandstone	2,200 - 4,000	7,200 - 13,000
Basalt, fresh	2,600 - 4,300	8,500 - 14,000
Metamorphic Rock	2,400 - 6,000	8,000 - 20,000
Steel	6,000	20,000
Dolomite and Limestone, fresh	4,300 - 6,700	14,000 - 22,000
Granite, fresh	4,800 - 6,700	16,000 - 22,000

Table 1 - Typical compression wave velocities (V_p) for earth materials. These are useful for determining type of rock in a refraction survey.

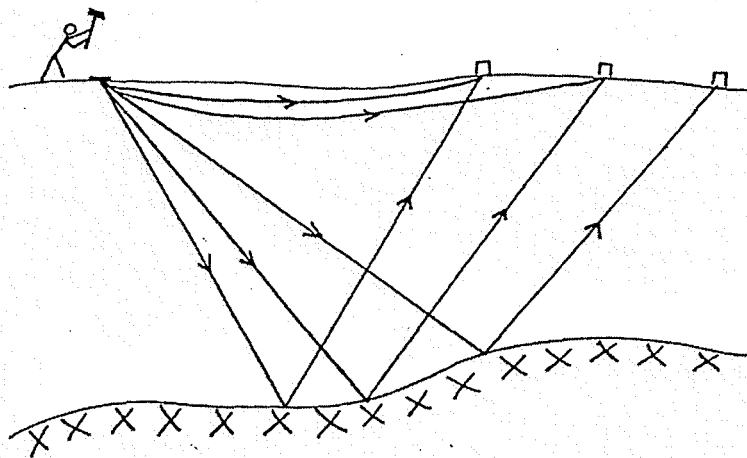


Figure 9 - Basic principle of the seismic reflection method.

Seismic Reflection Survey: Optimum Offset Method

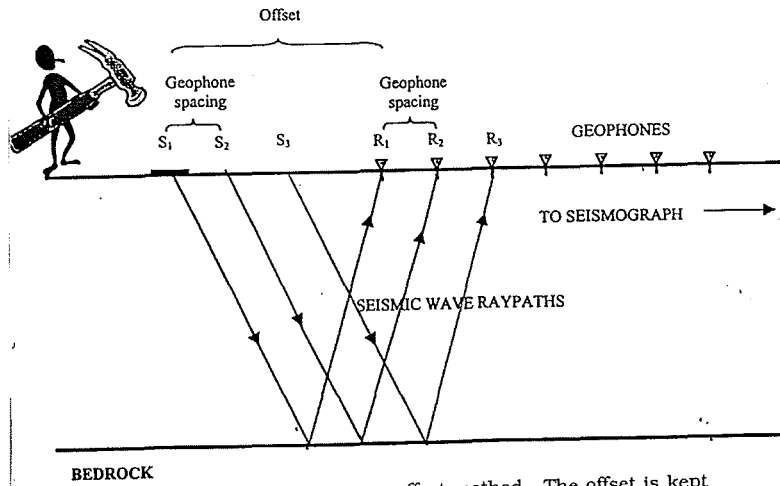


Figure 10 - Optimum offset method. The offset is kept constant for each geophone.

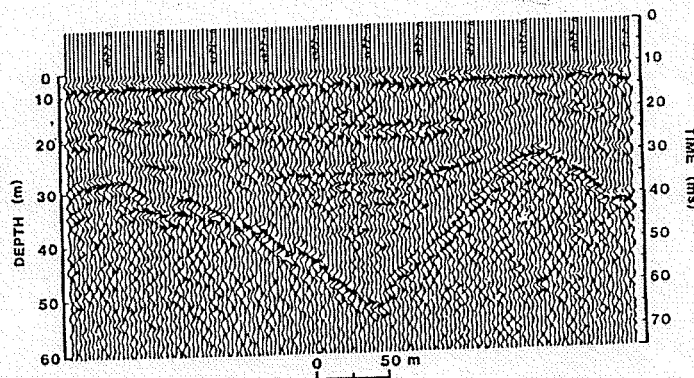
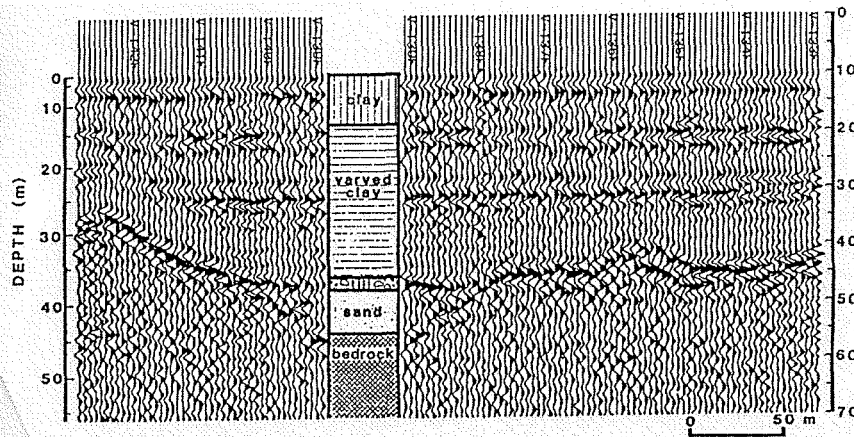


Figure 11 - "Optimum offset" shallow reflection section from ValGagne, Ontario.

EARTH RESISTIVITY SURVEY

Applications

The electrical resistivity method has many applications in shallow subsurface geologic studies. The method may be used to determine depth to bedrock and water table. It can be used to locate sand and gravel deposits, buried stream channels and mineral deposits. It is also an effective tool for mapping salt water-fresh water interface and contaminant areas associated with landfill sites. Some other uses are in geothermal exploration and mapping archaeological sites.

Earth Resistivity Methods

Electrical resistivity surveying measures the apparent earth resistivity from the surface. Various types of earth materials have resistivities that can be distinguished from one another. The basic types of field procedures used are vertical electrical sounding and resistivity profiling. In vertical electrical sounding (VES) we determine how resistivity varies with depth by increasing electrode spacing. In resistivity profiling, a fixed electrode separation is maintained, however, the location of the spread is changed to determine horizontal variations in resistivity.

Vertical Electrical Sounding (VES)

Figure 1E shows the main elements of electrical resistivity surveying and illustrates the procedure used in vertical electrical sounding. Four electrodes are laid out along a line. The outer electrodes (C1 and C2) are current electrodes and the inner electrodes (P1 and P2) are potential electrodes. A current is supplied through the current electrodes and the voltage drop is measured between the potential electrodes. Measurements of the current flow, potential drop and electrode spacing are used to calculate the apparent resistivity of the material to a depth assumed equal to the electrode spacing. Measurements at greater depth are made by increasing the spacing between electrodes. The method for most vertical electrical sounding surveys is the Wenner configuration where the spacing between electrodes is kept equal. When the Wenner method is used the apparent resistivity (ρ) is computed by the formula:

$$\rho = 2\pi A \frac{V}{I}$$

Where

- P = apparent resistivity
- A = electrode spacing
- V = voltage drop
- I = current flow

The term V/I is resistance with units of ohms. The electrode spacing will be measured in meters so our resistivity values will have units of ohm-meters. As a rough guide, materials with resistivities less than 100 ohm-meters are considered low and materials greater than 1000 ohm meters are considered high. Resistivities of various earth materials are listed in Table 1E.

Field Procedure

Figure 2E is a data sheet used to record the resistivity values for vertical electrical sounding by the Wenner method. Readings are made at intervals shown in the left column. Note these spacings begin with 1 meter then proceed through values equally spaced on a logarithmic scale. This is done because a larger electrode spacing yields information over a much larger volume of earth, thus a given volume becomes proportionately less important. A second reason is that normally data is plotted on log-log graph paper. We record resistance values for current flow from C1 to C2 under R1 or R2 on the data sheet.

Resistivity Equipment

Our resistivity survey will be conducted with a Terrameter SAS 300c instrument manufactured by ABEM. The instrument can be used for both self potential surveys and resistivity surveys. In the resistivity surveying mode it comprises a battery powered deep-penetration resistivity meter with output sufficient for a current electrode separation of 2000 meters. The instrument contains three main units all housed in a single casing: the transmitter, receiver and microprocessor. The instrument measures and displays the resistance in ohms or milliohms.

The Terrameter SAS300c is shown in Figure 3 E. The instrument is turned on with off-on toggle switch. Battery should be checked to see if it is properly charged at 12.5-15 Volts. If reading is less than 11.5V, then battery will soon need recharging.

Resistivity Surveying Mode

The procedures for conducting a survey are as follows:

Position the SAS300c midway between the potential electrodes. Connect electrodes P1 and P2 into P1 and P2 terminals, connect C1 and C2 electrodes to C1 and C2 terminals.

Turn the MODE selection to the Ohms (r) position and the CYCLES selector to position 4.

Turn the current selector to 20ma. Switch the power on and press the MEASURE button. If an error mode Code 1 appears and a beeper sounds, reduce the current step by step until the beeper stops. A reading will appear on the display. Observe the four readings that appear successively on the display. If they are nearly equal, the noise level is low. If the readings differ significantly turn the CYCLES to position 16 or even 64.

The proper functioning of the meter should be checked periodically by using a known resistor, usually 15000 ohms. The instrument should be tested at least weekly.

Lee Modification of the Wenner arrangement

In the Lee Modification of the Wenner Method, an electrode is placed midway between P1 and P2. Three potential measurements are made across three pairs P1P2, P1P0, P2P0. The resistivity is calculated by using the expression:

$$\rho = 4\pi A \frac{V}{I}$$

This method has the advantage of detecting horizontal variations in resistivity whenever one is conducting vertical electrical sounding.

Schlumberger Method

For vertical electrical sounding the Schlumberger Method is recommended, although the Wenner is acceptable. The Schlumberger arrangement has a smaller spacing than Wenner for the potential electrodes. Figure 5E shows the Schlumberger arrangement. A widely used condition in this method is that MN is kept less than 40% of L. This method has the advantage of being

less sensitive to lateral variations in resistivity. It is also faster in field operation since only the current electrodes must be moved between readings.

Dipole-Dipole Method

The dipole-dipole arrangement is shown in Figure 6E. It can be used for sounding by increasing the distance between C1C2 and P1P2 or profiling. It is useful in deep geothermal studies and in mining. Keller (1974) recommends it as a preferred electrode arrangement for resistivity mapping. A formula for calculating resistivity for this method is:

$$\rho = \pi \left(\frac{r^2}{a} - r \right) R$$

Where a is electrode spacing, R is resistance measurement in ohms and r is the distance between electrode pairs.

Interpretation of Data

While the acquisition of resistivity data is relatively simple, the results are difficult to interpret. A procedure normally followed for the interpretation of the resistivity data is as follows. First the resistivity data is plotted on log-log paper with one axis being electrode spacing and the other being apparent resistivity. This preferred method of plotting on log-log paper makes the shape and size of the curve independent of units and electrode separation used. The standard procedure used to interpret resistivity sounding data consists of the following steps.

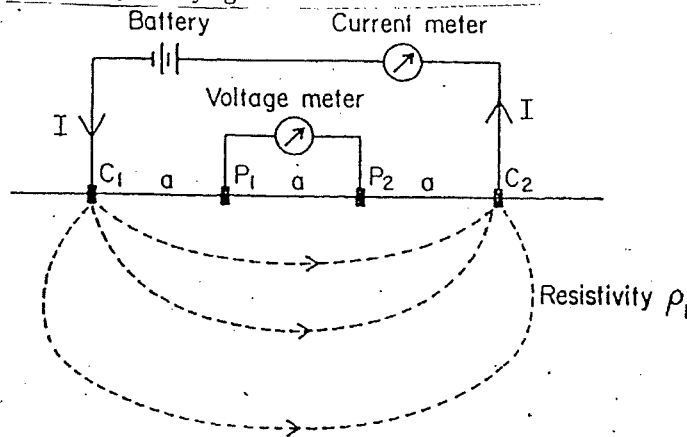
1. Assume a resistivity model based on the resistivity profile and any other information you may have such as well logs and seismic surveys. A model consists of the number of layers, resistivity of each layer and thickness of each layer.
2. Compute the apparent resistivities expected from your assumed model. This is usually done with a computer program.
3. Compare the observed resistivity field curve with the computed values based on your assumed model.
4. Modify the model until a best possible agreement is obtained between computed and field values. Keep in mind that a good fit means only the fit is good and that the model isn't necessarily the correct one. It is always possible that many different models may produce equally good fits. Additional information such as well logs are always needed to choose the most likely correct model. Also computer software is available (Burger 1992) that will modify your model until an excellent fit occurs between the field curve and computed resistivity values. Some typical resistivity curves are shown in Figure 7E with their interpretation or model shown below the curve.

It is difficult to correlate resistivities with specific rock types without geologic information because of the great range of resistivity values of rocks. No other physical property of naturally occurring rocks or soils displays such a wide range of values. Bedrock has higher resistivities than saturated sediments. Unsaturated sediments above water table have higher resistivities than saturated sediments. Table 2E from Burger (1992) shows various materials and their resistivities in ohm-meters.

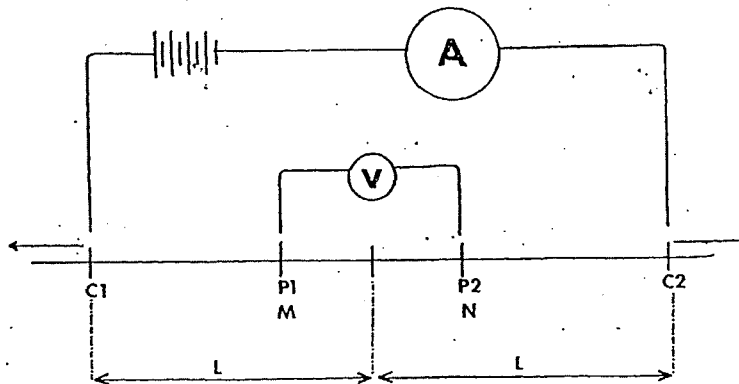
Resistivity Profiling

In resistivity profiling the location of the spread is changed while maintaining a fixed electrode spacing. Profiling is done when we wish to learn how resistivity varies in a horizontal direction. Some applications are locating boundaries between different lithologies, location of faults, locating contaminated or salt water or permafrost zones. The Wenner electrode arrangement is used in profiling and an electrode spacing of twice the depth of interest is chosen. Measurements may be made at distances equal to electrode spacing, however, if more detailed coverage is needed then the measurement could be made at intervals less than electrode spacing. Resistivity profiling data may also be presented as a contour map by conducting a series of profiles parallel to each other over an area. Profiles may also be conducted to present a resistivity cross section by doing a series of profiles over an area with increasing electrode spacings (Fig. 8E).

Figure 1E - Setup and principle of Wenner Method of resistivity surveying.



The Wenner array. This is the setup and principle behind the Wenner method. The battery symbol represents the battery source. The current meter and voltage meter are both inside the Terrameter SAS 300C and are what our readings are based on, (Voltage/Current = Resistance). C1 and C2 represent the two current electrodes and P1 and P2 are the two potential electrodes.



The basic setup and principle behind the Schlumberger method. Again the current and voltmeter are inside the Terrameter SAS 300 C. There is the battery source. The different distances for the formula to solve the Schlumberger way are also given in this picture.

Table 1E - Resistivities of various materials.

3. Representative resistivity values

As a rough guide, we may divide earth materials into

- low resistivity less than 100 ohm meters
- medium resistivity 100 to 1000 ohm meters
- high resistivity greater than 1000 ohm meters

Some representative resistivity values are:

Regional soil resistivities

- wet regions 50-200 ohm meters
- dry regions 100-500
- arid regions 200-1000 (sometimes as low as 50 if the soil is saline)

Waters

- soil water 1 to 100
- rain water 30 to 1000
- sea water order of 0.2
- ice 10^5 to 10^8

Rock types below the water table

- igneous and metamorphic 100 to 10,000
- consolidated sediments 10 to 1000
- unconsolidated sediments 1 to 100

Ores

- massive sulfides 10^{-4} to 1
- non-metallics
(gypsum, quartz, dry rock salt) order of 10^{10}

Effect of water salinity

.005 g/liter	1050
.10	110
.5	12

Material	Resistivity (Ω ·m)
Wet to moist clayey soil and wet clay	1s to 10s
Wet to moist silty soil and silty clay	Low 10s
Wet to moist silty and sandy soils	10s to 100s
Sand and gravel with layers of silt	Low 1000s
Coarse dry sand and gravel deposits	High 1000s
Well-fractured to slightly fractured rock with moist-soil-filled cracks	100s
Slightly fractured rock with dry, soil-filled cracks	Low 1000s
Massively bedded rock	High 1000s

Table 2E - Resistivities of various earth materials.

Figure 2E - Data sheet for recording resistivity data by using the Wenner survey.

WENNER SURVEY

Sounding Location/Number _____

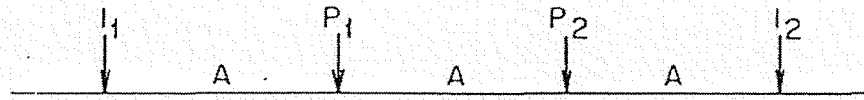
Operator/Date _____

Equipment _____

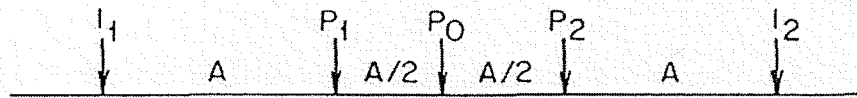
Computation Formula: $\rho_a = K (V/I)$. $K = 2 \pi a$

a(m)	P	C	K	R ₁	R ₂	R (AV)	ρ_a
0.47			2.95				
0.68			4.27				
1.00	0.50	1.50	6.28				
1.47	0.75	2.25	9.24				
2.15	1.07	3.22	13.5				
3.16	1.60	4.74	19.9				
4.64	2.32	6.96	29.2				
6.81	3.40	10.22	42.8				
10.0	5.00	15.00	62.8				
14.7	7.35	22.00	92.4				
21.5	10.75	32.25	135				
31.6	15.80	47.40	199				
46.4	23.20	69.60	292				
68.1	34.05	102.15	428				
100	50.0	150.0	628				
147	73.5	220.50	924				
215	107.5	322.5	1351				
316	158.0	474	1985				
464	232	696	2915				
681	340	1021	4279				
1000	500	1500	6283				

WENNER



LEE MODIFICATION OF WENNER



SCHLUMBERGER

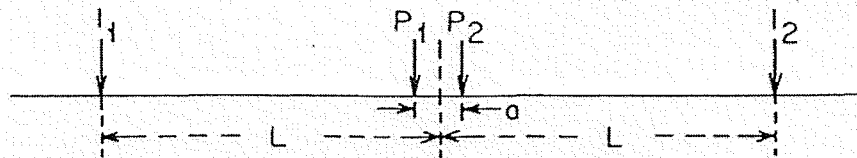
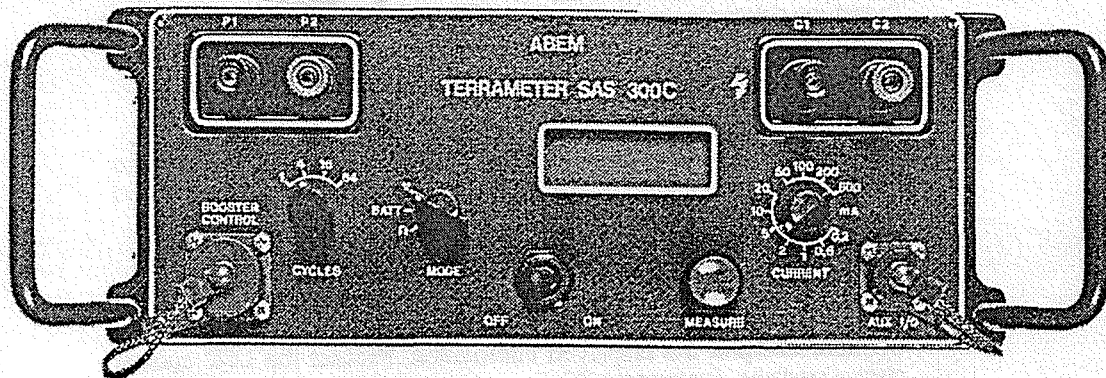


FIGURE 4-1. Common electrode arrangements

8

Figure 4E - Wenner, Lee Modification of Wenner and Schlumberger Methods of resistivity surveying.

Figure 3E - Resistivity equipment used for resistivity surveys (ABEM Terrameter SAS 300C).



SCHLUMBERGER METHOD
schematic diagram

- C1, C2, — CURRENT ELECTRODES
- P1, P2 — POTENTIAL ELECTRODES
- A — AMMETER
- V — VOLTMETER
- MN — DISTANCE BETWEEN P1 AND P2
- 2L — DISTANCE BETWEEN C1 AND C2

$$\rho = \pi MN \left[\left(\frac{L}{MN} \right)^2 - \frac{1}{4} \right] \frac{V}{I}$$

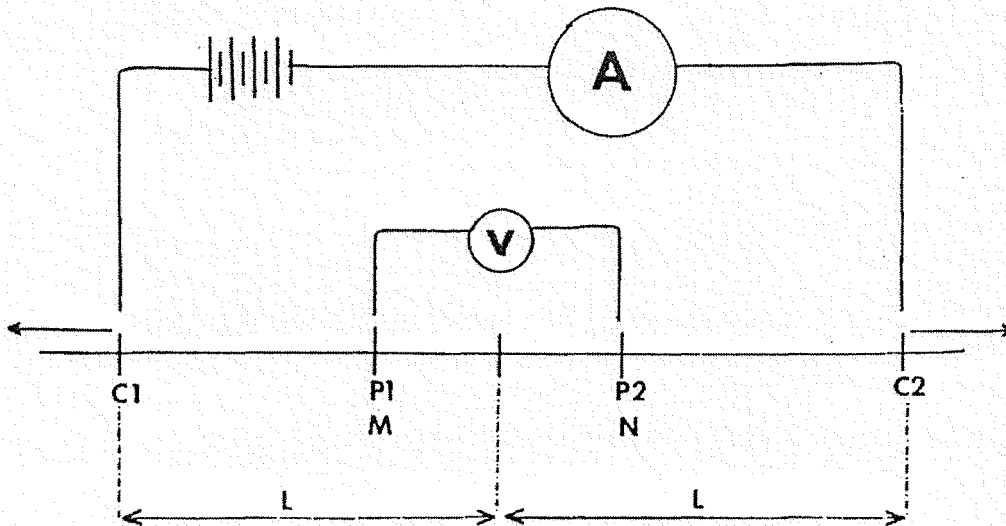
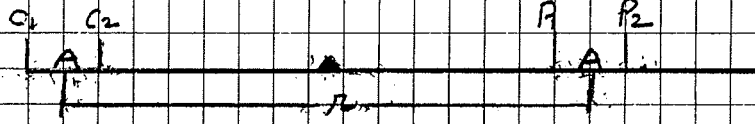


Figure 5E - The Schlumberger Method of conducting resistivity surveys.

RESISTIVITY SURVEY

DIPOLE-DIPOLE



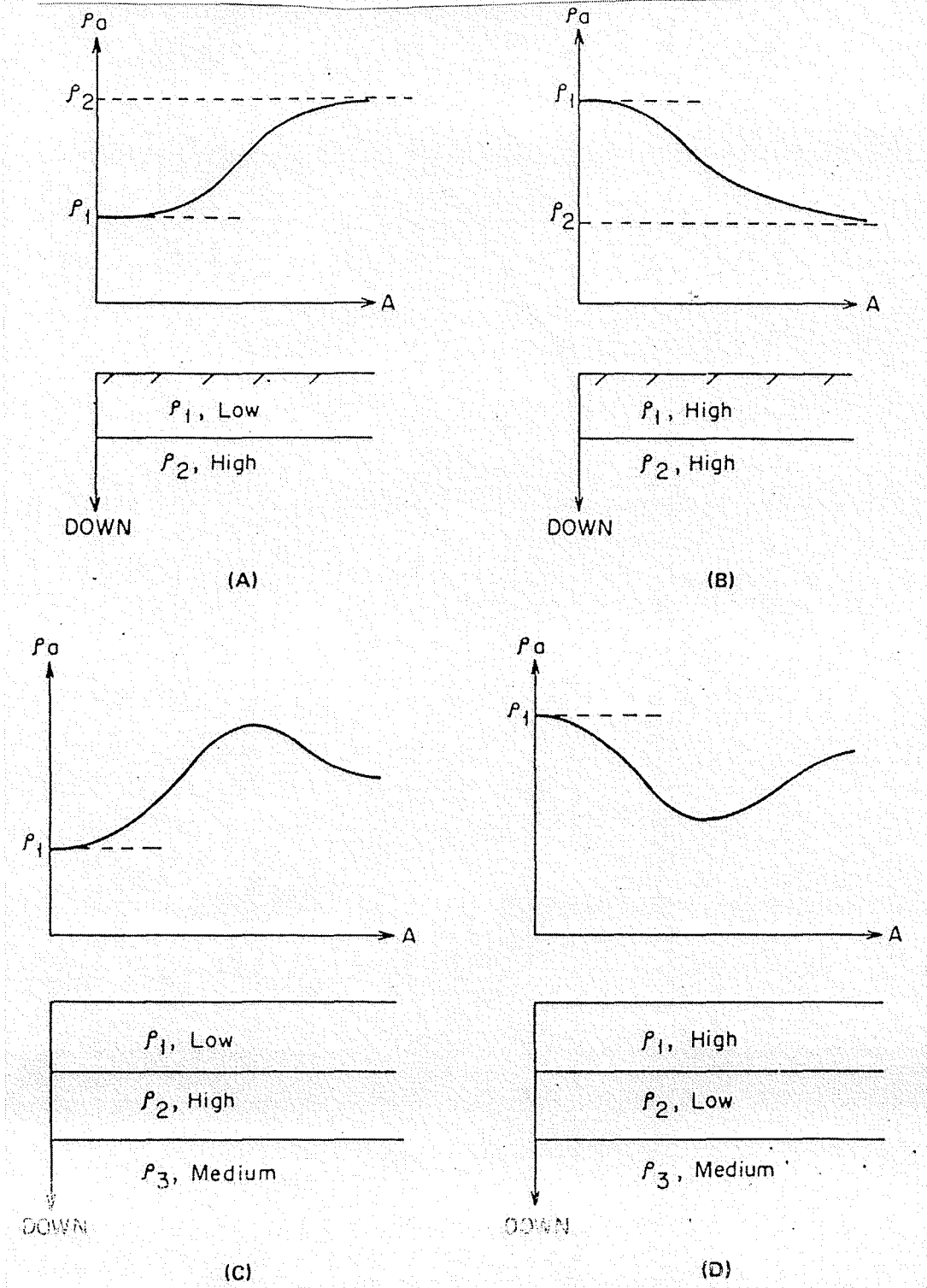
Current electrodes well separated from the potential electrodes

$$\rho_a = \pi \left(\frac{r^2}{a} - a \right) R$$

meter a	Meters a	R ohms	ρ ohm-meter	meter a	Meter a	R ohms	ρ ohm-meter

Figure 6E - Dipole-Dipole Method of resistivity surveying.

Figure 7E - Resistivity sounding curves over two and three layer models.



Profiling of Soccer Field

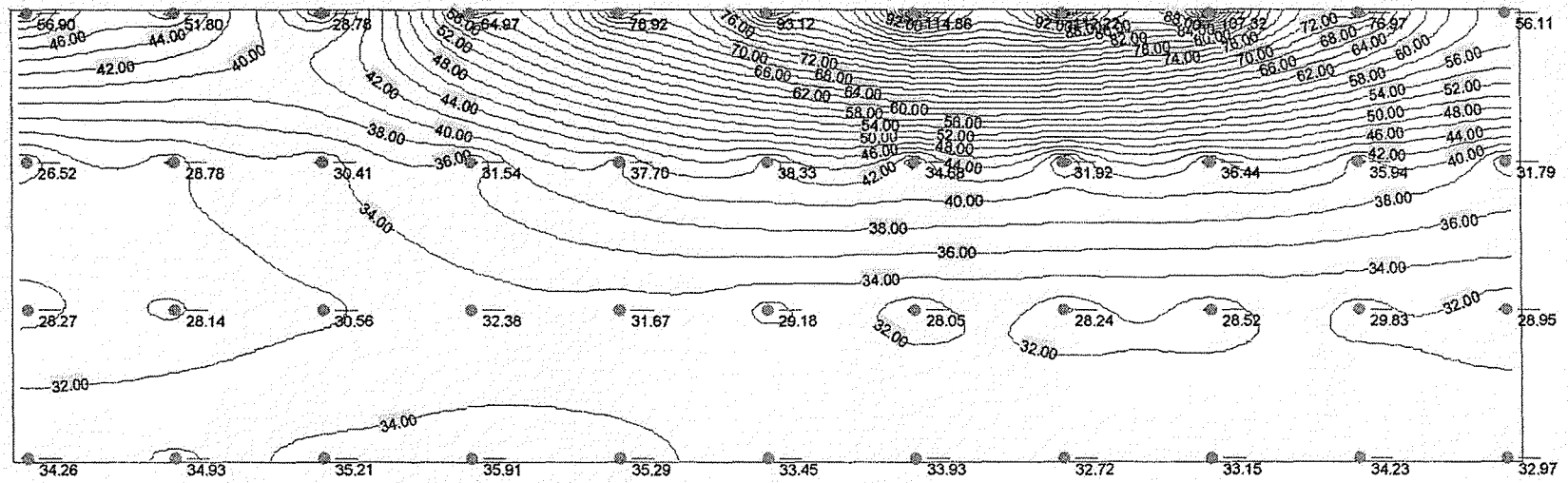


Figure 8E - Resistivity cross-section showing variations in resistivity with depth.

GRAVITY AND MAGNETICS

Gravity and magnetic maps show how the subsurface rocks produce changes in the gravity and magnetic fields. A gravity map shows the gravitational field produced by subsurface rocks of varying density. A gravity high of 10 mGals shown on the gravity map (Figure 1G) just north of Plattsburgh indicates a high density body beneath the surface in that area. Other gravity highs are located northwest of Plattsburgh. South of Dannemora is a gravity low of -16 mGals indicating a low density body in that area. Again, these gravity anomalies or irregularities in the gravitational field reflect the variation in the densities of the rocks in the area.

The magnetic map shows a magnetic high over a 55 gallon buried drum on Potsdam Campus. The anomaly caused by the drum indicates it is a magnetized body at shallow depth causing a distortion in the earth's magnetic field. This distortion (anomaly) in the Earth's magnetic field is detectable from magnetic measurements made with a magnetometer. The measurements are contoured to produce a magnetic anomaly map showing the location of the buried drum.

What Gravity and Magnetic Data Can Do For You

“Ten Commandments”

by Robin Riddihough

Chief Scientist

Geological Survey of Canada

1. Gravity and magnetic surveys are both methods of REMOTE SENSING. They can detect the properties of rocks at distance - from the air, on the ground or at the sea surface.
2. Anomalies and changes in the value of gravity (after allowance of varying elevation and topography) reflect changes in DENSITY.
3. Anomalies and changes in the value of the Earth's magnetic field (after allowing for changes with time) reflect changes in MAGNETIZATION.
4. These two properties of rocks are often diagnostic. Taken together they can eliminate many possible geological alternatives and provide fundamental constraints on a geological model.
5. Both gravity and magnetic anomalies are a function of the distance between the detector and the source (rocks). Amplitudes decrease faster with distance for magnetic anomalies therefore they tend to “see” shallower structures. Both methods, however, provide an INTEGRATED depth spectrum of the sources they are seeing - they see much more than just the surface rocks.
7. The PATTERN of a gravity or a magnetic anomaly map is a powerful indicator of how subsurface rocks and formations are distributed. It can provide rapid indications of TRENDS, GRAIN and DISCONTINUITIES. The style of the pattern may be diagnostic of a particular rock sequence or assemblage (for example: sea-floor magnetic anomalies).
8. The SHAPE of individual anomalies can be used to determine the shape and position of density or magnetic contrasts (rock units). In theory, there are a number of geometries that will “fit” a particular anomaly. IN PRACTICE, by using realistic geological or other geophysical controls, anomaly “fits” will provide REAL NUMERICAL CONSTRAINTS on the anomaly sources.
9. However, always understand and appreciate the weaknesses and inaccuracies of the data. Never waste time trying to “fit” anomalies with greater precision than they were measured at.

10. Any final interpretation must satisfy ALL the available geophysical and geological data. Gravity and magnetic anomaly information cannot be ignored. It will not go away. It is real and it is telling us something even if we do not always understand it and even if it appears to be contradicting the surface geology.

Gravity Meter

In principle, the gravity meter is simply an extremely sensitive weighing device. It consists of a mass suspended on a spring (Figure 3G). The gravitational attraction on the mass changes with variations in the gravitational field. The change in the elongation of the spring is proportional to the change in gravity so the gravity meter measures changes in gravity. The readings made with the gravity meter are in scale divisions. The differences measured in scale divisions are changed to units of acceleration by using the calibration factor (.1015mGals/SD) of the meter. The Worden Meter is very light and portable and housed in a thermos to keep the temperature nearly constant. Changes in temperature will cause changes in the elongation of the spring.

These changes are corrected for drift by returning to a base station several times a day for readings. The unit commonly used in gravity surveying is the milliGal, which is an acceleration of .001 cms/sec².

Determination of Observed Gravity with the Gravity Meter

Measurements of differences in gravity with the meter enables one to calculate the observed gravity at a point. This is done by taking readings at a base (a station where the absolute value of gravity is known) and a station where you desire to know the observed gravity. An example of how to determine the observed gravity at a station is given below. The calibration factor of the meter is .1015 mGals/SD.

Base Gravity	980558.04
Base Reading	1100.8 S.D.
Station Reading	1300.8 S.D.
Difference in Scale Divisions	200.0
Difference in Gravity	20.30 mGals
Observed Gravity at Station	980578.34 mGals

Calculating the Simple Bouguer Anomaly

The simple Bouguer anomaly (SBA) is the difference between the observed gravity (g_o) and the expected or theoretical gravity. It is the value that is plotted and contoured to produce the gravity map or profile. The Bouguer anomaly is corrected for latitude and elevation. The simple Bouguer anomaly is calculated as shown below:

$$SBA = g_o - (\gamma - .06h)$$

where

SBA = simple Bouguer anomaly (mGals)

g_o = observed gravity (mGals)

γ = theoretical gravity at latitude of measurements at sea level

.06h = correction for elevation and attraction of material between sea level and station

"h" = elevation in feet

A sample of a calculation of the simple Bouguer Anomaly is in Figures 4G and 5G.

Modeling of Gravity Anomalies

Normally, gravity profiles are drawn across selected gravity anomalies and geologic models are constructed that produce computed gravity values that satisfy the observed gravity profile. A program GM-SYS computes gravity and magnetic values of two-dimensional geologic models. Figure 6G shows models of Precambrian basement in western New York. The solid line is the observed gravity and the dots are computed gravity values based on the model.

Recording Gravity Data in the Field

Figure 7G is a data sheet showing how gravity measurements are recorded in the field. The following is a discussion of this data sheet.

1. First measurement is made at a base. Time is recorded to construct drift curve.
2. First column is station number. This number is also written on a map showing location of station.
3. Column 2 is station reading and column 3 is time of measurement needed for drift correction.
4. Column 4 is elevation in feet obtained from topographic map.
5. Column 5 is the latitude in degrees and minutes measured with a GPS or from maps in the lab.
6. Column 6 is the longitude in degrees and minutes.
7. The second line from top is the second base reading used to construct a drift curve.

The top of the data sheet shows the Potsdam base was used and the measurements were made in the Potsdam Quadrangle.

Computing the Simple Bouguer Anomaly

Figure 4G shows an example of a calculation of the simple Bouguer anomaly. These calculations can be done by using a calculator or EXCEL spread sheet. The calculations are discussed below.

1. Base RD column is base reading corrected for drift.
2. ΔS column is the difference between Station RD and Base RD in scale divisions. Station 1 is 28.2 scale divisions higher than the base reading.
3. Δg is obtained by multiplying ΔS by the calibration factor which in this example was .1032 mGals/SD.
4. Base gravity is already known and in this example is 980558.04 mGals.
5. Observed gravity column is the Base Gravity plus the 2.91 mGals which is 980560.95.
6. Theoretical gravity column is value of gravity at the stated latitude at sea level. This is obtained from tables of calculations using the 1930 formula.
7. Elevation correction is .06h where h is elevation in feet.
8. The last column is the simple Bouguer anomaly calculated by using the formula:

$$SBA = g_0 - (\gamma - .06h)$$

The SBA is -11.35 mGals which means the observed gravity is 11.35 mGals less than expected.

Bouguer Gravity Map Northeastern New York State

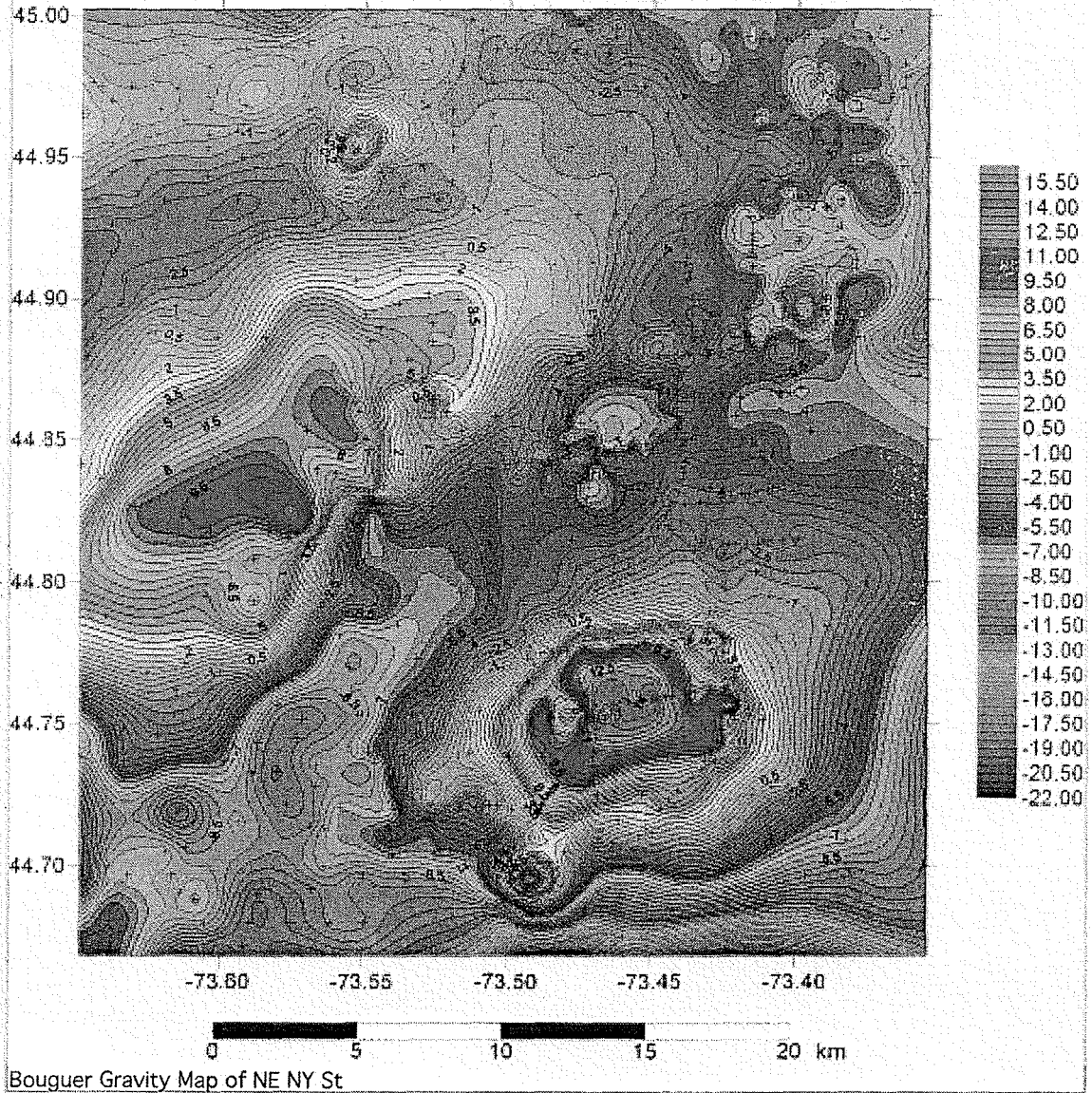


Figure 1G - Gravity map of Lake Champlain Valley showing the gravity high north of Plattsburgh.

Map of Lehman Park and Location of 55 Gallon Drum

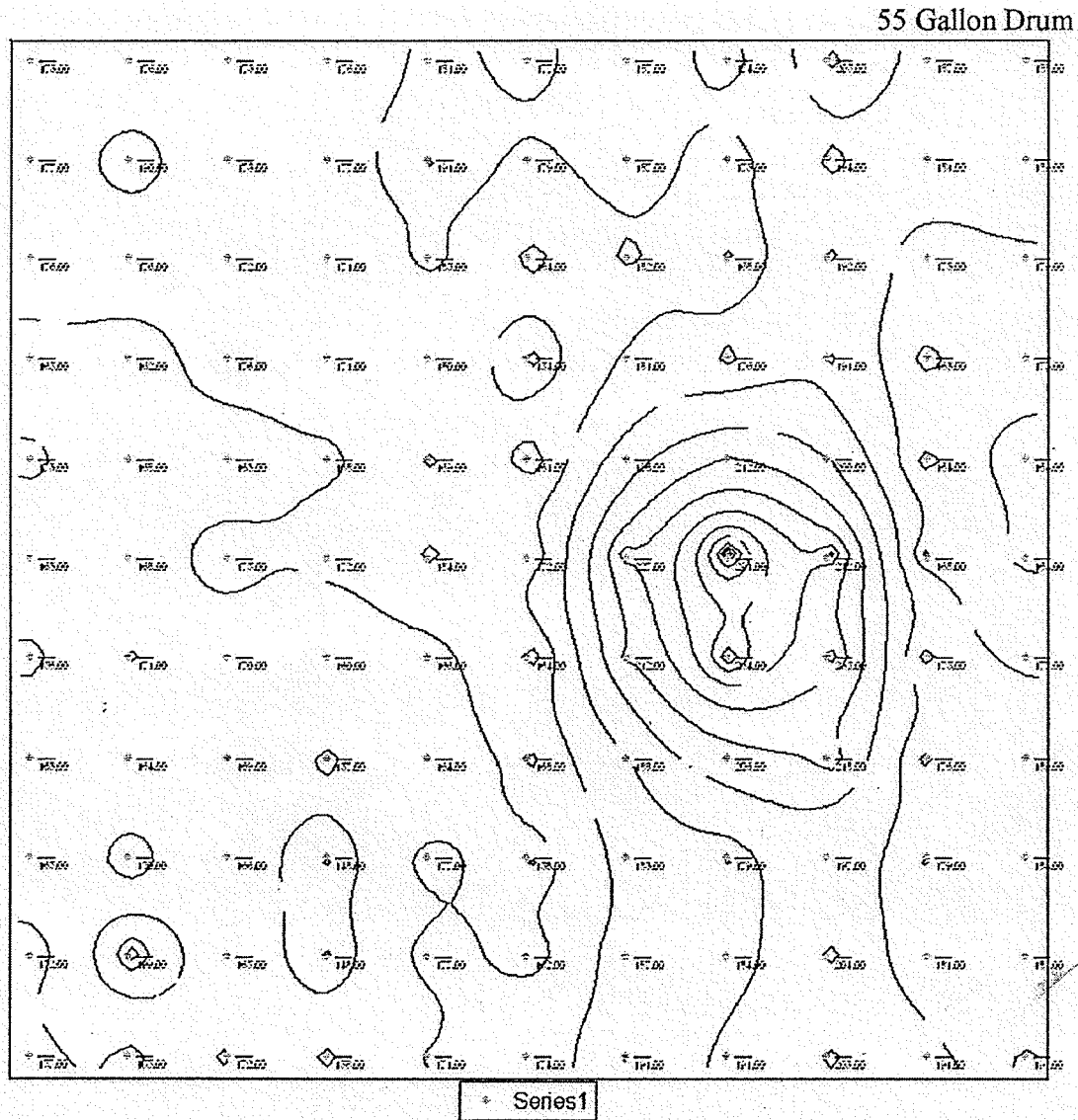
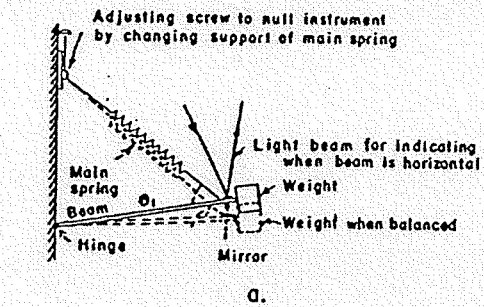
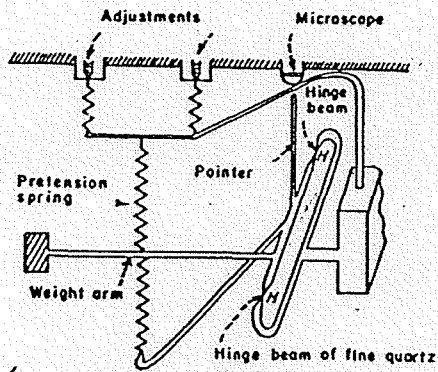


Figure 2G - Magnetic high over a 55 gallon drum buried in Lehman Park.



a.



b.

Gravimeters. (a) La Coste-Romberg schematic. (b) Worden schematic.

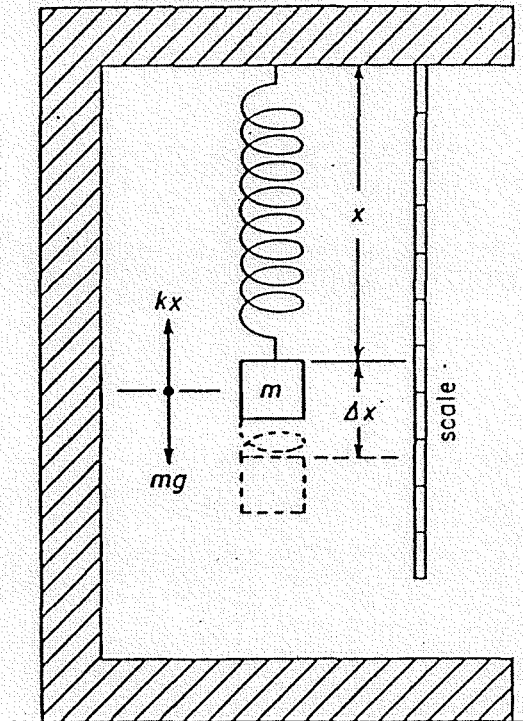


Figure 3-10

Mass supported by a vertical spring. A change in gravity will produce a change in the distension of the spring.

Figure 3G - Worden and LaCoste Romberg gravity meters consist essentially of a mass supported by a spring.

STATEMENT NUMBER		FORT AS STATE NO 32 mgals/sp												MEASURED SEASIDE STATION																																																																																					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
ST #	LAT	LONG	ELEV (FT)	STATION RD	BASE RD	AS SCALE	TAIR CORR	BASE GRAVITY	OBSERVED GRAVITY	THEORETICAL GRAVITY	ELEV CORR	SBA Bouguer Anomaly																																																																																							
				SCALE	CORRECTED	DIV	AS	(milligals)	go	g	(1066)	(milligals)																																																																																							
1	49° 40.0	75° 1.3	450	1252.8	1224.2	+28.2	+2.91	980.558.04	980.560.95	980.599.3	27.00	-11.35																																																																																							
2	49° 40.2	75° 3.1	418	1295.6	1224.7	+70.9	+7.32	"	980.565.36	980.599.6	25.08	-9.16																																																																																							
3	49° 40.3	75° 4.1	384	1329.4	1224.9			"																																																																																											
4	49° 40.2	75° 5.4	366	1362.0	1225.0			"																																																																																											

Figure 4G - A sample calculation of the simple Bouguer anomaly. The SBA is corrected for latitude, free air effect and Bouguer Effect.

How to calculate the Bouguer Gravity Anomaly

Gravity Anomaly = observed gravity - expected gravity

$$\Delta g = g_o - (\gamma - .06h)$$

Δg = gravity anomaly (m Gals)

g_o = observed gravity (measured with gravimeter)

γ = theoretical gravity at latitude of measurement at sea level.
(Obtained from formula)

$.06h$ = Correction for elevation (free air) and attraction of material
between sea level and station.
 h = elevation of station in feet

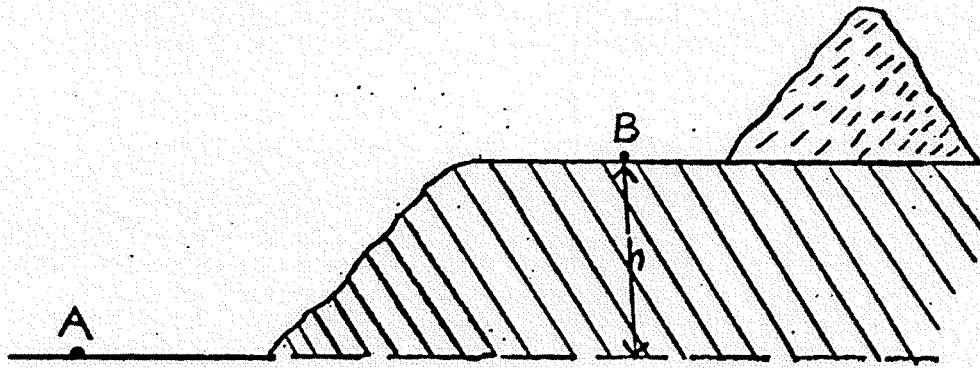


Figure 5G - Calculation of the Simple Bouguer Anomaly.

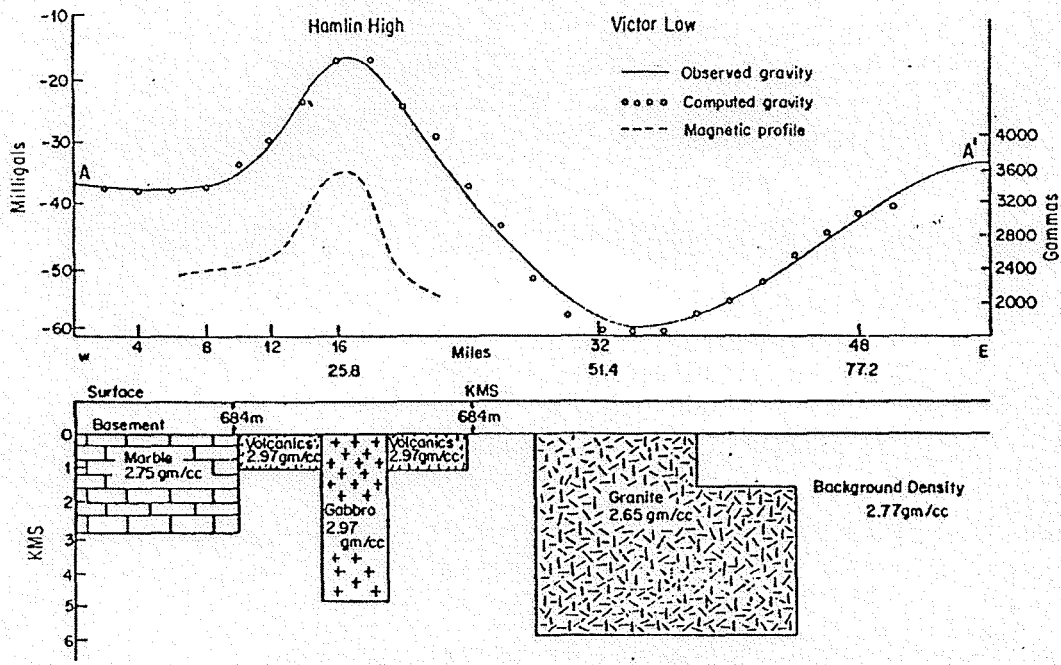


Figure 2. The Hamlin two-dimensional gravity profile AA'.

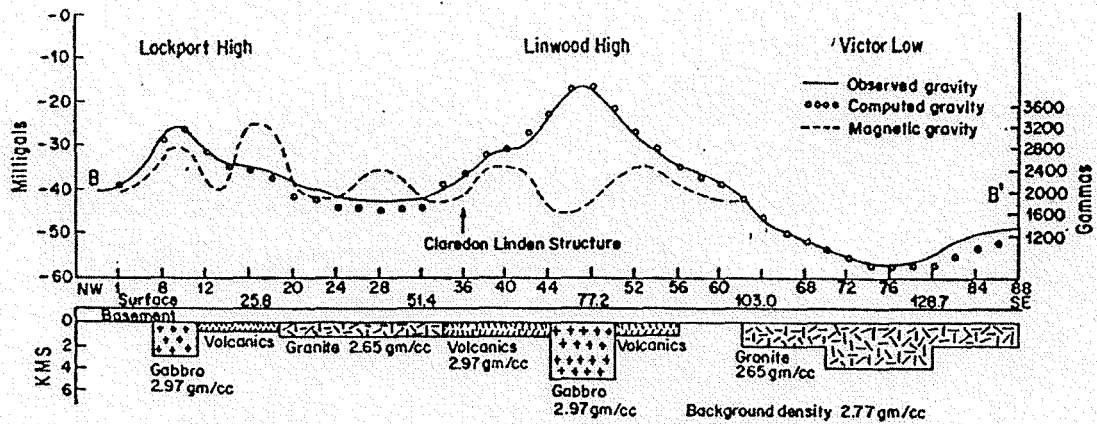


Figure 6G - Computed and observed gravity profiles and models of the Precambrian basement in western New York.

GRAVITY SURVEY

Operator REVETTA Sheet # 1
 Date 1/14/95 Gravity Meter Worden
 Units (gal, mgal, g.u.) Mgal Calibration Factor .1013
 Quadrangle Surveyed Potsdam Base Potsdam
 Base Gravity 980558.04 Theoretical Formula (1930, 1967) 1930

Station #	Reading	Time	Elevation	Latitude	Longitude
BASE (1)	1414.8	11:25			
BASE (2)	1421.8	13:50			
1	1406.5	11:40	433	44° 39.0'	74 58.1
2	1396.3	11:50	460	44 39.2	74 57.6
3	1361.7	12:05	490	44 38.6	74 57.1
4	1361.2	12:15	479	44 38.2	74 57.5
5	1331.5	12:30	520	44 37.8	74 57.3
6	1322.8	12:39	542	44 37.7	74 56.1
7	1225.8	12:47	654	44 37.7	74 53.5
8	1254.4	12:54	624	44 38.6	74 53.6
9	1338.4	13:05	521	44 39.0	74 55.6
10	1300.4	13:19	454	44 39.6	74 55.8

Figure 7G - Field gravity data sheet showing method of recording gravity measurements in the field.

MAGNETIC METHOD

Applications

A magnetometer measures changes in the earth's magnetic field strength. Any magnetic object that alters the earth's magnetic field can potentially be detected by magnetic surveying. Traditionally, magnetic surveys have resulted in the construction of magnetic maps (Figure 1M) that show patterns diagnostic of a particular rock assemblage; thus the method is useful in geologic mapping. The method has also been used to estimate depth to Precambrian basement by oil companies. Other applications are the use of magnetics to detect buried steel tanks and drums containing hazardous waste materials. Archeologists have also found the method useful for locating cultural features with anomalies being due to ferrous metals, hearths, and kilns.

Magnetometers also have the option of measuring the vertical magnetic gradient, which has several advantages over the use of total field measurements. Near surface sources of magnetic anomalies are accentuated over deeper regional bodies by the gradient measurements. The magnetic gradient also exhibits superior resolving power. This combined effect is important in locating lithologic contacts and shallow buried steel drums. Magnetic gradient data also aids in the interpretation of the physical characteristics of the source.

Equipment

The G856 Memory-Mag magnetometer will be used to locate a buried 55 gallon metallic drum. This instrument is a proton-precession magnetometer that measures the total intensity of the earth's magnetic field in gammas. The readings are stored along with time, data and station number. The data is then fed into a computer and a printout may be obtained. A computer program MAGLOC and a contouring program can be used to plot magnetic contour maps based on the data. The magnetometer can also be used as a gradiometer. This is done by placing two sensors, one above the other, separated by 1 meter distance.

Physically, the G856 is compact and lightweight. It is weatherproof and operates over a wide temperature range. It is powered by eight D-cell batteries sufficient for about 3000 readings. It is a very high precision instrument.

The instrument comes with a sensor which is mounted on a staff. The sensor is mounted vertically for surveys in high latitudes and horizontally for lower latitudes having a dip of less than 40°. The sensor is marked with an arrow to align in a north direction for an optimum signal.

The instrument must also be tuned for the strength of the field in the survey area to achieve the best signal. For the Potsdam area the magnetometer would be tuned at 55000 gammas.

Magnetic Surveying

The magnetometer measures the total intensity of the earth's magnetic field. Most rocks contain some magnetite, a common magnetic mineral that produces distortion in the earth's field. The volume of magnetite in the rock determines its magnetic susceptibility and intensity of magnetization. Magnetic surveys can be useful in finding iron or steel objects such as buried drums and storage tanks, archaeological features such as tombs, pottery and brick, pipelines, weapons, and many other metallic objects. In determining whether the magnetic survey is useful, it must first be determined whether the object is truly magnetic. The most important single factor determining the detectability is distance between the magnetometer and object. Most anomalies vary inversely as the cube of the distance. A second consideration is the degree of magnetism of the material. Figure 2M shows how a buried drum produces a magnetic anomaly that can be

detected by magnetic surveys, and Figure 3M shows magnetic profiles over a buried drum in Lehman Park.

What causes magnetic anomalies?

Differences in the intensities of magnetization of rocks cause variations in the strength of the earth's magnetic field. The total intensity of magnetization of a rock is due to the induced magnetization and remanent magnetization of the rock. The induced magnetization is given by the expression:

$$I = kH$$

where I is the intensity of the induced magnetization, k is the magnetic susceptibility and H is the strength of the earth's magnetic field. The magnetic susceptibility (k) is determined with a magnetic susceptibility bridge and the value of H is obtained from the magnetometer measurements. The induced magnetization is induced by the present earth magnetic field. The remanent magnetization of the rock is that magnetization instilled in the rock by the earth's magnetic field at the time the rock was formed. It is usually determined from cores placed in a spinner magnetometer. The remanent magnetization will not necessarily have the same direction or intensity as the induced magnetization.

Field Procedure

In magnetic surveying it is important that the magnetic field measurements be as true as possible and not affected by articles of clothing or personal accessories such as keys, watches, knives, jewelry or zippers. Measurements should not be made near cars, fences, powerlines, buildings or railroad tracks. The operator need only to depress the READ key to observe the reading then the STORE key.

The sensor is normally mounted on the staff. However, it may be mounted on a backpack for rapid operation. Cardboard or plastic jacketed batteries should be used when mounted on your backpack.

Depths from Magnetic Anomalies

The deeper the source of the magnetic anomaly, the broader the anomaly and the shallower the source, the steeper the gradient of the anomaly. This enables the determination of the approximate depth to the source. Several depth rules are shown in Figure 4M for calculation of depth to a source. One of the most important factors in the interpretation of magnetic anomalies is the relation between anomaly wavelength (width) to depth.

Gradiometer Surveys

A gradiometer survey is conducted by mounting one sensor about 1 meter above a lower sensor. The G856 will then take two readings, the first from the bottom and the second from the top sensor. The gradient measurements accentuate near surface bodies over deeper bodies and exhibit superior resolving power. The combined effect is useful in locating shallow buried steel drums or lithologic contacts. Figure 5M shows a magnetic and gradiometer survey over a magnetic source.

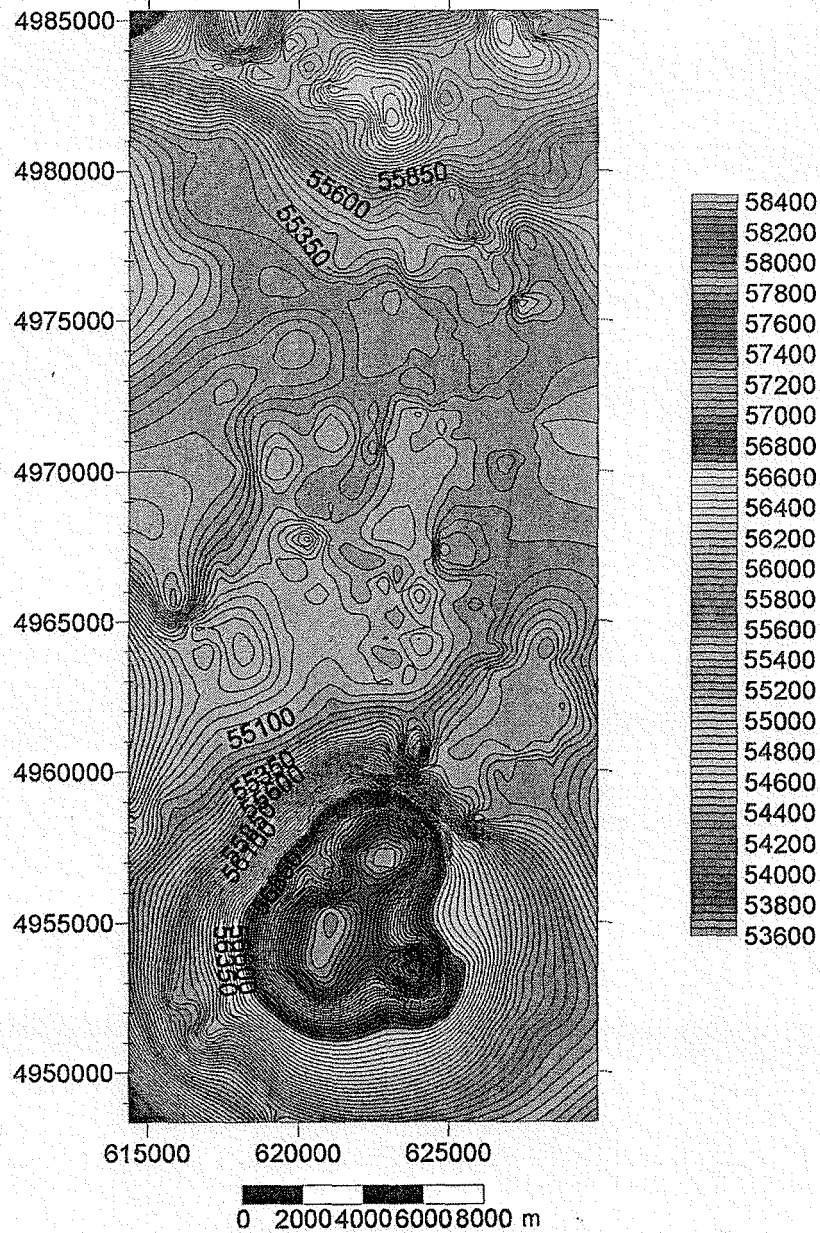
Some Important Considerations in Interpretation of Magnetic Anomalies

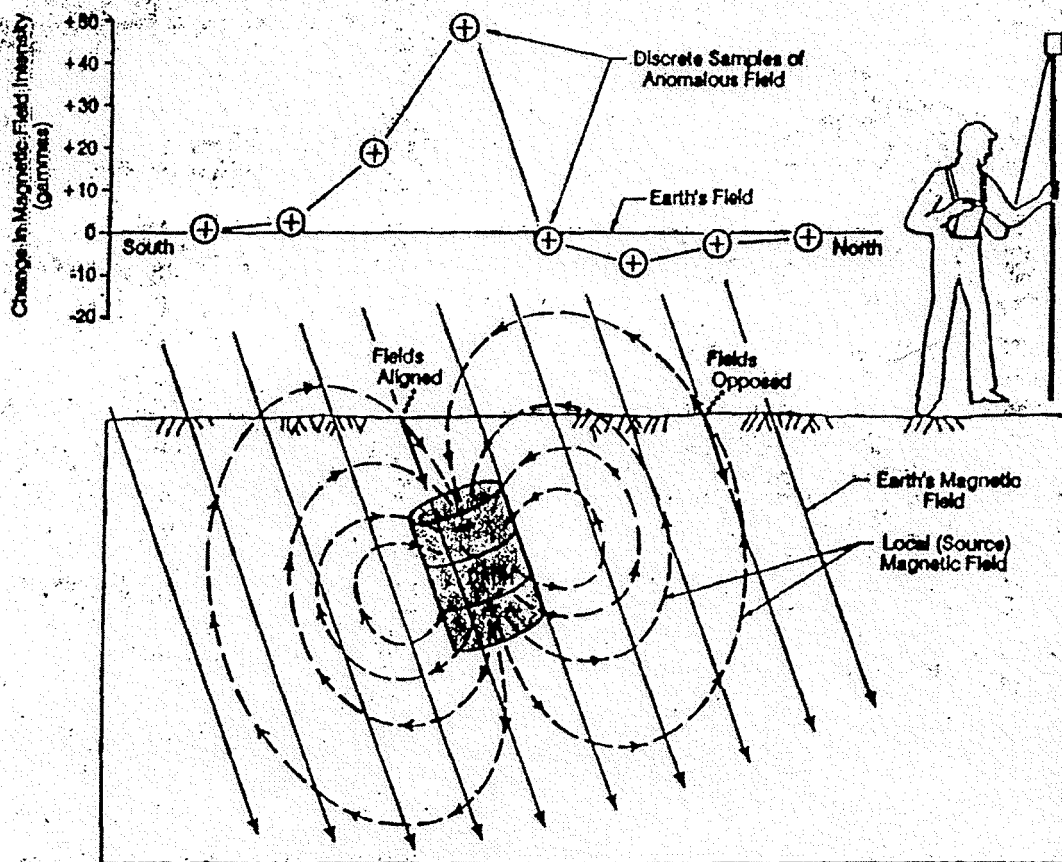
1. A magnetic survey is only able to detect sources or map contacts of rock types or locate faults when there is a magnetization contrast.

2. The most geologically significant anomalies on a map may be the subtle ones and not necessarily the largest most prominent anomalies.
3. Study the width and shape to determine a realistic geologic source and depth.
4. Know the geology of the area to arrive at a sound interpretation of the magnetic data.

Figure 1M - Magnetic map of Lake Champlain Valley. Note magnetic high north of Plattsburgh.

Diurnally Corrected Total-Field Magnetic Map of the Champlain, Beekmantown and Northern Plattsburgh Quadrangles





(Adapted from Benson et al., 1983; Breiner, 1973; and Hirze, 1990)

Figure 2M - Magnetic effect of a buried metallic drum.

Lehman Park Buried Drum Project
 November 7, 2003
 Angela M. O'Shea

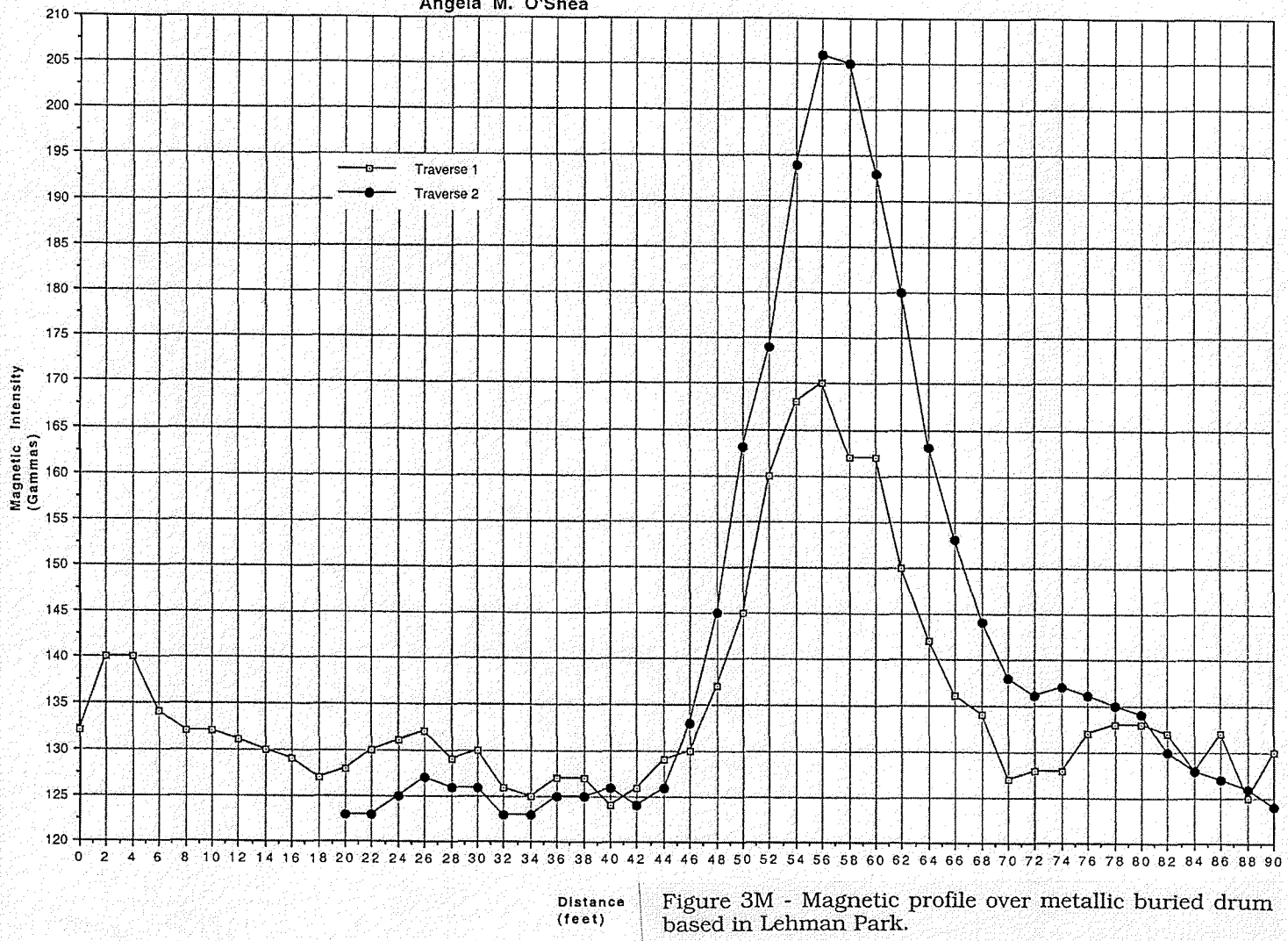


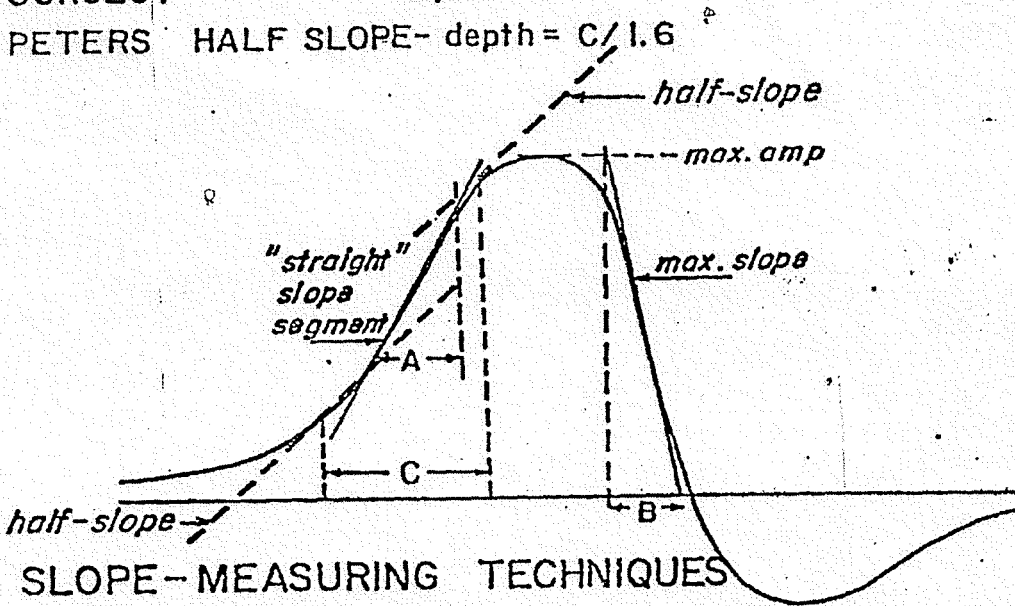
Figure 3M - Magnetic profile over metallic buried drum based in Lehman Park.

DEPTH RULES

SLOPE DISTANCE — depth = A

SOKOLOV — depth = B

PETERS HALF SLOPE — depth = $C/1.6$



SLOPE-MEASURING TECHNIQUES

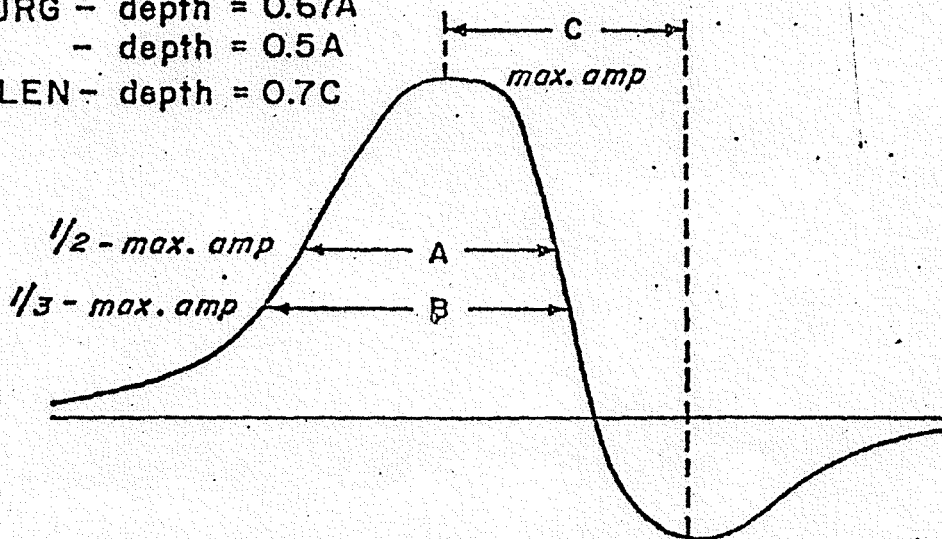
DEPTH RULES

HANNEL — depth = $0.5 B$

TIBURG — depth = $0.67A$

MAC — depth = $0.5A$

THALEN — depth = $0.7C$

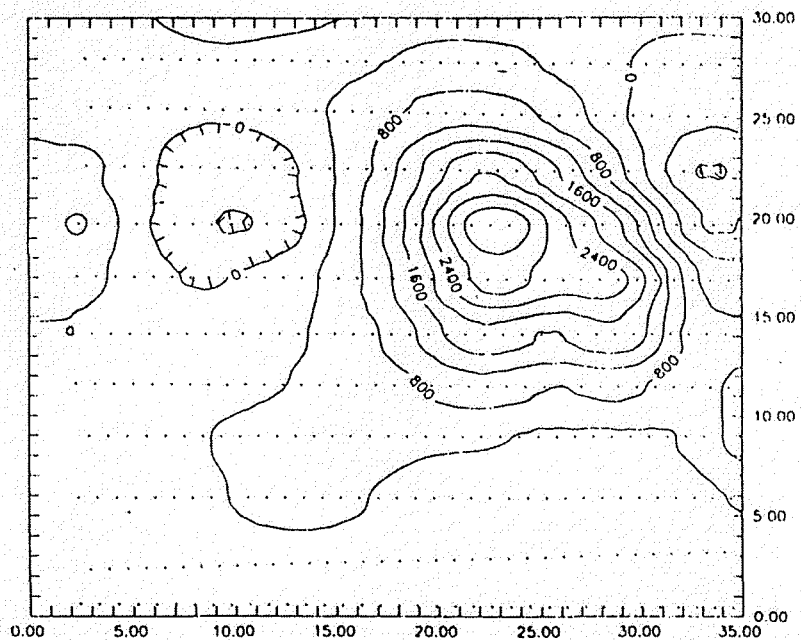


AMPLITUDE-MEASURING TECHNIQUES

Figure 4M - Depth rules used to calculate approximate depth to magnetic source.

Site 1 Area A

A Magnetometer Survey (nT)



B Gradiometer Survey (nT/m)

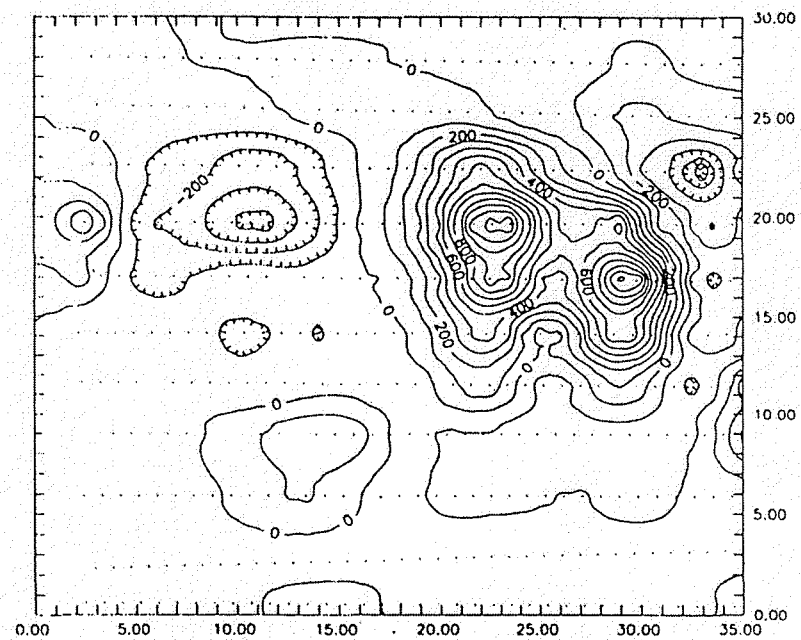


Figure 4. A) Contour map of anomalies in the earth's magnetic field strength for Area A of Site 1. Contour interval: 400 nT. B) Contour map of the vertical gradient of the earth's magnetic field strength for this site. Contour interval: 100 nT/m. The solid dots mark the locations of the observations. Horizontal distances are given in meters.

Figure 5M - Magnetic maps showing how a gradiometer survey increases resolving power on map.

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Trip A-1

PRECAMBRIAN BASEMENT AND CAMBRIAN-ORDOVICIAN STRATA, AS DISPLAYED IN THREE PROVINCIAL PARKS OF CANADA

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INTRODUCTION

General overviews of the region covered by this excursion are provided by Wilson (1946) and by Williams (1991). A regional sedimentological study of the Nepean formation was carried out by Wolf and Dalrymple (1984). The relationship of Paleozoic strata of eastern Ontario to the Frontenac Axis remains a problem not yet resolved: Was the arch a positive structure during sedimentation, or did it become so as a result of elevation through faulting/subsequent crustal upwarp/compactional draping or some combination of these processes? This question will be considered during the trip, which was designed to provide an overview of Paleozoic strata and the underlying Grenvillian basement along a traverse from the Ottawa River to the St. Lawrence River.

One highlight will be a visit to a shallow underground mica-apatite mine at Murphys Point Provincial Park to view workings abandoned in 1920. Another will be a visit in Charleston Lake Provincial Park to view a giant cylindrical structure in Nepean quartz arenite, which appears to represent the outline of an exhumed dewatering structure. The Paleozoic-over-Grenville unconformity will be viewed at two localities, both showing evidence of paleoweathering of the Precambrian basement. Stops will be made to view a variety of abundant trace fossils, including *Skolithus* and *Diplocraterion*, as well as several Cambrian and Ordovician stromatolite localities (complementary to those seen during Trip F-1). Local sedimentary units have been used extensively as building stone, as will be seen in several historic examples. Teachers and other educators are particularly encouraged to attend this trip, as an introduction to the geoheritage potential of Ontario's Provincial Parks.

This trip has been modified from a series of three guided geoheritage hikes in Ontario Provincial Parks (July 10th, 17th, 24th, 2004), organized by Friends of Canadian Geoheritage, a group founded in 2003 to encourage greater public appreciation and understanding of Canada's geological diversity. The first of these hikes attracted 35 participants, the second drew 40 and the final one drew 80 participants, ranging in age from 3 to 90. The educational aspects of geology and geography provided by visits to these three parks, which offer different slants on the varied geoheritage of this part of North America, should be of particular interest to teachers. The geological heritage of eastern Ontario spans over 1 billion years of Earth history. Ontario's provincial parks provide significant examples of this heritage, ranging from bedrock that shows evidence of billion year-old mountains and ancient sea-floor deposits, to more recent signs of glaciation, succeeded by development of post-glacial lakes and river systems that were initially much larger.

ROAD LOG AND STOP DESCRIPTIONS

Meet at 9:30 am at entrance kiosk, Fitzroy Provincial Park, Ontario. The trip will finish southeast of Charleston Lake Provincial Park, about 20 km north of the Thousand Islands-Ivy Lea International Bridge, and about 50 km west of the Prescott-Ogdensburg International Bridge.

NOTE 1. Allow at least 1.5 hours to drive from the junction of Hwy. 401 and Hwy. 416 to our rendezvous point (Entrance kiosk, Fitzroy Provincial Park). Also be sure to have proper photographic identification for border crossings. Passports, if you have one, are recommended. Delays at the Thousand Islands crossing are common, whereas traffic at the Prescott-Ogdensburg crossing is usually light and border crossing faster.

NOTE 2. Field Trip A-1 will end around 4 pm, near the village of Mallorytown (about 50 km west of the Prescott-Ogdensburg International Bridge). This will allow ample time to return to Potsdam for the NYSGA Banquet and Business Meeting (Adirondack Room, Lehman Hall, SUNY Potsdam, 6:00-8:00 pm).

NOTE 3. Although we hope to negotiate a single fee, daily park fees may apply for each park (\$9.50 Cdn. per vehicle for day-use; 20% discount for Ontario Seniors) and thus carpooling is financially, as well as, environmentally a sound decision and highly encouraged to limit the number of vehicles. For additional information, including the camping facilities available at all three parks, you can make direct contact (Fitzroy 613-623-5159, Murphys Point 613-267-5060, Charleston Lake 613-659-2065) or you can visit the Ontario Parks website: www.ontarioparks.com.

NOTE 4. This trip will involve some complex driving including entering a few narrow and/or gravel roads, and frequent turns to reverse direction and obey traffic laws. Thus it is very important to reset your odometer at each locality prior to leaving for the next. In addition, one locality is on private land and we wish to keep the exact location confidential in concert with the wishes of the owner.

To reach Fitzroy Provincial Park from the USA-Canada border: Follow Hwy 401 to Highway 416; take Hwy 416 north to Hwy 417 (also known as 'the Queensway'). Drive westward to Galetta Sideroad (Hwy. 22). Turn right and head north at this intersection. Continue straight, over the railroad tracks. Do **not** take the turnoff to Fitzroy Harbour. Turn to the left on Canon Smith Drive, just past intersection with Carp Road (County Road 5). The entrance to Fitzroy Park is on left side of Canon Smith Drive, less than 3 km from the Galetta Sideroad. Turn left at the green and yellow sign for the park. Our meeting spot is about 500m along the park road, in the parking area to the right of the park entrance kiosk. Stop locations are shown on Figure 1.

STOP 1 - TERRACES TRAIL, FITZROY PROVINCIAL PARK, OXFORD AND ROCKCLIFFE FORMATION (ORDOVICIAN)

N45°29.158' W076°13.251' Park entrance kiosk

From the Terraces Trailhead, a one-hour hike provides a snapshot view of the principal Paleozoic strata comprising the bedrock beneath this park (Figures 2 and 3). A succession of carbonates, sandstone, and shale record a succession of changing environments marginal to and within a sea that episodically covered the area from about 500 million years ago. Low-angle crossbeds in sandstones of the Rockcliffe Formation indicate unimodal southward transport, consistent with fluvial accumulation in a system feeding into a basin to the south. Low dispersion about the mean suggests deposition as

sandbars in a braided river system. Overlying green shale in the upper part of the Rockcliffe Formation gives way upwards to dull red shale. Both varieties contain abundant bedding-parallel vermiform trace fossils, as well as rare desiccation cracks, suggesting transition to relatively quiet-water deposition on tidal flats or in a delta.

The present landscape is largely the product of modification by ice and meltwaters related to the Wisconsin ice sheet that retreated from the Ottawa Valley less than 12,000 years ago. As the ice sheet melted, it left deposits of glacial drift containing boulders of Precambrian rock derived from the

Locations of field trip stops. Field trip A-1.

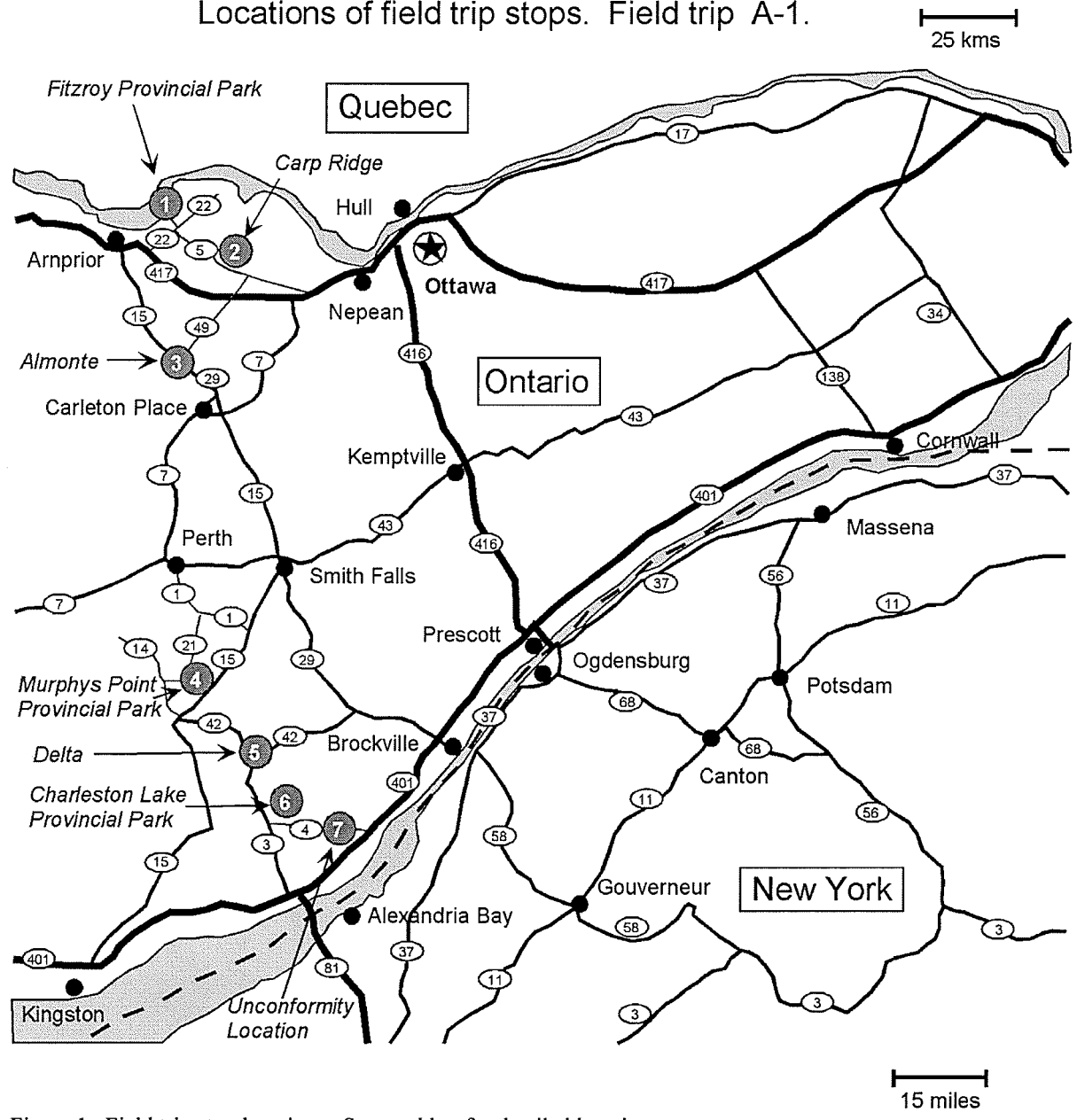


Figure 1. Field trip stop locations. See road log for detailed locations.

Canadian Shield (mainly from the adjacent Grenville Province, but a few from the more remote Superior Province). In addition, many large angular slabs were ripped up from nearby stromatolitic limestone and dolostone. As the once much larger post-glacial ancestor of the Ottawa River cut its way through the Ottawa Valley, it carved increasingly narrower channels in the Paleozoic rock, exposing a succession of bedrock cliffs along Terraces Trail.

On completion of the Trail loop, we will visit the shore of the Ottawa River, just north of the most northerly bathing beach, where a few small outcrops of Oxford dolostone that underlie the Rockcliffe Formation display domal stromatolites. These stromatolites, near the top of the Oxford, are laterally linked (Figure 4), generally with smooth, gently domed calcilititic laminae (some of the smaller stromatolites show incipient branching). The best bedrock exposures occur in shoals and along the shores of several nearby offshore islands in the Ottawa River, where individual stromatolite domes commonly exceed one metre in diameter, have a synoptic relief of up to 40 cm, and display a distinct north-south elongation trend. Discontinuous patches of silicification commonly accentuate the laminae. Locally derived stromatolitic blocks have been placed throughout the park along interior roads, and on both sides of the road at the park entrance. These large blocks provide opportunities to observe three-dimensional morphologies of the stromatolites.

Period	Series	Stage	SOUTHEASTERN ONTARIO					NORTHERN NY	
			Williams & Teleford (1986)			Wilson (1946)		Fisher (1977); Cameron & Mangion (1977)	
			Group	Formation	Member	Formation	Faunal Zone	Group	Formation
ORDOVICIAN	Cincinnatian	Richmond	Queenston			Queenston		No equivalents	
		Maysville	Carlsbad			Russell			
		Eden	Billings			Billings			
			Lindsay	Upper	Eastview				
				Lower	Ottawa	Coburg			
	Verulam		Sherman Fall			Sletuben			
	Sherman	Bobcaygeon	Upper	Hull		Denley			
	Kirkfield		Middle	Rockland		Sugar River			
	Rockland		Lower	Leray		Kings Falls			
	Champlainian	Black River	Gull River	Upper	Lowville		Napanne		
				Lower	Pamella		Selby		
			Shadow Lake		St. Martin		Watertown		
		Chazy	Rockcliffe	Upper	Rockcliffe		Black River	Lowville	
				Lower	Rockcliffe		Pamella		
	CANADIAN	Beekmantown	Oxford	Oxford		Beekmantown	St. Martin		
			March	March			Rockcliffe		
		Potsdam	Nepean	Nepean			Chazy	Ogdensburg	
	Covey Hill		Nepean		Potsdam	Theresa			
CAMBRIAN	Potsdam	Covey Hill	Nepean		Potsdam	Keeseville			
			Nepean			Ausable			

Figure 2. Stratigraphic correlation of Cambro-Ordovician units in the Ottawa area (Southeastern Ontario) with adjacent parts of northern New York (after Williams et al. 1992.)

PERIOD	GROUP	FORMATION	FIELD STOP NUMBER & AGE
EARLY ORDOVICIAN		St. Martin Rockcliffe	
	Beekmantown	Oxford March	
		Potsdam	
CAMBRIAN			
PRECAMBRIAN ERA	BASEMENT ROCKS OF THE GRENVILLE PROVINCE		

Figure 3. Relative stratigraphic position of units exposed at each of the field trip localities.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER AT THE INTERSECTION OF CANON SMITH DRIVE AND THE PARK ENTRANCE BEFORE LEAVING STOP 1 . Intersection of Fitzroy Park Entrance Road and Canon Smith Drive.
0.5 (0.3)	0.5 (0.3)	Turn right on Hwy. 5 and continue through the small village of Fitzroy Harbour.
1.8 (1.1)	1.3 (0.8)	At 1.8 km the road bends left and becomes Harbour Road.
3.7 (2.3)	1.9 (1.2)	At the intersection of Hwy. 5 (Harbour Road) and Hwy. 22 (Galletta Sideroad) turn right on Galletta Sideroad.
3.9 (2.4)	0.2 (0.1)	Travel about 200 meters and turn left onto Carp Road, the extension of Hwy 5. From here we will travel several kilometers down Carp Road and turn at a driveway to visit the land around a residence. A location is not provided for this site, because it is on private land. STOP 2 .



Figure 4. Laterally linked stromatolites of the Oxford Formation, Fitzroy Harbour Provincial Park. STOP 1.

The contact of the Oxford with the overlying Rockliffe is exposed in outcrops along the shores of the Carp River, adjacent to the bridge within the park. These exposures are best seen in the late fall, when the river level is at its lowest.

Departing Fitzroy Provincial Park, turn right on Canon Smith Drive. As we leave the park, look to the north to see the Gatineau region of Quebec, where Precambrian Grenville gneisses have been uplifted along a series of faults that form the Ottawa-Bonnechere Graben. This ancient tectonic feature controls the course of the Ottawa River for more than 600 kilometers to the northwest.

STOP 2 - GRENVILLE GNEISS, GRANITE, APLITE PEGMATITE AND XENOLITHS, CARP RIDGE

PRIVATE RESIDENCE

This locality is on the south margin of the Carp Ridge, a northwesterly trending window of Grenville basement bounded on the southern side by a fault, extending west-northwesterly more than 40 km from the Kanata subdivision of Ottawa to Arnprior.

More-than-metre-wide lichen-free coronas around each outcrop provide a great opportunity to study mineralogy, textures, structures and multiple episodes of deformation and intrusion (Figures 5 and 6). Although lacking formal training in geology, the owner has an enduring appreciation of the Precambrian basement, having hired a backhoe to remove considerable overburden from around a

number of lichen-covered outcrops. The unearthing project was finished by hand, to avoid scratching the newly exposed bedrock. Please keep this location confidential, as the owner has granted permission for our group to view these spectacular outcrops of Grenville gneisses and intrusive rocks -- a highlight of this trip -- for the official trip only.

The complex geology of the Grenville Province has been debated since a sequence of quartzite, marble, and related paragneisses exposed along the Ottawa River in Grenville, Quebec was named the 'Grenville Series' by Sir William Logan (Logan, 1863). Recent work, fueled by detailed mapping, and advances in structural geology and U-Pb geochronology, has provided the impetus for hefty compilation volumes (Moore et al., 1987; Tollo et al., 2004). This area occurs within what is known as the Central Metasedimentary Belt, a vast area underlain predominantly of originally stratified volcanic and sedimentary rocks now intensely deformed and highly metamorphosed. Numerous lines of evidence suggest that the area has been effected by several collisional events, the most recent named the Ottawa Phase of the Grenville Orogeny. The Ottawa 'Orogeny' occurred approximately one billion years ago and has been compared to more recent events leading to the rise of the Himalayan Mountains. Here however, we have a chance to peer into the very core of the orogenic belt because of the removal of many kilometers of overlying rock. Rocks with a similar tectonic history can be traced for vast distances to the northeast to Greenland, The British Isles, and Scandinavia and south into the Adirondack and Appalachian Mountains, suggesting the 'Grenville' Orogeny' formed an immense mountain chain likely encompassing parts of several continents.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		Leave STOP 2 and turn left onto Hwy. 5 (Carp Road) and head east. RESET ODOMETER AT THE INTERSECTION OF CARP AND MARCH ROAD
11.7 (7.3)	11.7 (7.3)	Intersection of Carp and March Roads. Turn right and head south for Almonte. Cavanaugh Quarry on left is a source of road metal and aggregate from a vast hillside outcrop of Ottawa Group limestones. Glacially scoured and flat-lying carbonate strata in this area form extensive near-surface pavements -- alvars -- with unique ecological features.
18.5 (11.5)	6.8 (4.2)	The road traverses a bridge crossing the Mississippi River in the village of Almonte.
18.6 (11.6)	0.1 (0.1)	Park in Metcalfe Park, just beyond the bridge, where the road veers to the right.
NOTE	LUNCH HERE	Walk back to the parking lot of the Victoria Woolen Mill on Mill Street. As one of several projects undertaken by Friends of Canadian Geoheritage, some of the large blocks bordering the parking area of Metcalfe Park have been selected from nearby building sites and quarries to illustrate a variety of sedimentary structures. The Town Council and several owners of construction companies and quarries played a key role in making arrangements to move and place these large blocks. STOP 3.

STOP 3 - OXFORD FORMATION STROMATOLITES (ORDOVICIAN), ALMONTE

N45°13.530' W076°11.875' Victoria Woolen Mill

This stop will allow an opportunity to see some of the various stones used to construct the many historic buildings in this village of approximately 4500 inhabitants. Depending on the water level we will observe several units of laterally linked stromatolites in Ordovician carbonate strata (Oxford Formation), right beneath the centre-town dam on the Mississippi River, in downtown Almonte. These stromatolite beds are best viewed from the observation deck behind the Victoria Woolen Mill on Mill St., immediately east of Slide Bridge (Main Street/Hwy 49).

Lunch may be obtained in any of several restaurants along Mill St. Information pamphlets are available from the Visitor Centre, immediately east of the Victoria Woolen Mill (note the stromatolite-bearing block near the entrance).

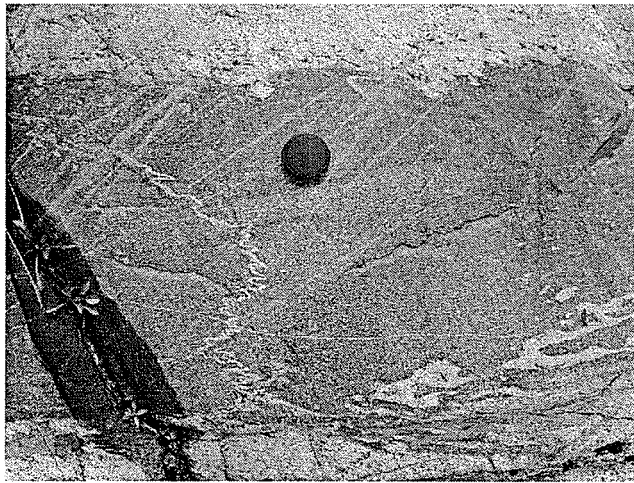


Figure 5. Complex relations between pegmatites, ptymatically folded aplitic dykes, and amphibolite gneiss, Grenville Province, Carp Ridge location. STOP2.



Figure 6. View of phenocryst-rich mafic gneiss at Carp Road location. Note zoning in large plagioclase phenocryst near lens cap. STOP 2.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER BEFORE LEAVING STOP 3 . From the Metcalfe Park parking lot, continue on Hwy. 49 (Mill Street) to Hwy. 29 (Christian Street).
0.7 (0.4)	0.7 (0.4)	At the intersection of Hwy. 49 (Mill Street) and Hwy. 29 (Christian Street) turn left. Follow Hwy 29 south into Carleton Place. Bear right and continue on Townline Road (Hwy 7B) until it intersects Hwy. 7.
14.0 (8.7)	13.3 (8.1)	Intersection of Townline Road and Hwy. 7. Turn right and follow Hwy. 7 south towards Perth.
43.8 (27.2)	29.8 (18.5)	At the intersection of Hwy. 7 and Wilson Road (Hwy.1) take a left (second traffic light). Follow Hwy. 1 as it winds through town (left at Code's Mill and then right onto Gore Street).
52.7 (32.7)	8.9 (5.5)	At the intersection of Hwy. 1 and Hwy. 21 (Elm Grove Road), take Hwy. 21 south.
63.3 (39.2)	10.6 (6.5)	Turn left into the entrance of Murphys Point Provincial Park and follow the park road to the entrance gate.
64.8 (40.2)	1.5 (1.0)	Park entrance gate). Group will proceed to the parking area of the Silver Queen Mine trail (Lally Homestead) after checking in (another 5 km farther along Hwy. 21, where it becomes a gravel road. STOP 4 .

STOP 4 - MURPHYS POINT PROVINCIAL PARK, SILVER QUEEN APATITE-MICA-FELDSPAR MINE, LALLY HOMESTEAD

N44°46.840' W076°13.844' Park Entrance; N44°46.044' W076°15.317' Silver Queen Mine Parking Lot

Murphys Point Provincial Park lies within the Grenville Province, on the eastern side of the Frontenac axis. A wide variety of both igneous and metamorphic rocks are exposed within the park. Some of the metamorphic rocks show evidence of multiple stages of folding, best seen in exposures of the several belts of crystalline limestone that traverse the park. We will park at the Lally Homestead, where an outcrop of marble displays folding, foliation, possible relic bedding and a variety of positive-weathering inclusions (Figure 7).

Closed in 1920, the Silver Queen Mine was an important source of phosphorous for munitions during World War I. A part of this mine has been restored to allow safe underground entry, where large crystals of mica and apatite stand out on the partially mined rock walls.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER BEFORE LEAVING STOP 4. Parking lot of Lally Homestead. Follow Hwy. 21 (here a narrow gravel road) west. Previously Elm Grove Road, it is now called Lally Road.
2.9 (1.8)	2.9 (1.8)	At the intersection of Hwy. 21 and Hwy. 14 turn left and proceed south on Hwy 14 (Narrows Lock Road).
8.4 (5.2)	5.5 (3.4)	Turn left at stop sign and head towards Crosby.
11.3 (7.0)	2.9 (1.8)	One lane Narrows lock on Big Rideau Lake.
17.4 (10.8)	6.1 (3.8)	Intersection of Hwys. 14, and 15/42 at Crosby. Turn left onto Hwy. 42.
17.6 (10.9)	0.2 (0.1)	At stop sign cross HWY. 15 and continue east on HWY. 42.
21.1 (13.1)	3.5 (2.2)	Bear right in Forfar.
31.5 (19.5)	10.4 (6.4)	Once in Delta the Old Stone Mill is on the right. Turn into parking lot just past the mill. STOP 5.



Figure 7. Grenville marble with isolated calc-silicate layers and xenoliths weathering in relief, Murphys Point Provincial Park. These xenoliths may once have been coherent layers, disrupted during deformation. STOP 4.

STOP 5 – TRACE FOSSILS IN NEPEAN SANDSTONE, OLD STONE MILL, DELTA

N44°36.587' W076°07.373' Old Stone Mill, Delta

Built in 1810 of Nepean (Potsdam) sandstone, this is the only stone gristmill in Canada designated as a National Historic Site. The quartz arenite blocks used to construct this building are remarkable for their almost universal abundance of the trace fossils, *Skolithus* and *Diplocraterion*. (Figure 8). We are currently unaware of the provenance of this building stone, but are attempting to track down where it was quarried. Some Nepean/Potsdam and March/Theresa beds have such traces in abundance (cf. Bjerstedt and Erikson, 1989).

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER BEFORE LEAVING STOP 5 . Leave Old Stone Mill by turning right and continuing east on HWY. 42.
3.1 (1.9)	3.1 (1.9)	At the intersection of Hwy. 42 and Hwy. 33, turn right on Hwy. 33, and drive through Lyndhurst. You will see signs to Charleston Lake Provincial Park and Lyndhurst Bridge.
9.4 (5.8)	6.3 (3.9)	One lane bridge at Lyndhurst.
9.8 (6.1)	0.4 (0.3)	Just after bridge, at the intersection of Hwy. 33 and Hwy. 3,, turn left onto Hwy. 3.
21.0 (13.0)	11.2 (6.9)	Take left turn off Hwy. 3 on Charleston Lake Road.
22.1 (13.7)	1.1 (0.7)	Turn left onto park road and proceed one km to entrance gate.
22.7 (14.1)	0.6 (0.4)	Entrance kiosk. STOP 6 .

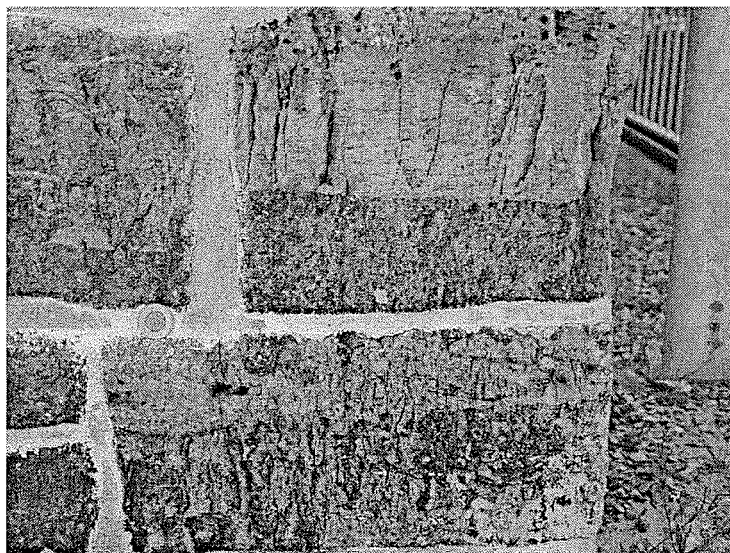


Figure 8. Bioturbation in blocks of Nepean sandstone used to build the old gristmill in Delta. Note abrupt truncation of burrows in the upper right hand block. STOP 5.

STOP 6 - CHARLESTON LAKE PROVINCIAL PARK, GIANT CYLINDER IN NEPEAN FORMATION

N44°30.100' W076°02.532' Entrance kiosk.

We will drive to Sandstone Island Trailhead, and follow Sandstone Island Trail (Figure 9) to view basal conglomerate and sandstone of the nearly 500-million-year-old Nepean Formation in unconformable contact with billion-year-old Precambrian metamorphic and igneous rocks of the Grenville Province (Figure 10). This contact, representing more than half a billion years of elapsed time, is best displayed at Post 2, where weathered granite at the top of the Grenville basement may well represent a paleosol. Isoclinally folded units of crystalline limestone and intercalated siliciclastic metasediments are abundant within the park (see map of Hewitt, 1961).

Many of the well-rounded conglomerate clasts (readily seen on the undersides of undercut bedding surfaces, as well as in vertical sections at Posts 3 and 4) consist almost exclusively of vein quartz and Precambrian quartzite, but a few clasts are identical to the Nepean, indicating early cementation and cannibalism of basal Paleozoic units (some Covey Hill reworking?). Crossbedding shows a preferential southerly trend, but herringbone patterns (well-exposed at Posts 6 and 7) are locally abundant, suggesting alternation between fluvial and marine depositional environments. A few cross-sections of probable tidal channels are visible in close proximity to packages of strata displaying herringbone crossbedding. Similar successions, as well as facies containing spectacular aeolian dunes, occur on the west side of the Frontenac Axis (cf. Dalrymple and Wolf, 1988).

A particularly fascinating structure occurs at the site described as 'The Waterfall' (Post 8). Initially thought to have been formed by rapidly flowing meltwater cascading over a cliff during Wisconsin deglaciation, it now is apparent that this hollowed segment of almost half a cylindrical structure (Figure 11), extending vertically through 5 m of well-indurated Nepean strata, is an exhumed dewatering structure (cf. Gruhman and Pederson, 1992). This interpretation, first presented here to account for 'The Waterfall', is provided by two lines of evidence: 1. A patch of sandstone on one side of the structure shows lamination parallel to the cylindrical surface; and 2. Below the level at which a conglomerate bed within the stratigraphic section intersects the cylindrical surface, pebbles and cobbles are cemented to the inner surface of this columnar structure by sand identical to sand in the horizontal source bed (Figure 11).

While still unconsolidated, forceful upward hydraulic overpressure could create such a structure, with streaming parallel to the walls accounting for creation of an annulus of nested concentric laminations in sand along the margin of the vertical dewatering column. During waning stages of dewatering, individual pebbles and cobbles from the intersected gravel bed could have readily sunk along the periphery of the dewatering cylinder, to then be concentrated along the cylinder's margin, and held in place by a matrix of sand until the walls and interior of the structure were completely cemented. Similar structures elsewhere within the Nepean/Potsdam have long been recognized and debated (Baker, 1916; Hawley and Hart, 1934; Hawley, 1935; Miser, 1935; and Deitrich, 1953).

We probably will return back along the path from this point, but if time permits, we will follow the trail forward to Post 11, where glacially polished surfaces on uppermost exposures of Nepean quartz arenite display high polish, parallel grooves and striae, and abundant chattermark clusters, all showing consistent facings of concave chattermark curvatures in a down-ice (southwestward) direction.

CUMULATIVE MILEAGE KM (MILES)	KM (MILES) FROM LAST POINT	ROUTE DESCRIPTION
0.0 (0.0)		RESET ODOMETER AT INTERSECTION OF PARK ENTRANCE ROAD AND CHARLESTON LAKE ROAD
1.1 (0.7)	1.1 (0.7)	Leave (STOP 6) by turning right onto Charleston Lake Road. At the intersection of Charleston Lake Road and Hwy. 3 turn left and head south.
5.2 (3.2)	4.5 (2.8)	Turn left onto Hwy. 4 (Warburton Road).
9.5 (5.9)	5.0 (3.1)	Sharp turn to the right on to Blue Mountain Road (Hwy 4).
10.6 (6.6)	1.1 (0.7)	Sharp turn to the left and continue through Rockfield.
16.3 (10.1)	5.6 (3.5)	Bear right on Junetown Road.
18.4 (11.4)	2.1 (1.3)	At the bottom of a downward slope bounded by tabular-bedded rock cuts, turn into the side road (Quabbin Hill Road) to the right and park on the shoulder. Walk back to the rock cuts on the hill.
END OF TRIP	RETURN DIRECTIONS	STOP 7. Proceed east on Hwy. 4 until you reach Mallorytown. Turn left onto Hwy. 2 and head east (13.5 miles). At the intersection of Hwy. 2 and Hwy.5 (13.7 miles) (Mallorytown Road) take Hwy 5. south to Hwy 401. Enter Highway 401 (14.4 miles) and head east to the Prescott-Ogdensburg Bridge to return to Potsdam.

STOP 7 - ORDOVICIAN LIMESTONE AND SANDSTONE UNCONFORMABLY OVERLYING GRENVILLE BASEMENT

N44°28.311' W075°54.934' Intersection of Hwy. 4 and Quabbin Hill Road.

Corestones in a variety of mafic and felsic basement rocks are preserved below the unconformity on the north side of the road. The overlying sandy carbonates, probably in the lower part of the March Formation, contain abundant trace fossils, as well as a few nodular zones that may represent soil profiles (Figure 12). The lowermost beds contain quartz sand and silt, and shaly beds become locally abundant upwards in the section. The lack of Covey Hill or Nepean beds suggests that this may have been a paleohigh during early Ordovician time.

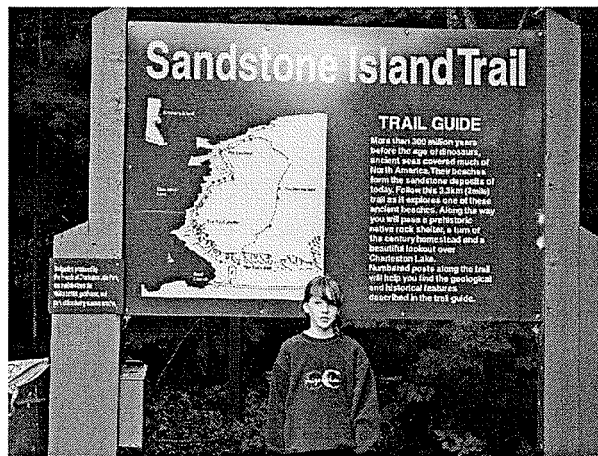


Figure 9. The start of the Sandstone Island Trail, Charleston Lake Provincial Park. Such signage, if properly presented and accurate, is an invaluable tool in promoting an area's geoheritage. STOP6.

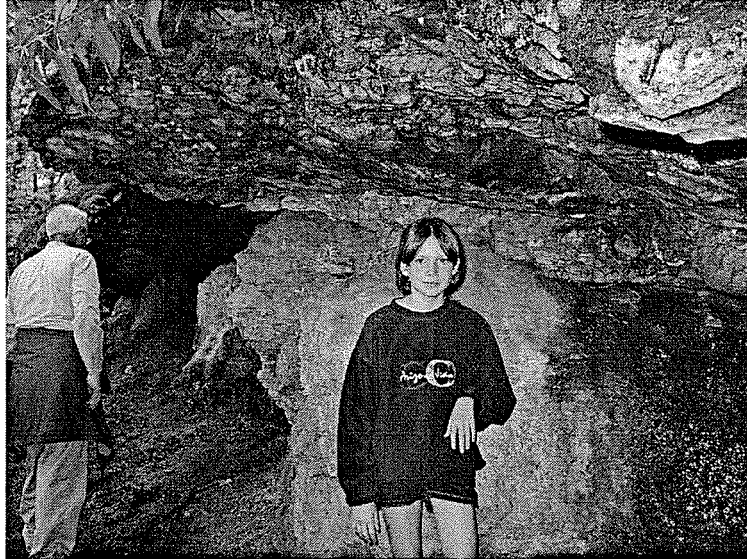


Figure 10. Contact of the Nepean Conglomerate unconformably overlying Grenville granitic basement rocks, Charleston Lake Provincial Park. Large clasts of quartzite, vein quartz, and quartz arenite occur in conglomerate forming the overhang just above the young lady. STOP 6.

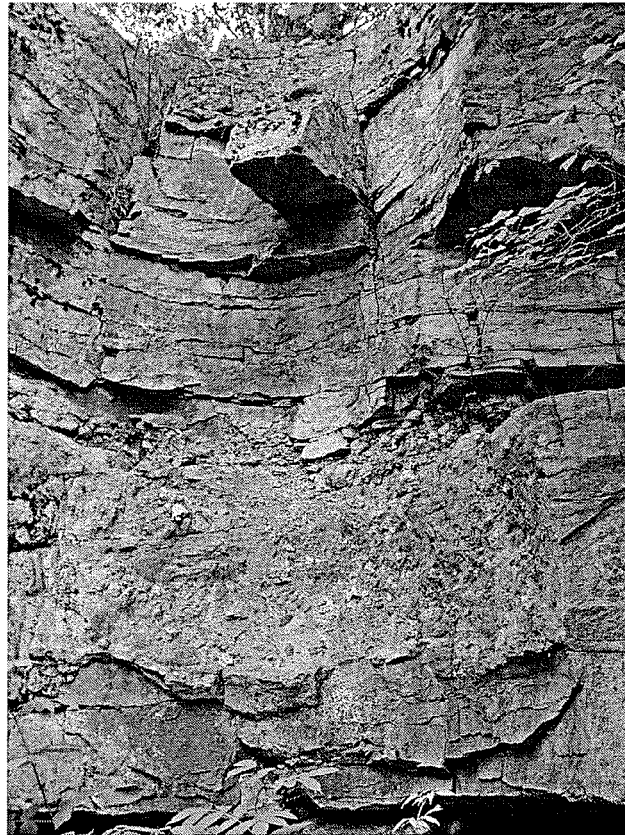


Figure 11. The cylindrical structure along Sandstone Island Trail, Charleston Lake Provincial Park. Note draping of conglomeratic layer half way up photograph into the annulus of the cylinder. STOP 6.



Figure 12. Possible pedorelics (?), circular structures above the lens cap, in the March (?) Formation, Mallorytown, Ontario. STOP 7.

END OF FIELD TRIP

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Trip A-2

SOME CLASSIC TEACHING LOCALITIES IN ST. LAWRENCE COUNTY, NEW YORK

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INTRODUCTION

Western St. Lawrence County, within the central section of the St. Lawrence Lowlands in New York, contains a wonderful variety of outcrops that lend themselves to illustrating a wide range of geological processes and principles for all levels. The purpose of this trip is to visit a limited number of these - 'tried and true' localities - those that have proven to be excellent ones for introducing students to a variety of geological problems in addition to the regional geology of the North Country. The stops on this field trip have been chosen for ease of accessibility in addition to their outstanding teaching possibilities. All have been used in introductory to advanced field labs in the Geology Department at St. Lawrence. They are, therefore, suitable for moderately large groups (say, a maximum of 20 or so). Our choice clearly had to be constrained by logistical limitations such as accessibility in the time available, and the number of stops appropriate for a single day field trip, but we may prove to have been over-ambitious (!) and so it should be anticipated that we might not be able to cover all the stops described in this field guide. What we offer here is, by necessity, far from comprehensive (and certainly not complete), but is a subjectively biased attempt to provide an introduction to some of the teaching possibilities in what is a geologically quite complex and varied terrain. Five of the ten stops are featured in Van Diver's (1976) highly recommended *Rocks and Routes of the North Country*.

A BRIEF BACKGROUND

The St. Lawrence Valley was an important area for mineral exploration in the early nineteenth century and a number of mines were developed in the western part of the region. Lead, zinc, and iron ore were important products. Most are now defunct but a few still remain in operation, notably the zinc and talc mines in Balmat, just south of Gouverneur (Fig. 1).

In part in response to this early exploration and also to subsequent research of the complex geology, the region has become an important collecting and study area for a wide variety of minerals (see *MATRIX: a Journal of the History of Minerals*, Fall 1998; also, field trips A7 and B4, this volume). The geology of this area is now generally well understood and this, coupled with some magnificent outcrop coverage, has resulted in the area becoming an important one for teaching at all levels, and has been a venue for many traveling field parties.

The geology of the St. Lawrence Valley, including St. Lawrence County, is essentially made up of three major rock groups. A ca. 1.35-1.0 Ga Precambrian basement (Stops 2-5) comprised of medium- to high-grade gneisses is overlain by sedimentary cover rocks, which may be divided into three age-defined packages. The oldest of these is somewhat enigmatic since these sediments (quartzarenites and breccias) likely represent a latest Precambrian to Cambrian phase of deposition, and infill

depressions on an undulating (in part karstic) Precambrian erosion surface. There is clear evidence for dissolution of marble and subsequent infill at many localities, as well as some interesting possible cave collapse structures (see Stops 6, 7 and 8). Clearly separating this 'transitional' sequence from the overlying Potsdam Sandstone, *sensu stricto*, has proven to be very difficult, and is still one of the outstanding problems in the region.

The Potsdam Sandstone represents the base of an east to west Lower Paleozoic marine transgression sequence. Overlying limestones and shaly limestones (Theresa and Ogdensburg formations) indicate a progressive deepening and distance from terrigenous sources. The age of the Potsdam is likely uppermost Cambrian to Ordovician.

Pleistocene glacial and related fluvial and lacustrine deposits (Stop 1) make up the third depositional package and these, together with glacial erosional features, provide the most significant control on the North Country landscape.

Location map for stops

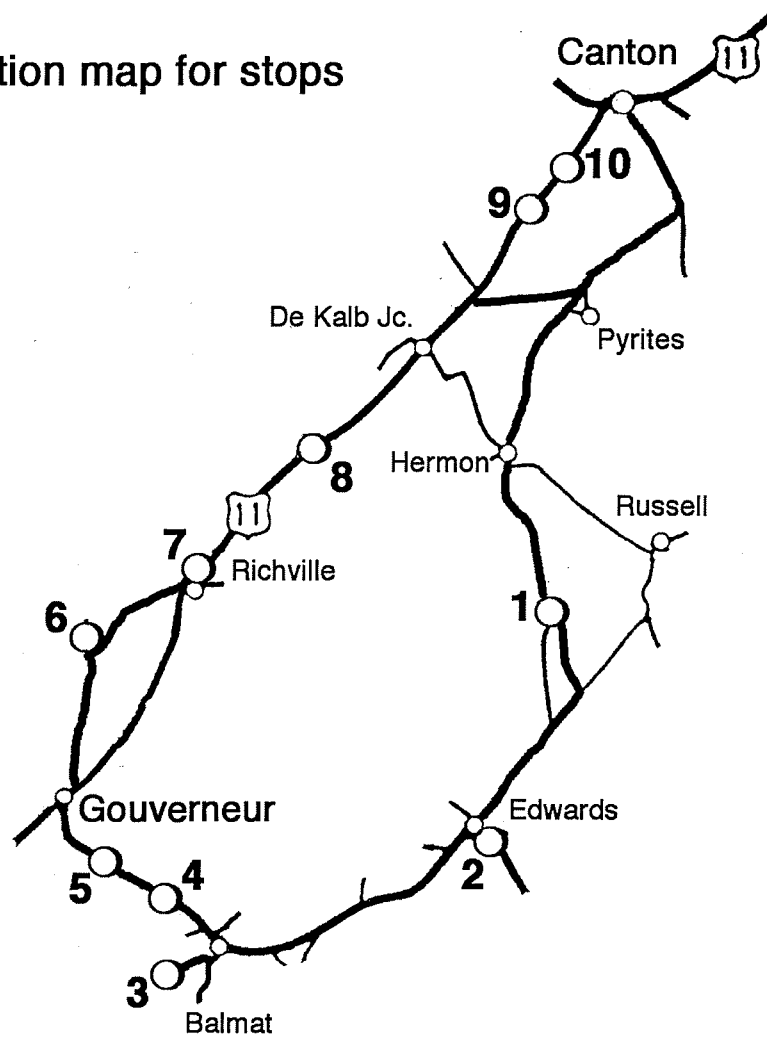


Figure 1: Location of stops described in the text. North to top.

ROAD LOG

Cumulative Mileage	Miles from last point	Route description
Start	0.0	Canton village park, in the center of Canton, junction of Rte 11 and Park Street. Follow Park St. southwards through St.Lawrence University.
2.3	2.3	Turn right at traffic lights onto County Route 25 (CR 25)
3.3	1.0	Turn right onto CR 21 and follow signs for Hermon. Notice small marble outcrop on right at 4.5 total miles and amphibolite at 5.2.
6.7	3.4	Sharp bend to left then turn right, continuing on CR 21.
7.0	0.3	Remains of pyrite mine on left just before bridge over the Grasse River, then large outcrop of marble on left. Continue straight ahead for Hermon. Notice outcrops of sand/gravel and horizontal surfaces indicating glacial meltwater deposits (delta top?). Adjacent outcrops of gneiss indicate significant relief on the post-glacial surface.
11.3	4.3	Enter Hermon.
11.6	0.3	Traffic lights, continue straight ahead and leave Hermon on CR 21 towards Edwards. Drive through a broad valley in Marshville and follow CR 21 noticing numerous roadcuts of basement gneiss. The valley is rejoined in a few miles.
16.5	4.9	Notice the small knolls in the center of the valley which is underlain by 300-900ft of till.
17.0	0.5	At a sharp right hand bend turn left.
17.1	0.1	STOP 1 , opposite one of these knolls



Figure 2: 'Moulin kame' (?) viewed from CR 21 (in front of smaller pylon).

This stop is a 'puzzler,' and may be only appropriate for those students who have taken an advanced glacial geomorphology class – although it was regularly, and quite successfully, used in a

summer session introductory course for many years. Notice that the four hillocks visible from this vantage point are comprised of poorly sorted boulder-rich sandy till (i.e., they do not have the characteristics of the agricultural boulder piles common elsewhere in the North Country). Jim Street (long time geomorphologist at St. Lawrence University until his untimely death in 1993) persuaded us that these are the remains of subglacial or englacial debris piles that collected at the base of glacial 'sinkholes'. [The term 'moulin' (mill) refers to the noise of moving pebbles and boulders at the base of the waterfalls producing these deposits, which is reminiscent of the noise of a mill.] What do you think of Jim's hypothesis?

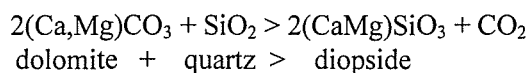
Return to vehicles and continue along this minor road, noting the severely 'underfit' stream to the other side of the valley.

17.7	0.6	Turn right onto Belleville Road and continue southwards to the junction with CR 24.
20.1	2.4	Turn right onto CR 24, past Edwards Knox School and drive obliquely across the termination of the valley of Stop 1. Notice the hummocky terrain to the right (moraine?) and the large gravel pit to the left at 22.6 miles.
24.1	3.0	Enter Edwards and turn left opposite the town hall onto Maple Avenue
25.0	1.9	Turn right at T-junction with Route 58 and park on verge beyond barrier. STOP 2 is a short walk behind on Route 58.

STOP 2. MINERAL IDENTIFICATION AND METAMORPHIC REACTIONS

A classic collecting site, now suffering from 'field party erosion'! **(PLEASE DO NOT SAMPLE FROM THE OUTCROP)**. Superb samples of diopside occur in the contact zone between pink calcite veins and the granular textured diopside-rich gneiss.

In our experience, a relatively large number of students will misidentify the salmon pink calcite as K-feldspar (providing an almost guaranteed teachable moment!) Other minerals present are actinolitic amphibole, phlogopite (a mica), pyrite, and rare molybdenite and blue apatite. Some genuine potassium feldspar has been collected from a pit just to the north. It is likely that the protolith for this rock was a siliceous dolomitic limestone with the abundant diopside in the outcrop being produced in part by the simple reaction:



Return to vehicles and continue northwestwards on Route 58.

29.0	4.0	Talcville road on right
33.2	4.2	Crossroads. Turn left onto Route 812 South towards Balmat. Notice tailings and stockpiles from Gouverneur Talc mine on left.
33.4	0.2	Turn right onto Sylvia Lake Road.
34.5	1.1	At right-hand bend pull over onto left-hand verge and park. near the gates to Ontario Zinc Co. (formerly Zinc Corporation of America, or ZCA).

STOP 3. STROMATOLITIC FORMS IN MARBLE.

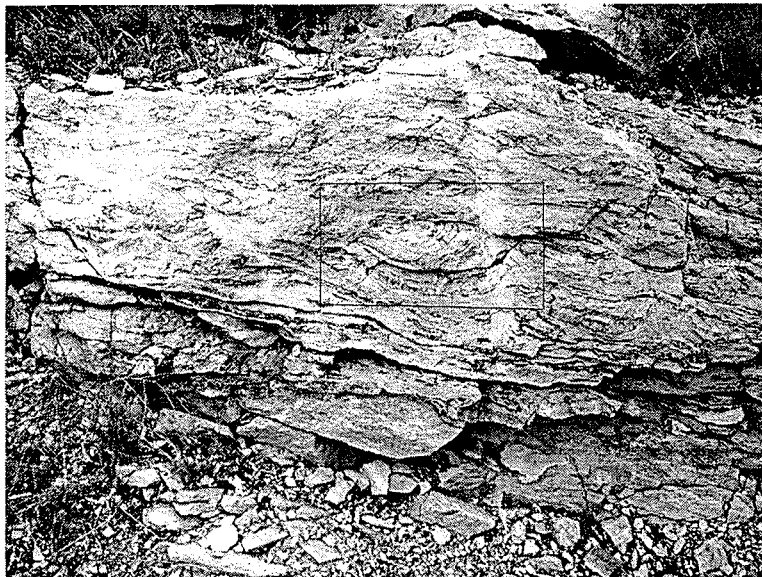


Figure 3: An overturned 'cauliflower' stromatolite occurs mid-photo (rectangle approx 20" wide).

One of the most significant outcrops in the Grenville geology of New York. The stromatolites are not only important as vestiges of past life (as old as 1.3Ga) but, since they are upside down, gives credence to the existence of postulated large-scale folds (nappes) in the St.Lawrence Valley. **AGAIN, PLEASE, NO HAMMERS.**

Return to the junction of Route 58 and 812

35.9	1.4	Turn left onto Route 58 and continue northwards.
36.9	1.0	Pull over and park just beyond the entry to a road on the right. These large roadcuts comprise STOP 4

STOP 4. MIGMATITIC GNEISS COMPLEX (POPLAR HILL GNEISS)

Gray paragneiss invaded by a variety of moderate to steeply dipping granitic veins and dikes, most of which have suffered (or enjoyed) significant extension (stretching). Rare veins that have low dip may be quite strongly folded. A very fine example of this occurs on a grass ledge at the top of the southern end of the western outcrop, and at least one structural geology text has featured these as 'ptygmatic' folds (see Fig. 4). The varied response of the veins to the deformation is systematic within small areas of these outcrops and can give a fairly crude assessment of the principal axes of finite strain – moderately steep extension and shallow shortening. Return to vehicles and continue northwards.

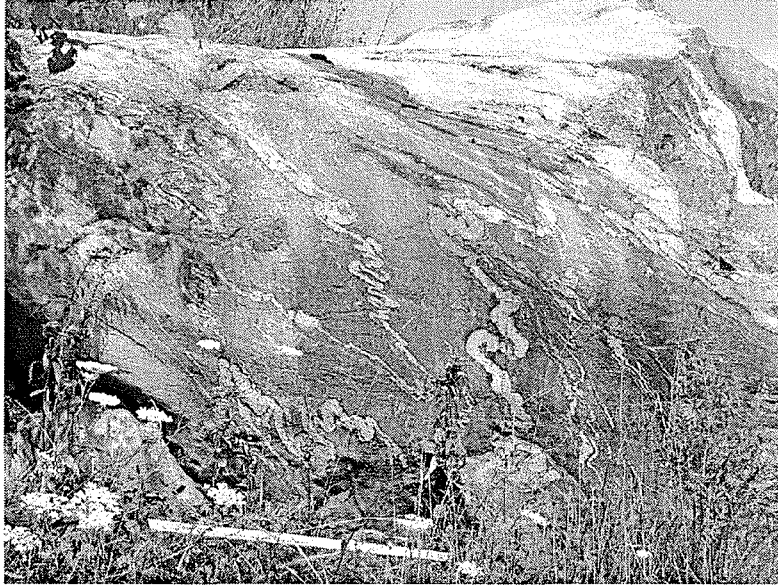


Figure 4: 'Ptygmatic' folds from the west side of Route 56. (3ft measure for scale)



Figure 5: The 'steers head'. Intrusive marble into gray gneiss.
(Outcrop approximately 15 feet high)

- | | | |
|------|-----|--|
| 39.9 | 3.0 | Pass the turn-off for Hailsboro and the 'steers head' on the right (marble injection into in gray gneiss, Figure 5). |
| 40.5 | 3.4 | STOP 5. Very large roadcut of marble. Park on the right. |

PLEASE WATCH FOR SPEEDING TRAFFIC!

STOP 5. DISRUPTED AND METAMORPHOSED MAFIC DIKE IN GNEISSIC MARBLE

The marble in this magnificent roadcut is a compositionally layered variety with alternating graphite-rich and graphite-poor layers. It is uncertain if the layers are original layering or are deformational in origin. Careful observation of the train of boudinaged dike fragments will indicate a complex relationship to the layers. Note also that the attitude of the layering along the outcrop suggests the existence of a large recumbent fold with the lower limb below road level in the southern part of the cut. More than one phase of folding is necessary to accommodate the complex geometry, even if the 'dike' was originally non-planar. Our introductory geology field lab exercise for this outcrop require students to make a sketch of the whole section on the east side of the road as well as to identify the principal minerals present in both the marble and the mafic dike remnants. Return to vehicles and continue north on Route 58.

41.2	0.7	Small low outcrops of marble on both sides of the road with a basaltic dike (short stop, if time permits).
42.1	0.9	Past large cemetery on right, down a short hill, under a railroad bridge and over the Oswegatchie and turn right at traffic lights.
42.25	0.15	Onto Route 11 at the traffic lights.

LUNCH PICK-UP: Pick-up at un-named fast food sources, Gouverneur

42.4	0.3	Second traffic lights on Route 11. turn left.
42.6	0.2	Turn right at T-junction, (fair ground straight ahead).
42.7	0.1	Turn left at T-junction onto Rock Island Road.
46.5	3.8	Turn right at top of hill onto Welsh Road and park on right,

LUNCH STOP

STOP 6: ROCK ISLAND ROAD CUT.

This outcrop is perhaps one of the most intriguing road sections in the North Country and is a common stopping point for field parties visiting the region. It is appropriate for all levels - introductory physical geology to advanced courses (senior level structural geology, for example). Our main interest here is to characterize the relationship of the presumed Potsdam Sandstone to Grenville gneisses, which at the upper part of the roadcut are calcitic marbles. This deep roadcut provides magnificent exposure and is one of the better outcrops in illustrating the variety of marble-sandstone relationships present in the region. Evidence for significant post-arenite deposition deformation is present at many localities.

At the southeast end of the cut, a well-bedded quartz-arenite illustrates the attractiveness of an interpretation that these represent the lowermost Potsdam Sandstone. However, the very complex relationships of these sandstones with the "underlying" marbles invite alternative explanations to a simple erosional unconformity. Moderate dips (~30°), angular marble clasts in quartzarenite, thin sandstone dikes extending outwards and upwards from contacts, and changes in composition of the sandstones close to the marble have all contributed to a karst surface depression infill (see Van Diver, 1976). Some of the contact relationships in this section have been used as evidence for structural control of deposition and basement remobilization (Bannerman *in* Carl and Van Diver, 1971) - similar

to that of Barber and Bursnall (1978) for outcrops in the area around Theresa, some twelve miles to the west.

For introductory students, clear evidence of faulting and a basaltic dike at approximately half-distance down the outcrop are additional important features.

Contact zones need to be carefully examined and advanced students should be directed to iron oxide and iron pyrite that armor many of the surfaces, and the potential significance of angular marble fragments. Subtle brecciation features particularly in the northern sections (perhaps, autobrecciation), matrix supported conglomerates (upper west side of northern section), etc., may be easily overlooked, and a spectacular tourmaline-rich breccia in the latter area further suggest a protracted and complex history for the section.

Return to vehicles and continue east along Welsh Road towards Richville.

49.7 3.3 Junction with Route 11. Turn left and immediately park on the right.

STOP 7. SANDSTONE WITHIN MARBLE AND THE RICHVILLE BRECCIA



Figure 6: Narrow seam of quartzarenite in marble. Drill-hole spacing for scale.

(a) If time permits, an outcrop of marble on the northwest side of Route 11, a few hundred yards to the south should be visited (see Fig. 6, above). It contains narrow subvertical veinlets of arenite at the northeast end, which provide good evidence for solution cavity infill (Bursnall and Elberty, 1993).

PLEASE CROSS WITH CARE (DUAL LANES IN THE UPHILL DIRECTION).

(b) Return to Welch Road and continue along a large outcrop on the north side of Route 11. Karboski et al. (1983) describe this outcrop as containing a “flow breccia” at its base. This is overlain by a densely consolidated breccia with an overlying highly deformed metaquartzite, overlain by an “orthoquartzite,” which contains pebble-sized quartz clasts – possibly derived from the underlying metaquartzite. The breccias contain quartz clasts set in a hematite stained, medium-grained arenite.

Large (0.5m) phacoidal blocks of the breccia are enveloped by thin shaley borders, the whole giving the impression of a shear zone.

This outcrop certainly inhibits any notion that the unconformity between Precambrian basement and overlying arenaceous cover rocks is a simple one!

Points of interest are:

- i) possible shear fabrics in the lower part of the outcrop, in part defining the borders of coherent blocks of breccia;
- ii) compositional variation of clasts in the breccias; and,
- iii) the relationship between and the textural character of each of these identified rock types.

If the upper part of this outcrop is indeed comprised of rocks which are parts of the Grenville basement, as supposed by Karboski (1976) and Karboski et al. (1983), then the current disposition of lithologies seems not to be satisfied by a model that involves karst infill alone. It is possible, however, that the wall collapse of a large solution depression may have allowed a slab of basement to slide into a sediment filled basin. The presence of shear fabrics within the breccia may be accommodated by this model, provided that these rocks were only partially lithified at the time. Another possibility, since there is evidence of folding and brittle faults in Lower Paleozoic rocks elsewhere in the St. Lawrence Valley (Barber and Bursnall, 1978), is that these shear fabrics are a remote product of Alleghenian deformation.

Cross over Route 11 to return the vehicles and investigate the southern end of the outcrop on the southeast side of the road. Here, a narrow zone of sandstone breccia dips steeply through marble. One of the contacts is sheared indicating high angle faulting. Is there evidence for displacement sense? Continue northeast on Route 11.

54.8	4.1	Junction with Route 812 from Ogdensburg. Continue on Route 11.
55.4	0.6	Pull over on right beside large outcrop, STOP 8.

STOP 8. SANDSTONE/MARBLE CONTACT, EAST DEKALB.

This series of outcrops (Figure 7), known as the 'Red and White' by St. Lawrence introductory geology students illustrates some of the complexities of the unconformity between the Grenville metamorphic rocks and overlying quartzarenite sediments, which may, or may not, be Potsdam Sandstone. The stop has a number of interesting features that will test students' abilities in assessing field relationships and has similarities to the Rock Island Road outcrops (solution pockets, sulfide mineralization close to gneiss-sediment contact, etc.). A number of small sandstone breccia wedges (see below) penetrate downwards into the underlying marble close to its steep contact with a rusty sulfidic quartzarenite in the central section of outcrops on the northwestern side of the road.

A poorly defined cylindrical structure (supposed solution pocket collapse structure, Bursnall and Elberty, 1993; see Figure 8, below) may be seen on the top of a low outcrop of compact, rusty weathered, quartzarenite in the southernmost outcrop on the northwest side of Route 11. Bedding in the sandstone is irregular and breccia/conglomerates are present low in this section and in the outcrop on the southeast side of the road a short distance to the south.

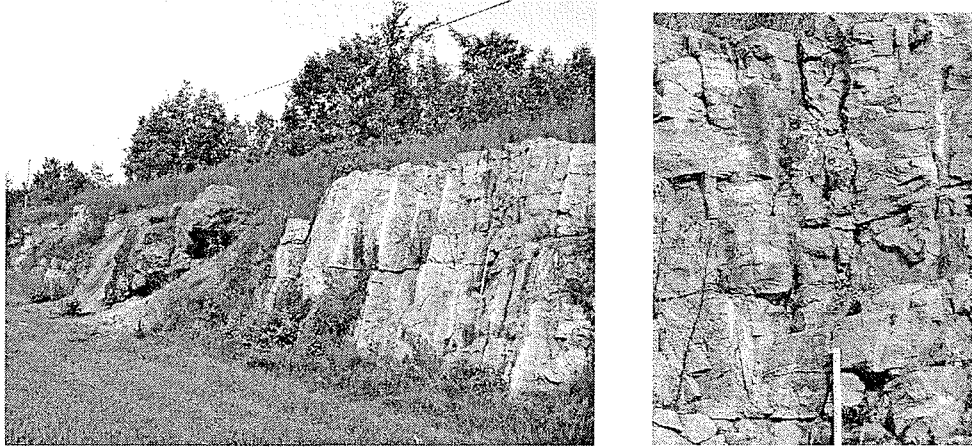


Figure 7: Left. General view of the contact between Grenville marble on the right and rusty weathered sandstones to the left. Notice position of meter rule and breccia solution pocket infill above it – right-hand photograph.



Figure 8: Cylindrical structure in well-bedded sandstone. (Lowermost Potsdam?)

Also of interest is well-layered marble at the north end of this long outcrop showing excellent recumbent folds and calcite fiber slickenlines.

Continue northeast on Route 11, driving through Dekalb Junction at approximately 59 miles.

62.5 7.1 Small outcrop on left.

STOP 9. THE DEKALB ANTIFORM (if time and interest permits)

The Dekalb antiform occurs in garnetiferous gneiss. Layering changes from a relatively shallow dip at the northern section of the outcrop to steep to vertical at the southern end. The change in dip and “S” and “Z” parasitic folds suggest an antiformal structure with a few complications including a fault near the large granitic vein toward the northern end of the outcrop and a change of parasitic fold plunge direction. A lab exercise for structural geology students includes sketching the change in orientation of layering, measuring strike and dip of layering across the outcrop, measuring the trend and plunge of the parasitic fold axes and then interpreting the structure taking into account the afore-mentioned “complications”. Return to vehicles and continue northeast on Route 11.

63.3 0.8 Large roadcut in marble on both sides of road.

STOP 10. THE ‘SNAKE’ (if time and interest permits)

This classic outcrop is well described by Van Diver in *Rocks and Routes of the North Country*. It is appropriate for introductory and advanced students. A thin band of feldspar-rich rock, thought to be a metamorphosed volcanic ash layer, snakes across the outcrop displaying at least two phases of folding on the outcrop face on the east side of the road. Interference patterns on the top of the east side outcrop and at the far northern edge of the west side outcrop show two and possibly three phases of folding.

Continue on Route 11 towards Canton.

67.8 4.5 Junction with Route 68. Turn right.
67.4 0.3 Canton Village Park.

END OF TRIP

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Trip A-3

THE 1993 LEMIEUX LANDSLIDE AND MER BLEUE BOG, SOUTHEASTERN ONTARIO, CANADA

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SECTION 1. THE LEMIEUX LANDSLIDE

Marine silts and clays were deposited through much of the St. Lawrence and Ottawa Valleys during the incursion of the Champlain Sea. These clays, known in Canada as Leda clay and in the U.S. as Massena clay, are sensitive to disturbance and prone to low-angle slope failure despite the muted topography of the area. Landslides have been occurring in the Ottawa Valley (Figure 1) since the recession of the Champlain Sea at about 10 ka (Aylsworth *et al.*, 2000). Several of these landslides have resulted in significant loss of life and property damage. Geotechnical testing for slope stability and landslide potential led to the abandonment of the 28 homes making up the community of Lemieux in 1991. Only 2 years later, on June 20, 1993, a large (17 ha) retrogressive landslide occurred near the former townsite. The landslide occurred within the scar of an earlier rotational failure, and widened through lateral spreading and subsidence, translation, and rotation of blocks separated from the side walls. About 2.8 million cubic meters of debris flowed into the South Nation River valley, extending for several kilometers up and downstream. Since the landslide, the site has changed considerably owing to erosion of the sides of the crater, erosion and revegetation of spoil piles, and the incision of the river into the debris. This field trip (Figure 2) visits the landslide scar and will discuss the conditions that led to these low-angled failures. An additional stop will be made at Mer Bleue, one of the largest ombrotrophic peatlands in southern Canada. This bog has developed in a former channel of the Ottawa River, and in places is underlain by Champlain Sea sediments.

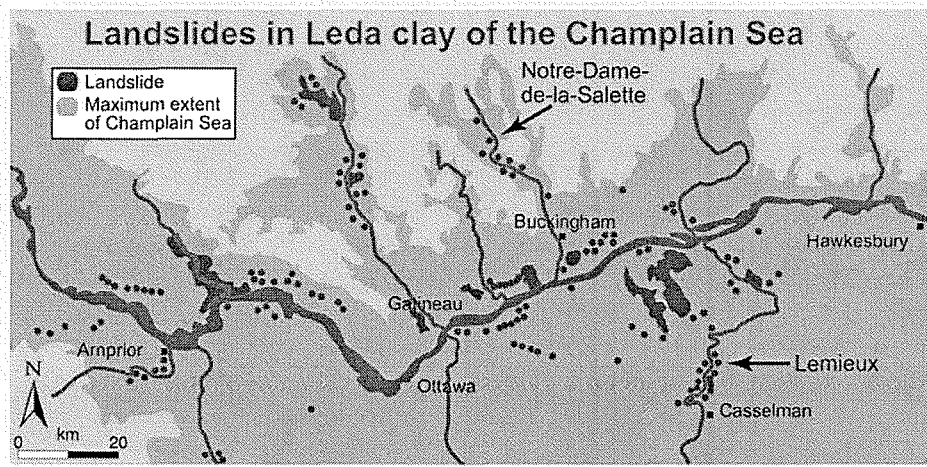


Figure 1. The maximum extent of the Champlain sea and the distribution of landslides in Leda clay. More than 250 landslides, historical and ancient, have been identified within 60 km of Ottawa. Figure from Natural Resources Canada.

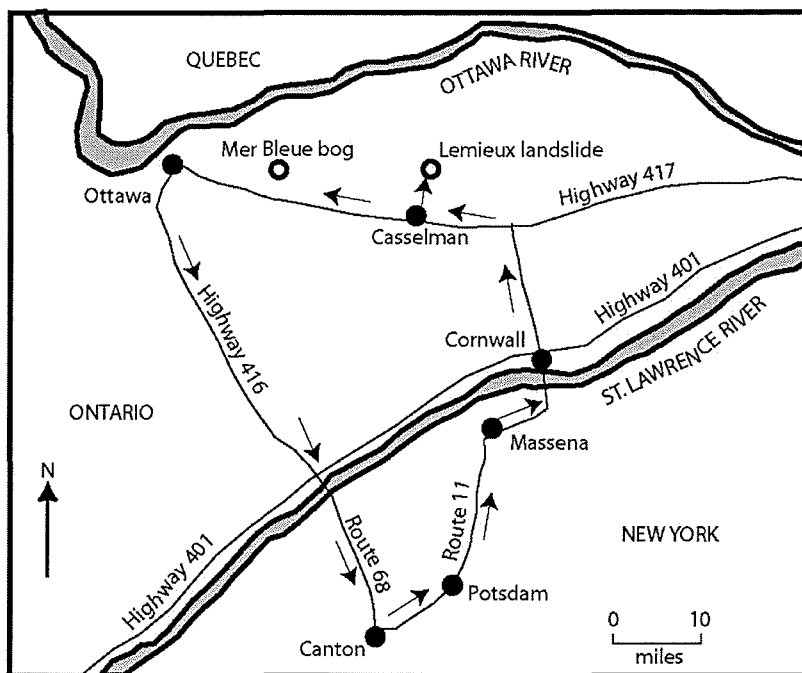


Figure 2. Field trip route to the Lemieux landslide and Mer Bleu, Ontario.

SURFICIAL GEOLOGY OF THE OTTAWA VALLEY

The Ottawa Valley is largely underlain by Paleozoic sedimentary rock that lie in a northwest-trending graben with uplifted Precambrian bedrock to the north in Quebec, and to the south in Ontario. Quaternary infilling consists primarily of a thin till overlain in places by glaciofluvial deposits of silt, sand, and gravel (stratigraphic unit A in Figure 3). Overlying the glaciofluvial sediments is a thin layer of freshwater, commonly varved, fine-grained sediments.

Depression of the Ottawa and St. Lawrence valleys by up to 200 m was caused by ice loading during the last glaciation. The retreating ice margin to the north resulted in the brief impoundment of a freshwater glacial lake and the deposition of a rhythmite series overlying glaciofluvial sediments. A marine inlet called the Champlain Sea occupied this depressed area starting at about 11.4 ka BP (Rodrigues, 1988) (Figure 4). Gadd (1986), and Fransham and Gadd (1977) indicate that the lowest depositional unit of this marine incursion consisted of weakly stratified clay and silty marine clays. Subsequent regressive deposition resulted in a coarsening-upwards sequence grading from marine to estuarine to freshwater sediments (Unit B in Figure 3). The freshwater sediments are overlain by interbedded silt and fine-grained sand deltaic sands (Unit C). The Champlain Sea had retreated from the Ottawa valley by about 10 ka owing to ongoing isostatic rebound. Many low-lying areas, especially those in former channels of the proto-Ottawa River, were subsequently filled with organics. Mer Bleu bog is one of the largest of these ombrotrophic peatlands.

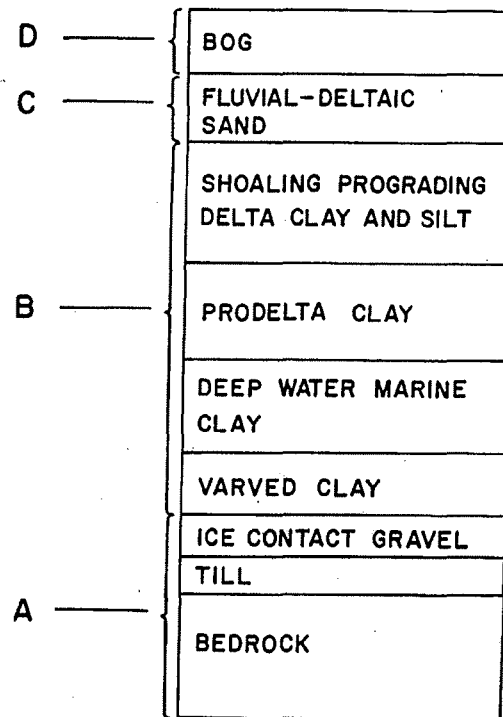


Figure 3. Generalized Quaternary stratigraphic units in the Ottawa Valley. Note that not all units are present at all sites. Figure from Fransham and Gadd (1977).

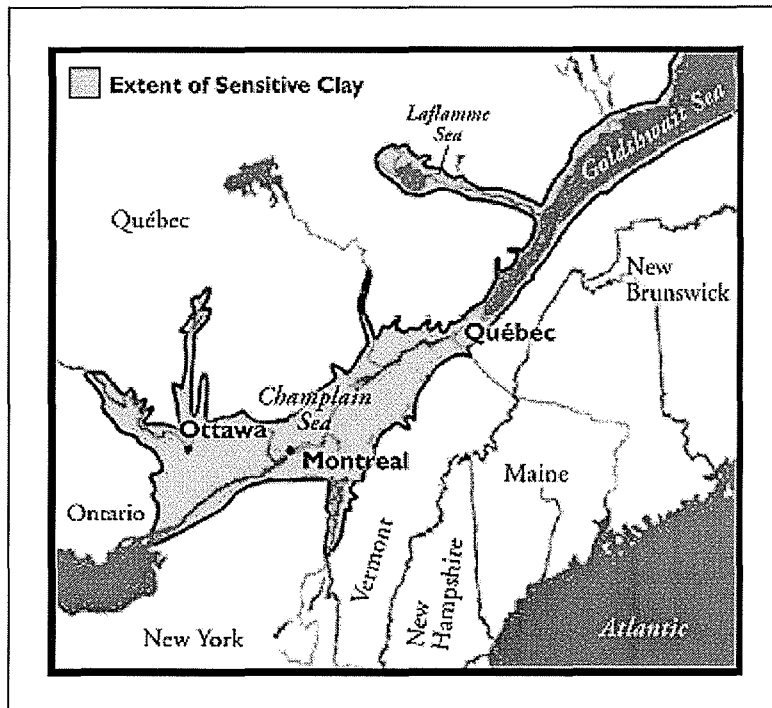


Figure 4. The extent of the Champlain Sea in the Ottawa and St. Lawrence River lowlands. Sensitive marine clays and silts are found throughout this area. Figure from the Canada Mortgage and Housing Corporation web site (www.cmhc-schl.gc.ca)

Broad channels were cut into the Quaternary sediments by the anastomosing paleo-Ottawa River. The current Ottawa River occupies the northernmost channel, with the Mer Bleue bog developing in an abandoned channel. Ongoing downcutting by local rivers (e.g. the South Nation River) has exposed sections of deltaic sediments underlain by the sensitive marine clays. Landslide development has been most significant along the immediate banks of these Ottawa River tributaries.

SENSITIVE CLAYS AND LANDSLIDES

The fine-grained sediments deposited in the marine to brackish waters of the Champlain Sea are composed primarily of quartz, feldspar, amphibole, illite, and chlorite, derived from Canadian Shield bedrock to the north ground into a rock flour by the action of the waning continental glacier to the north. True clay minerals make up only a small portion of the sensitive soils. As such, these fine-grained deposits lack the strong interparticle attractive forces commonly found in soils of true clay mineralogy. Clay-sized particles deposited in salt water often form aggregates with individual particles that are randomly aligned. These factors, combined with their deposition in waters with significant salt ions, resulted in an unstable, “house-of-cards” structure of material (Figure 5) accumulated to an average thickness of 30-50 m (Aylsworth *et al.*, 1997) in a relatively short time span (maximum 2,000 years).

Following the retreat of the Champlain Sea, meteoric water percolation through the sediments during the Holocene has resulted in a loss of salt ions and an overall decrease in the cohesive strength of the soils. Upon disturbance, the loss of strength transforms these clays into a mud-like consistency, with the remolded strength being only a fraction of the *in situ* strength. In many cases, the natural moisture content of the soils actually exceeds the liquid limit of the material (Aylsworth *et al.*, 1997)(Table 1).

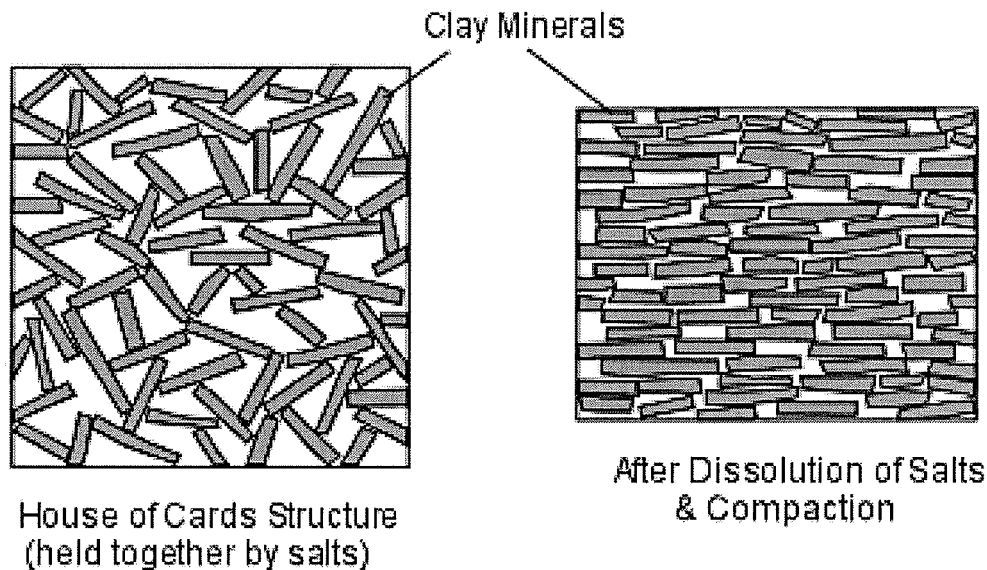


Figure 5. A “house of cards” structure often found in clays deposited in a marine environment (left). The pore spaces are often occupied by salt ions. Ongoing removal of the salt ions, in combination with disturbance can result in sudden liquefaction and compaction of the sediments (right). Structural failure often results, even on low-angled slopes such as those found in the Ottawa Valley.

The loss of strength in these soils has resulted in many landslides in the Ottawa Valley (Figure 1). Aylsworth *et al.* (2000) indicate that several massive landslides may have been triggered by earthquakes in the early Holocene. More recent landslides have likely been triggered by fluvial erosion and high water tables.

These landslides (technically earthflows) are retrogressive in nature. Initial failure commonly occurs at a riverbank where the slope is greatest. The failure of the initial block then triggers the collapse of another section, with ongoing failure proceeding in a retrogressive manner. The majority of failures in Leda clay are small, but some retrogress as much as 1 km, often in less than one hour.

In many cases it is fairly deep-seated sediments that fail, transporting a relatively intact sediment cap in blocks into the failure bowl (Figure 6).

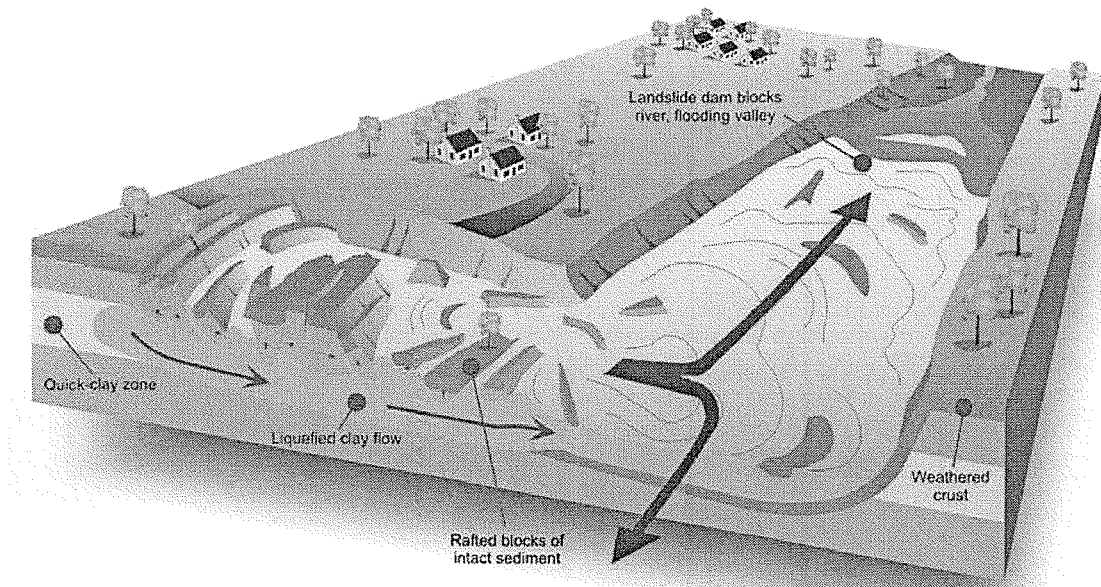


Figure 6. A typical sensitive clay landslide, showing a zone of liquified clay and relatively intact capping sediments. Figure from Natural Resources Canada.

FIELD TRIP STOPS

- Start Junction of Highway 417 and Regional Road 7 in Casselman, Ontario. This is exit 66 on Highway 417. Drive north towards Casselman, and turn right on Regional Road 3 (the sign says to Ste. Isadore).
- 5.0 km Turn left at the T-junction onto Regional Road 8.
- 8.0 km (13 km cum) Turn right onto Regional Road 16 just before the bridge. The remains of the village (cemetery) are 400 m ahead on the left. Park at the monument in front of the cemetery.

STOP 1. The Lemieux Townsite

The small village of Lemieux (28 homes, 50 km east of Ottawa) was a predominantly French-speaking farming community started in the 1850's as a mill town to service the local lumber industry. The Roman Catholic church was the focal point of the small community that became known as La Paroisse Saint Joseph de Lemieux. The villagers had always known about the local landslides, as a significant failure occurred nearby in 1895 and there are numerous older landslide scars in the area.

Engineering studies were conducted in the area following the large landslide on the South Nation River in 1971 (Eden *et al.*, 1971) (Figure 7). In 1989, the South Nation Conservation Authority (SNCA) engineers discovered that soil conditions underlying the community were unstable. Mindful of the landslide that had killed 33 people under similar conditions in Notre-Dame-de-la-Salette, and the loss of 31 lives in 1971 at St. Jean Vianny, Quebec, government authorities decided that the community of Lemieux would have to be abandoned. Homes were purchased by the SNCA as part of a landslide mitigation program.

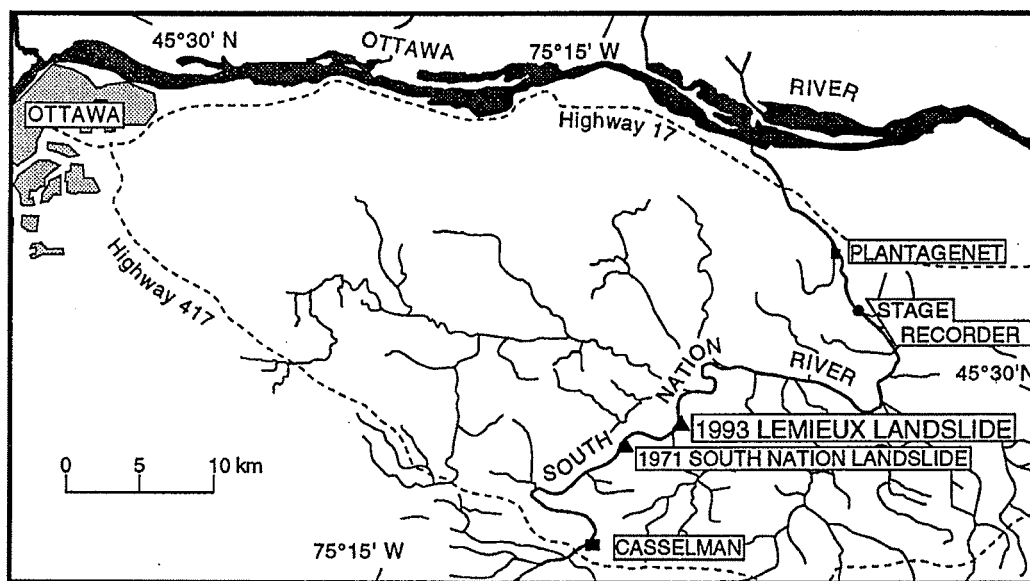


Figure 7. Recent landslides in the South Nation River valley. Figure from Evans and Brooks, 1994.

Some homes were moved and others were bulldozed. All that remains of the community is the cemetery and a plaque reading

“...The village was located over an area of sensitive clay soils, known as the Champlain Sea clays or Leda clays. These soils are unique to eastern Ontario and western Quebec and exhibit the characteristic that, when disturbed, they can liquefy. River banks and slopes composed of Leda clay, when left unprotected, have a tendency to fail and can cause large and small scale landslides.

After consultation with residents, the South Nation Conservation Authority, in conjunction with the Ministry of Natural Resources and the Township of South Plantagenet, purchased the residences in 1989 to eliminate the possible threat to life and property. Some houses were relocated while others were destroyed. With the closing of the church, the parish of Lemieux ceased to exist on August 4, 1991.”

Several homesites are still easily seen as small clearings in the forest with obviously recent vegetation, and several sections of driveway tarmac.

Continue along Regional Road 16 for 2.85 km, turning left along a small access lane (very sharp turn doubling back on itself...see also Figure 9). This small lane leads to the landslide headwall about 200 m off the main road. The lane is passable except following severe rains.

STOP 2. The Lemieux Landslide

Late on the afternoon of June 20, 1993, a 17 ha area of sensitive marine silt and clay close to the Lemieux townsite failed with flow proceeding rapidly into the South Nation River (Figure 8). The first eyewitnesses noted a water displacement of up to 2 m high moving along the river both up- and downstream. Trees and spoil accumulation were soon noted at the bridge crossing Regional Road 8. It took over half an hour for the retrogressive failure to reach and sever Regional Road 16, with portions of the road surface being rafted up to 200 m down into the crater. One motorist on Regional Road 16 ended up in the crater, and was rescued by a Canadian Forces helicopter. In all, Brooks *et al.* (1994) estimate that the entire failure event probably lasted less than one hour. The debris from the landslide eventually buried 3.3 km of valley bottom and caused flooding 18 km upstream. Costs relating to the failure event have been estimated at \$12.5 million Canadian dollars.

Figure 9 shows the extent of the failure area. The bowl of the landslide is about 10-12 m below the unfailed sediments. The failure retrogressed between 680 m from the river (Evans and Brooks, 1994), and involved between 2.5 and 3.5 million m³ of sediment. Evans and Brooks (1994) suggest that the failure was constrained at the margins by gullies (Figure 9).



Figure 8. The Lemieux landslide several days after failure. Note the large intact rafted sections, and the severing of Regional Road 16. Some of the rafted blocks show rotation while the bedding in other blocks remains horizontal suggestive of lateral translation. The blocked South Nation River, flowing from right to left, is at the bottom of the picture. Photograph from the Geological Survey of Canada.

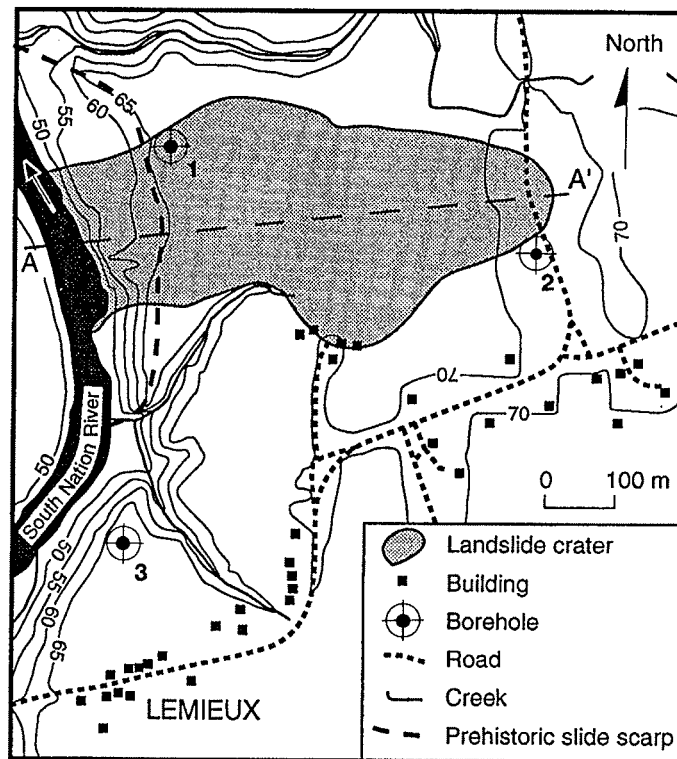


Figure 9. Map showing the extent of the Lemieux landslide, including the area affected during a prehistoric failure event. From Evans and Brooks, 1994.

Three boreholes had been drilled in 1986 and 1987 as a part of the geotechnical investigation. Three coarse units are delineated from these boreholes by Evans and Brooks (1994) (Figure 10; Table 1). An upper cap of loose brown silty sand forms the upper 3-7 m. The middle unit is composed of laminated interbedded silts and sands ranging in thickness from 5 to 10 m and depth below the pre-failure surface of 3 to 17 m. These are the sediments that make up the majority of the blocks and sharp crests in the landslide crater. One of the boreholes indicated that the strength of this unit decreased with depth.

The lowest unit is composed of marine clay below about 8 to 17 m depth (Figure 10). During drilling the auger rods of the drill descended into the hole under their own weight (Evans and Brooks, 1994); a testament to the low strength inherent in this layer. Below 19 m the liquidity index (a measure of the sensitivity to remolding and failure, with values greater than 1.0 indicating extreme sensitivity) is measured to be up to 1.6, and shear strength testing also indicate low strengths when remoulded (Figure 10; Table 1). This lower layer of soft marine clay is thought to be the failure plane that caused the failure owing to liquefaction, with the overlying sediments remaining somewhat intact but transported into the crater (Evans and Brooks, 1994).

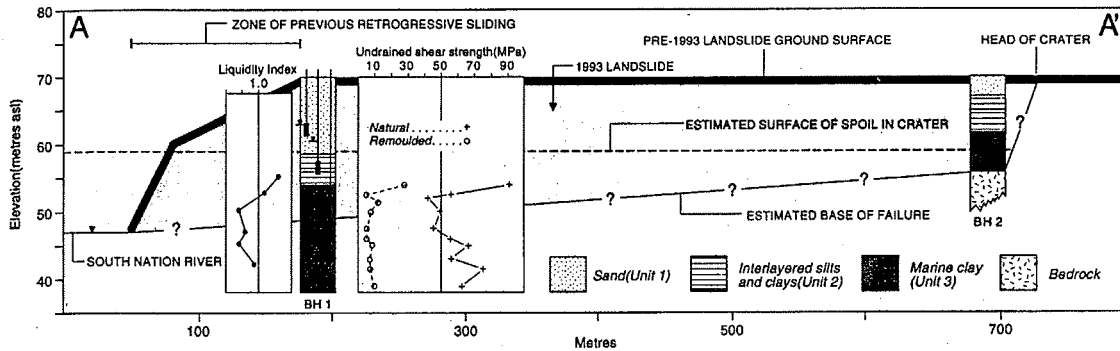


Figure 10. An approximate cross section of the Lemieux landslide based upon drilling conducted in 1986 and 1987. Failure occurred in the upper marine clay sediments with high indices of liquidity and low remoulded undrained shear strengths. Figure from Evans and Brooks, 1994.

Unit	Lithology	Depth range (m)	Index properties				Undrained strength C_u (MPa) ^a		
			W_p (%)	W_L (%)	W (%)	I_L	Natural	Remoulded	Sensitivity
1	Silty fine sand	0-7	—	—	—	—	—	—	—
2	Interlayered silty clay	3-17	25	52.5	36.7	0.4	68.7-91.7	23.8-28	2.19-3.18
3	Silty clay	8-32	19.9-27.8	31.4-56.2	36.4-59	0.8-1.6	41.7-76.7	3.7-10.9	4.3-11.4

^aField vane tests.

Table 1. Summary of geotechnical data for boreholes near the Lemieux landslide. From Evans and Brooks, 1994.

There was no obvious trigger for the landslide (Evans and Brooks, 1994), although an elevated water table appears to have been an important factor (Aylsworth *et al.*, 1997). The first 6 months of 1993 were the wettest on record for the first half of the year since 1947 (Brooks *et al.*, 1994). The region had above average snowfall, a rapid spring melt and heavy spring rainfall, resulting in a water table that was at or near the ground surface in many areas. Ongoing erosion from the South Nation River played an important role in providing an initial scarp for failure along its banks.

The field trip vans park along a road that represents the original path of Regional Road 16. From here the headwall and landslide crater are easily visible. Failure of the landslide occurred in blocks, and intact tilted blocks of the original stiffer surface cap are visible. Several trees survived the rafting into the crater and have continued to grow on the ridge and furrow topography. It is unclear why the landslide terminated at this point, although the bedrock rise noted towards the headwall (Figure 10) may have contributed to stabilization. Sections of the headwall have been regraded and flattened to prevent further retrogressive retreat.

In walking through the bowl eleven years after the event, it is obvious that previously sharp-edged blocks and topography have been muted through ongoing erosion (Figure 11). Several of the ridges contain trees that survived the rafting event, while the general vegetation is of more recent succession. Several sections of impounded drainage contain cattails.

The failure occurred at depths of greater than 10 m (Evans and Brooks, 1994), so the majority of the surficial material in the failure bowl is reworked sand that provided the stiff cap sediments. Transported Leda clay is not noticed until the banks of the South Nation River are reached (Figure 12). Tilted rhythmic bedding is noticed on both banks of the river. Groundwater piping at the edge of the crater, noted shortly after failure (Aylsworth *et al.*, 1997), is no longer visible. The river has entrenched 5-6 m into the spoil pile and river flow has essentially been restored (Aylsworth *et al.*, 1997), with striated limestone bedrock exposed to the north of the failure.



Figure 11. The Lemieux landslide crater in 2004, 11 years after the failure. Total crater depth is approximately 10-12 m. Notice the muting of the previously sharp-edged blocks of cap material. Revegetation of the crater is also well underway.



Figure 12. Rhythmic bedding of silt and clay on the banks of the South Nation River.

Retrace your steps back to Regional Road 8, and turn right (north) towards the bridge. Park on the north side of the bridge. Walk onto the bridge for a view of the Lemieux landslide debris in the river valley.

Stop 3. The South Nation Bridge.

Landslide spoil up to 12 m deep is visible at this site upstream of the landslide (Aylesworth *et al.*, 1997). The debris at this location consisted of the liquefied clay and silt, intact silt and sand blocks, and rafts of sod with some intact trees (Evans and Brooks, 1994). Several of the trees hit the bridge, although no damage was reported. Fishermen near the bridge report running for their lives to avoid an “8ft. high wall of water” (Ottawa Citizen, June 21, 1993 reported in Evans and Brooks, 1994). The landslide dam was overtopped by the South Nation River late on June 22, two days after the failure, with a strong current flowing over the debris by June 23. Incision into the spoil pile has been ongoing since then, with bedrock reached in several areas.

A Water Survey of Canada hydrographic station at Plantagenet Springs, 28.4 km downstream, recorded the abrupt increase in water level in response to the displacement wave (Figure 13), followed by a dramatic drop in stage as upstream flow was disrupted by the dam at the failure site.

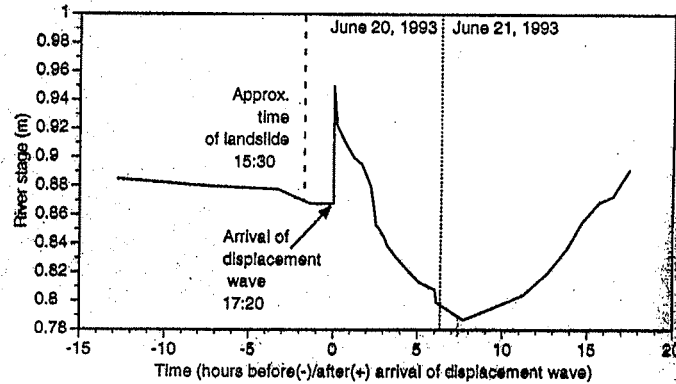


Figure 13. Hydrograph from the South Nation River at Plantagenet Springs, 28 km downstream from the landslide. The displacement wave arrived at the site just over an hour after the landslide. Impoundment of the river caused a drop in water level. Recovery of water levels starting 8 hours after the displacement wave was caused by rainfall in the basin. From Evans and Brooks (1994) with data from Environment Canada.

Recross the bridge and drive south on Regional Road 8 for 1.0 km. On the right (west) side of the road just past a dairy farm is the headwall of the 1895 landslide.

Stop 4. The 1895 Landslide.

This brief stop is at the headwall of the 1895 landslide (Figure 14) that covered 24.4 ha and retrogressed a total of 600 m from the South Nation River. Notice that the landslide scar is now well vegetated and is used by the owner as a pasture.



Figure 14. The headwall scar of the 1895 landslide.

From the 1895 landslide scar, retrace your steps to Casselman and get onto Highway 417 westbound towards Ottawa. Exit the Highway at Anderson Road (exit 104), 38 km west of Casselman. Take Anderson Road north to Ridge Road, and turn right. Four km along Ridge Road is a parking lot for the Mer Bleue nature trail. Park in this lot and follow the nature trail signs.

SECTION 2. MER BLEUE BOG

Mer Bleue Bog is a Provincial Conservation Area in the eastern portion of the National Capital Region, and less than 10 km from the city of Ottawa. The bog covers approximately 3500 hectares (Figure 15), and has formed in an abandoned channel of the Ottawa River. The western section of the bog has three distinct arms, separated by sand ridges that were formed by the anastomosing river channel.



Figure 15. A satellite image of Mer Bleue surrounded by farmland. Sand ridges formed by the paleo Ottawa River produce a digitate nature to the western portion of the wetland.

The majority of the central portions (Figure 16) of the bog are composed of a raised carpet of *Sphagnum* mosses, representing an ecological community usually found further north in the boreal forest of Canada. Other vegetation dominating the raised central portions includes Labrador tea (*Ledum groenlandicum*), bog laurel (*Kalmia polifolia*), Leatherleaf (*Chamaedaphne calyculata*), and various sedges. The majority of trees in the central portions are tamarack (*Larix laricina*), with some black spruce (*Picea mariana*) in more acidic areas. The dominance of *Sphagnum* species and a lack of contact with mineralized groundwater leads to acidic conditions within the bog.



Figure 16. The raised, central portion of Mer Bleue.

Raised bogs such as Mer Bleue obtain all of their nutrients through rainwater, and are termed ombrotrophic peatlands. Drainage from the raised portions flows laterally to the marginal channels. These channels, or lagg areas, provide the slow continual lateral drainage for the central portions of the peatland. Marginal areas of the bog are actually marsh (Figure 17), composed of open water lagg and vegetated primarily by cattails (*Typha sp.*), *Salix sp.*, and various sedges. Drainage of the wetland downwards is impeded by the presence of fine-grained material, including Leda clay. Lagg areas generally have greater contact with mineralized groundwater and their less acidic waters are able to support more luxurious vegetation.

Peat deposits in Mer Bleue are up to 6 m thick, but are most commonly about 3 m in thickness, and are underlain by up to 40 m of Champlain Sea sediments (Fraser et al., 2001). This peatland has been forming for approximately 8,500 years. The ecosystem here is unique as the vegetation assemblages are more typical of northern boreal forest, found over 1000 km to the north.



Figure 17. The marginal areas of Mer Bleue act as drainage for the central portions, and are dominated by open water and marsh vegetation, predominantly cattails.

The return to Potsdam, New York can be conducted by retracing your steps to Casselman and crossing the border at Cornwall. Alternatively continue west along Highway 417 through Ottawa to Highway 416 south. This route crosses the border at Ogdensburg, from which you can take Route 68 south to Canton and Route 11 east to Potsdam.

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Trip A-4

WORKING ACROSS THE DISCIPLINES: BIOLOGY, ART, AND GEOLOGY MEET AT THE ADIRONDACK HIGHLAND-LOWLAND BOUNDARY

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The purpose of this field trip is to explore the kinds of interactions the biologist, artist, and geologist can bring to bear on a location geologists might tend to think of as “their own.” We have selected Stone Valley in Colton New York as a place where an interdisciplinary approach to the locality is particularly fruitful. Too often, the geologist’s eye is so fixed on the bedrock or the geomorphology of an area that he or she scarcely notices the animals and plants of the area. Although we all probably recognize the importance of being able to sketch the landscape, geological, and biological features of places as a way of recording what we see, we rarely sit down really to devote full attention to recording in sketches the esthetic dimensions of field sites. Drawing is also a fantastic tool for seeing. The act of drawing forces us to look more carefully at the scene we are observing.

NOTE: PLEASE BRING A DRAWING PAD OR NOTEBOOK AND DRAWING PENCILS. YOU MAY WANT TO BRING ALONG A FEW COLORED PENCILS AS WELL.

THE LOCATION

Stone Valley is located along the Raquette River, north of the village of Colton, NY. The area is in the center of the Colton 7.5-minute. The instructions below indicate how to reach the meeting point for this field trip:

- 0 SUNY Potsdam Main Entrance along Route 56S (also known as Pierrepont Avenue). Drive south on Route 56S.
- 2.6 Note gravel pits to the left (east) filled in with water.
- 3.8 Note bridge over Raquette River with a Dam to the right (village of Hannawa Falls). For those interested, there is a newly laid foot trail to an old Potsdam Sandstone quarry. If you take a right directly after this bridge and park near the new sign there is a nice walk along river which ends at the quarry.
- 8.4 Adirondack Highland granitic gneiss crops out on the right (west) below the school.
- 8.5 Turn left onto Main Street in the village of Colton). Note the Hepburn Library on the right after you turn; it is made of blocks of Precambrian Gneiss. On the left, across the road from this is the Episcopal church, made of Potsdam Sandstone.
Meet Bill, Lucretia, and Bill, the trip leaders, on Main Street at these buildings. We will then lead you on to the first stop.

We will walk down Stone Valley on either the west or east bank of the Raquette River, depending on conditions. This guide describes the trail along the west bank, but outcrop descriptions apply to both trails. Before going down the trail, however, we will begin by doing some sketching to limber up our artistic muscles. We will lead you to a suitably picturesque location for beginning a first sketch.

SKETCHING AS A MEANS OF SEEING: NOTES FROM LUCRETIA

Drawing is training your eyes to really *see* a landscape or object, and to observe the relationship of one item to another. To begin with I use a 5.5 inch by 8.5 inch Strathmore 100-sheet sketchbook. In the comb binding I put a pilot-brand precise extra-fine pen. I keep the sketchbook shut with a rubber band. It fits neatly in my pocket. If you want to be fancy you can add some colored pencils to your pocket.

Starting:

Why did you look at this landscape or rock in the first place? Pick an image that interests you. If we are beside a stream, a good place to start would be the “horizon” of that stream. Your pen should “walk” slowly along the edge of the stream. The next line would be rocks or ripples” *connected* to the first line. Do not make scratch marks all over the paper, but build upon that first line.

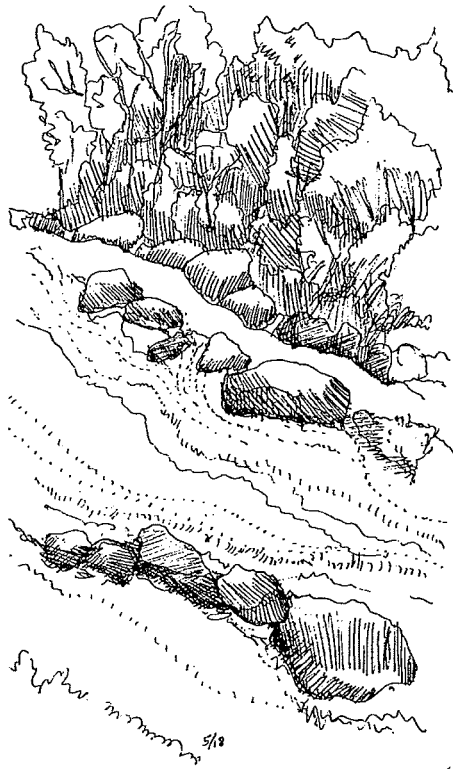
A tree limb has two sides. Draw the first. Then add the second. For a tree in full leaf, draw an outline of the foliage. Then later you can add some cross-hatching to indicate the darker, denser areas.

Remember that you are creating an image and not taking a photograph. This is *your* picture. Since you cannot draw everything in a landscape you will have to choose the part that is most important to you and build on that. A rock in the middle of the stream probably has other rocks *behind* it. Of these second and other rocks, you will probably see only parts of them. You will see only part of the more distant objects, as well.

In a landscape, the closer mountain or other feature would be drawn first and more distant landforms would be added later. In a stream, if you see a fish, think, “What makes it a ‘fish shape’?” Draw the barest outline and later you could add fins, mouth, etc. A bird settles on the sand. How could you indicate it is a bird and not a boulder? Well, it probably has a tail and a beak. Rocks usually do not. If it rains, the water will speckle the ink lines on the paper, and you will always know when looking at the drawing that it rained that day.

After Lucretia does a 10-minute demonstration of some sketching techniques, we will all spend some time together doing some initial sketching. Lucretia will circulate among the group to provide help as needed, and Bill, Lucretia, and Bill will lead a discussion of some of the biological and geological aspects we and you see in them.

Later, when we head down into Stone Valley, we encourage you to sit down and do some more sketching on your own. When we return to the cars at the end of the trip, Lucretia will be waiting to discuss your sketches with you, and we can all share our ideas about them and the connections we’ve found among the geological, biological, and esthetic aspects of the excursion.



Two sketches
Lucretia did in Stone Valley last spring.

EXPLORING STONE VALLEY

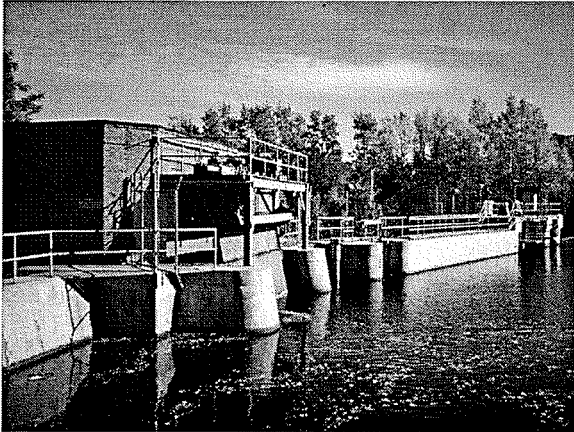
The Raquette River flows north from the Adirondack Highlands from Tupper Lake. It is the most dammed river in the Adirondacks, with 8 major dams. South of Colton it flows through Potsdam, Norwood, Norfolk, and passes just south of Massena before flowing into the St. Lawrence River at St. Regis Village. The reservoir behind the dam at Colton extends some 6 km south to the next dam up the line, at South Colton.

The West Side of the Valley

We begin our descent to Stone Valley along the gravel road leading north from the parking lot on River Road. We will first see the power plant at the dam. It is one of several such plants such as the ones at Hannawa Falls and Norfolk. The photos below show the dam at Colton (left) and the penstock that leads water from the Colton reservoir 5 km south to the power plant just south of Brown's Bridge. This generating plant produces 30 megawatts of power and is one of 8 generation stations on the upper Raquette River that produce a total of approximately 100 megawatts of power (owned by Reliant Energy).

Cross over the penstock via a small brown-painted metal foot-bridge onto the main path which then follows the river downstream past some spectacular falls. A short distance down the trail is the stone foundation of a tanner's mill. During the expansion to the western states, bison pelts were shipped east by rail and tanned wherever tanners could find the raw materials for the tannin, such as in the Adirondacks. Huge piles of bison fur accumulated outside tanneries such as this and remain today (hair is not easily degraded by microorganisms). Right past the foundation there is a 15 foot section of trail

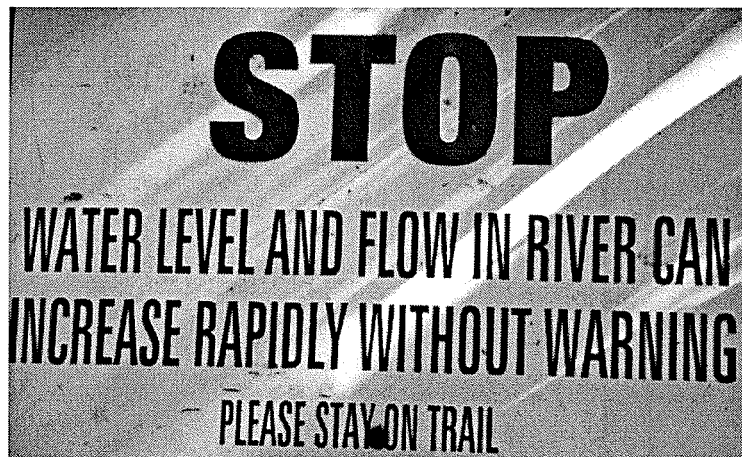
where the “buffalo fur mountain” can be seen underfoot. The ground sounds hollow here when you stamp on it. A look at the ground reveals clumps of matted buffalo fur that remain here to this day.



The dam and penstock at Colton

The gorge of the Raquette River as it tumbles down Stone Valley from below the dam at Colton is steep, narrow, and scenic. Vast numbers of logs were floated down the north-flowing Adirondack rivers to the St. Lawrence. Many towns were established along the “fall line,” the escarpment where the hard Precambrian rocks of the Adirondacks are in contact with the flat-lying Lower Paleozoic sedimentary rocks of the St. Lawrence Valley. This contact is marked by relatively sharp topographic drops between the harder metamorphic rocks to the south and the flat-lying sediments to the north. The crystalline rocks form steps over which the river tumbles in waterfalls that provided hydropower to operate saws and other equipment. The falls at Colton represent such a place. In these days of extreme sports kayak races are now popular, as daring boatmen test themselves through the roaring falls in times of high water.

A caution: Depending on the water level (which in turn depends on the time of year and the amount of water being released at the dam), various platforms of bedrock can be visited along the river. Signs warn of the possibility of being caught by rapidly rising water levels, but the power company provides no advance warning. The excellent hiking trails along both sides of the river make it possible to examine many of the excellent bedrock exposures.



Once down along Stone Valley we will assemble on one or another set of stream-polished outcrops of rocks of the Carthage-Colton mylonite zone, the boundary zone between the Adirondack Highlands and Northwest Adirondack Lowlands. First we will look around at the gneisses and the general topography and geomorphology of the area, with commentary from Bill D. (“older Bill”). Then we will explore the area for its biological dimensions with Bill L. (“tall Bill”). We invite you to do some sketching so that you will have things to show to Lucretia when we return to the cars and things to discuss on the outcrops as well. Throughout, the group leaders will interact with each other and with the trip participants to consider the connections among the geological, biological, and artistic attractions of the area. What can the geologist, biologist, and artist contribute to each other and take from each other in exploring an area such as Stone Valley? What kinds of new insights can emerge from cross-disciplinary action and an earth-systems approach to an area?

THE BIOLOGICAL SETTING

Local people take favorite short hikes in the beautiful deciduous forest surrounding the falls. The energy companies have worked with the communities to make this land accessible to the public. This is an interesting case of how development has led to “preservation,” or at least continued public access to spectacular river frontage that might otherwise have gone to private owners who could have blocked access. A broad variety of mosses and ferns exist along the river. In the outcrops in the river are pools that come in a variety of sizes. Some of these are the result of glacial scouring while others are potholes formed by the erosive action of pebbles. The photo below shows some pebbles in a pothole.



Like the tide pools in a rocky intertidal zone along the ocean, these pools create mini-ecosystems with algae growing in them that feed crayfish, trapped minnows, and a variety of insects including the larvae of dragonflies, mayflies, and black flies. Other insects such as water striders and riffle bugs colonize the surface of these pools. The exoskeletons shed by some of these insects can be seen along the sides of pools. In early spring these pools are full of frog tadpoles and the larvae of salamanders. It is not clear what species of fish exist in the main channel of the river, though the damming and water fluctuation may severely impact them.

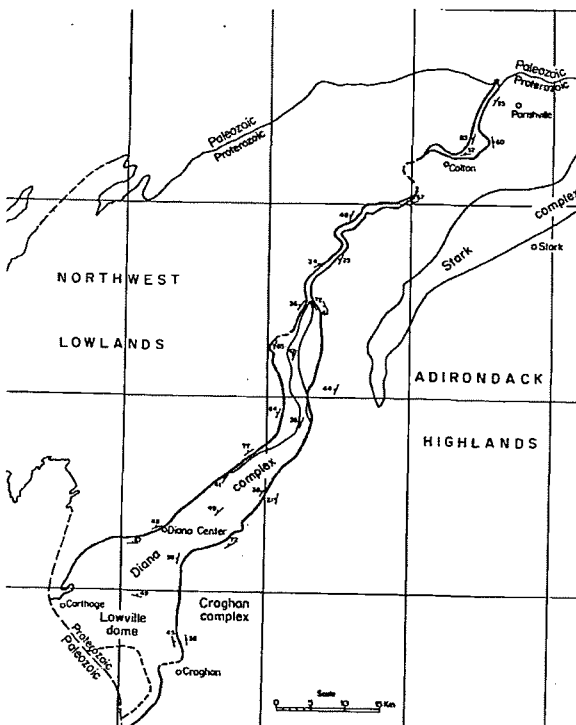
From a biological perspective, the rocks define boundaries such as rock pools where the animals live and they provide the channel leading to high water velocities which limit the types of organisms that live there. The scouring of the bedrock along the edge of the river by the high waters in the spring and the ice in the winter creates a yearly disturbance which makes it difficult for animals to hold a territory or home for long. The main types of animals that can live along and in the river are opportunistic animals that reproduce quickly during the summer.

As a biologist looking at the geology, one could see the physical geology (rock and water) as a starting point to which the animals have adapted over the years (evolution of certain adaptations), as well as the environment that an individual deals with in the short term. The outcrops and naturally

changing water flow provide a harsh environment for most aquatic organisms, but one to which many animals and plants have evolved adaptations. However, the recent changes due to damming and random fluctuations in water level to suit the needs of power generation have probably severely impacted the aquatic life here. As in any system that is dammed (the Grand Canyon and Green River have received much attention recently), there are a variety of impacts to the aquatic organisms. Dams reduce the amount of silt deposited downstream, and cause it to settle upstream. Too much silt blankets organisms; too little reduces the nutrients available. This severely reduces the types of aquatic insects that can live in such a stream, with repercussions up the food chain to the top predators such as fish and birds. Additionally, the constant changing of water levels in a non-seasonal pattern leads to a separation between the aquatic and terrestrial ecosystems. Recent research (summarized in Allan 1997) shows the importance of stream banks to the lives of most aquatic organisms. For example, fish need undercut banks to hide in and to lay eggs and many aquatic invertebrates, especially the herbivorous “shredders”, need the input of leaves and wood from the surrounding forests to eat. Dams lead to the disturbance of these all-important riparian zones.

Power dams also tend to leave the water colder and with less oxygen, which impacts which fish and insects can live in an area. Perhaps more important, but more subtle, is that the water levels in the river below a power dam don't fluctuate in the predictable yearly pattern to which organisms have adapted. Instead, they fluctuate due to consumer demand and market forces. This can lead to problems for developing fish eggs or the development and emergence cues for aquatic insects (Allan, 1997). So, despite the beauty of the area, and its value as a recreation area (swimming, kayaking, hiking), the anthropogenic disturbances caused by the dam have probably led to a decrease in diversity of organisms and perhaps a decrease in abundance of top predators such as fish. Little work has been done on the biological health of this particular area, but one would predict that a more steady release of water that mimics the natural yearly fluctuations would increase the diversity and abundance of organisms in the area.

THE GEOLOGIC SETTING



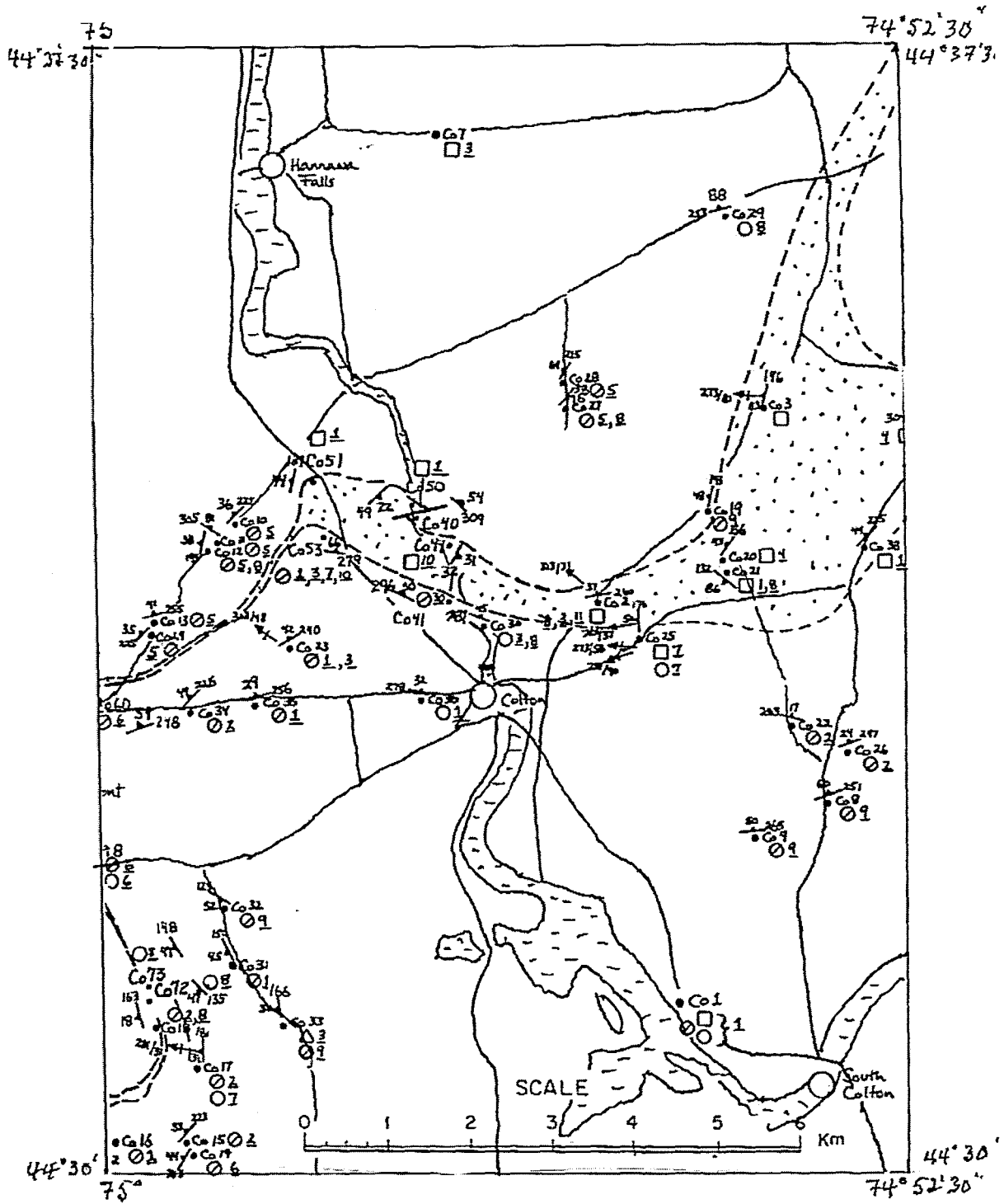
Colton is located near the northeast end of the Carthage-Colton mylonite zone, which separates the high-grade Precambrian (Grenvillian) metamorphic rocks of the Adirondack Highlands to the south and east from the lower grade Precambrian metamorphic rocks underlying the Northwest Adirondack Lowlands to the north and west. This zone begins near Carthage, NY where the Paleozoic sedimentary rocks southwest of Carthage cover the Precambrian rocks of the Adirondack. It extends almost continuously some 110 km northeastward to the point where Paleozoic rocks of the St. Lawrence Lowlands again cover the Adirondack rocks at Allen's Falls, just east of Potsdam. The zone is not exposed over a distance of a few km just southwest of Colton where it is apparently covered by Quaternary materials. This zone of highly deformed, sheared rocks separating the rocks of the Adirondack Highlands from those of the Adirondack Lowlands has been described in detail by Geraghty and others (1981). See their map (above left). This

zone ranges in width from a few feet just southwest of Colton to as much as 5 km in the area between Croghan and Carthage. Quartzo-feldspathic gneiss, rocks of the anorthosite suite, and some clearly metasedimentary rocks (marble, quartzite) form the rugged terrain of the Adirondack Highlands. The northwest Adirondack Lowlands are relatively flat and include more abundant clearly metasedimentary rocks than do the highlands.



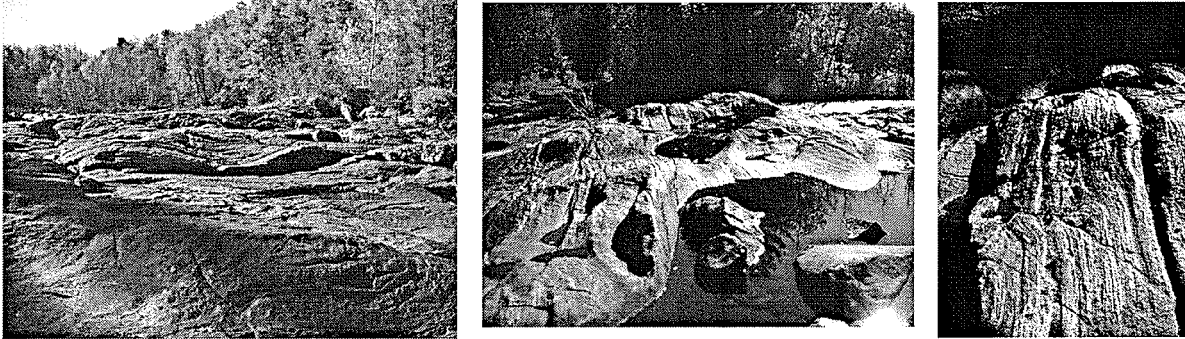
As we descend along Stone Valley, in addition to seeing the dramatic topography and geomorphology of the valley, mentioned above, many fine exposures of Grenvillian Precambrian rocks crop out in the gorge. See photo, left.

The map on the following page, modified slightly from Geraghty and others (1981), shows some details of the geology of the Carthage-Colton-zone rocks in the Colton Quadrangle. The strike and dip symbols show the orientation of foliation in the gneisses, which are mainly quartzo-feldspathic and amphibolitic in Stone Valley. Numbers refer to rock types. See Geraghty and others, 1981, for details. Colton is located in the center of the map, just south of the Carthage-Colton Zone, on the Adirondack Highland side of the mylonite zone. The Colton dam is indicated by the heavy, dark line across the river just north of the circle representing the center of Colton. The outcrops just below the dam are of Highland granitic gneiss. Those in the stippled area are of highly sheared gneiss. Those north of the stippled area belong to the Adirondack Lowland group. South Colton is in the lower right of the map, and Hannawa Falls is in the upper left corner. The mylonite zone is stippled, and the Raquette River is indicated by short dashes.

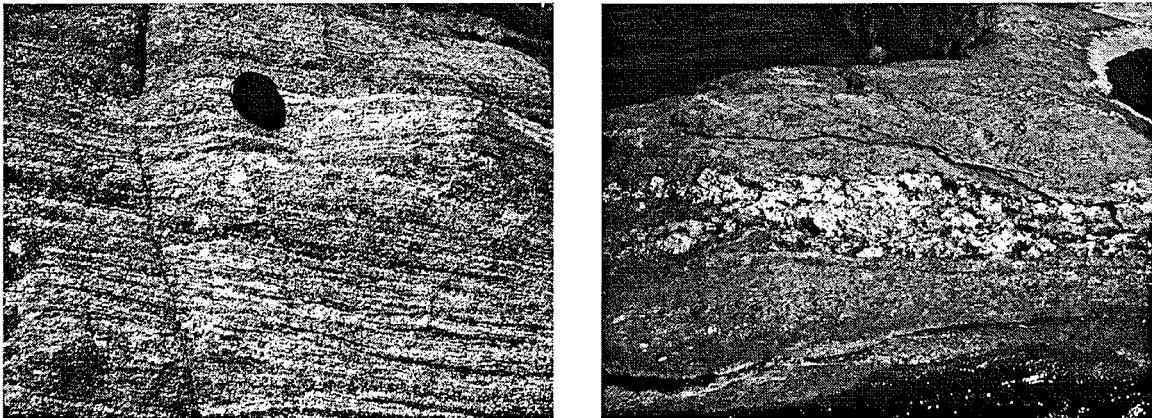


Geology from Geraghty and others (1981), with addition of road network and river.

The outcrops along Stone Valley are of various kinds of quartzo-feldspathic gneiss. They have been sculpted, smoothed, and polished by the glaciers that covered this area during the last glaciation, which ended in this area something over 10,000 years ago. In the photo, below left, the glaciated rocks of the stream bed can be seen to be well foliated as well. Closer views of this metamorphic foliation can be seen in the photos below at the center and at the right.



As shown in the photo at the left, below, a distinct, streaky foliation of alternating layers of quartzo-feldspathic and mafic layers can be seen in many outcrops. Discontinuous layering ranges in thickness from a couple of millimeters to a couple of centimeters. A typical pegmatite dike appears in the photo at the right, below. What significant metamorphic minerals can we find in these outcrops? Garnets



The photo below (left) shows small isoclinal folds in the foliation of streaky quartzo-feldspathic gneiss seen on the rocky platform shown in the photo at the upper right, below. The photo at the lower right shows well-developed foliation in mylonitic gneiss.



Much of the surface area of the outcrops in the stream has been glacially polished, although river action has further eroded the surface. Note many river-formed potholes in addition to glacial grooving. The top surface of the rocks retains polish in some areas. In others, it has been eroded off. A thin, partially exfoliated surface can be seen on many outcrops.

Acknowledgements: Thanks to Lou-Anne Conroy for sharing her ideas and masters thesis on the effects of dams on macroinvertebrates. Thanks also to Robert Badger for organizing this volume.

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Trip A-5

THE NATURE AND TECTONIC SIGNIFICANCE OF THE CARTHAGE COLTON SHEAR ZONE: ADIRONDACK MOUNTAINS, NEW YORK STATE.

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ABSTRACT

This trip will examine the nature and geologic significance of the Carthage-Colton Shear Zone (CCSZ) and late to post-Ottawan intrusive activity along this zone. The CCSZ marks the boundary between the Central Metasedimentary Belt and the Central Granulite Terrane (Frontenac-Adirondack Belt). The significance of this shear zone and the bounding terranes has been a matter of continued debate. This trip will analyze field, geothermometric, and geochronologic relationships along several transects across the CCSZ with the goal of better elucidating the nature and timing of this complex and enigmatic structure.

INTRODUCTION

Grenville-aged rocks to the south and east of the Grenville Front Tectonic Zone (GFTZ) are subdivided into a number of terranes with differing tectonothermal histories that are separated from one another by shear zones (Davidson, 1986; Rivers et al., 1989; see figure 1). Using the terminology of Wynne-Edwards (1972) and Davidson (1986; 1998), from west to east these terranes are the Central Granulite Belt (CGB), the Central Metasedimentary Belt (CMB) consisting of the Bancroft, Elzevir, Mazinaw, Frontenac and Adirondack Lowlands Terranes and the Adirondack Highlands which belongs to the Central Granulite Terrane (CGT) (see figure 1). Conversely, Carr et al (2000) breaks the NE Canadian/US Grenville Province into three belts: the pre-Grenvillian Laurentian margin, The Composite Arc Terrane, and the Frontenac-Adirondack Belt. For the purpose of this discussion, we will utilize the Wynne-Edwards (1972)/ Davidson (1998) terminology.

Ductile shear zones ranging from greenschist through granulite grade separate the various terranes and are the critical link to understanding the overall tectonic development of this region. On this trip we will examine the nature and timing of activity along the Carthage-Colton Shear Zone which separates rocks belonging to the Central Granulite Terrane (CGT: Adirondack Highlands) and the Central Metasedimentary Belt Terrane (CMB: Adirondack Lowlands).

Geologic/tectonic relationships between the CMB and CGT and the role of the CCSZ have been a matter of some debate. Geraghty et al. (1981) and Isachsen and Geraghty (1986) interpret the CCSZ to represent a through-crustal shear zone along which the CMB terrane was thrust over the CGT terrane during the 1.1 billion year old Grenville Orogeny. Wiener (1983) interprets the CCSZ to represent the lower limb of a large fold-thrust nappe and does not view the CCSZ as a boundary between separate (or once separate) terranes. Isotope data (U/Pb; $^{40}\text{Ar}/^{39}\text{Ar}$), however, support the assertion that the CCSZ does indeed separate two terranes with differing thermal histories (McLelland, et al. 1993a; Mezger et al. 1991; Mezger et al., 1993). Isotopic evidence clearly show the Adirondack Highlands Terrane (CGT) reached granulite facies conditions during the 1030-1070 Ma Ottawan Orogeny (McLelland and Chiarenzelli, 1990) while isotopic data

from the Adirondack Lowlands Terrane suggest that maximum temperatures in never exceeded 400°C at this time (Mezger et. al, 1993; McLelland et al. 1993a). Both terranes, however, contain 1155 Ma AMCG suite magmas leading to an unusual history in which the CGT and CMB are together prior to and during the ~1155 Ma event, separate during the 1050-1070 Ma Ottawan

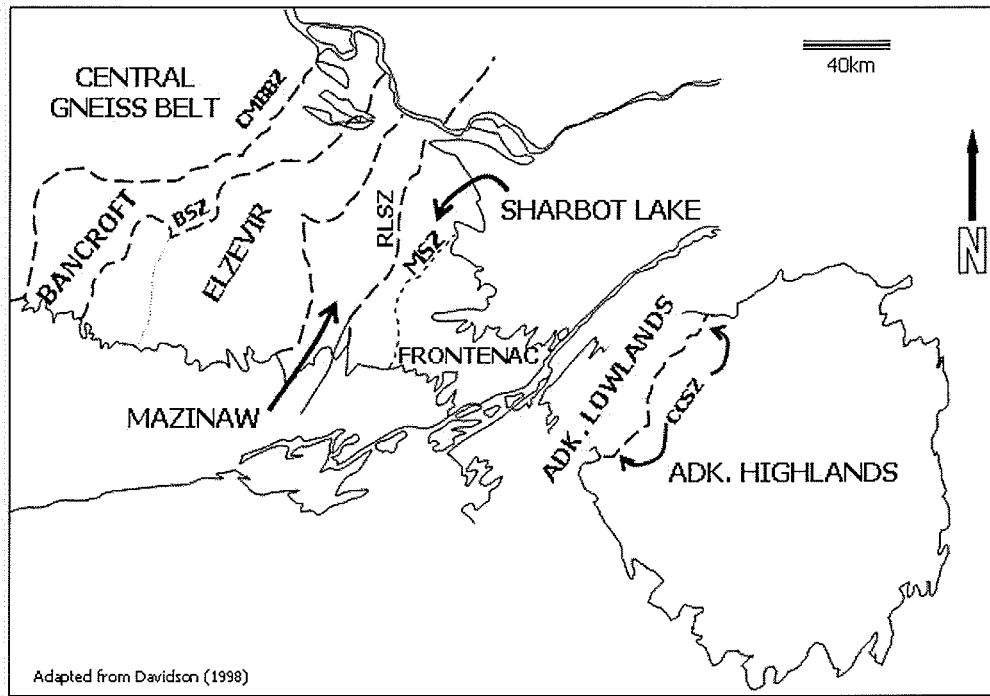


FIGURE 1 Map of the Grenville Province showing the various terranes and their bounding shear zones. CCSZ=Carthage Colton Shear Zone; RLSZ=Robertson Lake Shear Zone; MSZ = Mazinaw Shear Zone; BSZ=Bancroft Shear Zone; CMBBTZ = Central Metasedimentary Belt Boundary Zone.

event and then reunited at some later time. Mezger et al. (1992) identify the CCSZ as a major crustal collapse structure that juxtapose the CMB and CGT rocks syn- to-post-Ottawan Orogeny. Mezger et.al. (1992) propose that the CMB and CGT terranes where separated by the opening of a small ocean basin (post 1150Ma) allowing these two terranes to follow different P-T-t paths during the Ottawan Orogeny. An alternative view is that the CMB and CGT rocks were united since the 1160 Ma event but that the CMB rocks during the Ottawan Orogeny were at too high of a structural level in the crust to undergo significant thermal heating. In this model, late to syn-Ottawan collapse along the CCSZ juxtapose the two terranes at their current structural level (Mezger et al., 1992; McLelland et al. 1993b). Zones of ductile deformation in the Diana Complex, a CMB lithology, record retrograde conditions of 400-550°C at pressures of 3 to 5 kbar which Lamb (1993) attributes to late activity along the CCSZ during slow uplift and cooling. Zhao et al. (1997) and Martignole and Reynolds (1997) report granulite-grade strike-slip movement along the Labelle and Morin Shear Zones in Quebec, Hanmer et. al (2000) report 1.09-1.06Ga oblique sinistral movements along the Tawachiche Shear Zone, and Streepey et al. (2001) and Johnson et al. (2004) report oblique dextral movements along the CCSZ introducing the possibility that lateral displacements may be important during the Ottawan phase of the Grenville Orogeny. In all of these models, the precise role of the CCSZ (and Labelle Shear Zone/Tawachiche Shear Zone) is the critical link to understanding the tectonic relationship(s) between the CMB and CGT.

Excellent exposures of highly-deformed and variably metamorphosed rocks belonging to the CMB, and CGT along the CCSZ form the basis for this field trip and we will cross the CCSZ at several locations in the Harrisville, Fine, South Edwards, and Hermon 7.5 minute quadrangles. Detailed descriptions are presented in the road log. The Carthage Colton Shear Zone is not a simple boundary between adjacent terranes as it has been partially dissected and offset by later (post Ottawan) ductile and brittle events. We will examine several of these on this trip and discuss their relationship to zones of economic mineralization in the region. The overall goal of this field guide is to examine the existing models which attempt to relate the tectonic development of the Adirondack Highlands and Lowlands Terranes and the role of the Carthage Colton Shear Zone in this history.

This trip will focus on the wealth of geochronologic data that has recently been collected in and along the CCSZ. In addition, this guide presents new and previously unpublished U/Pb and $^{39}\text{Ar}/^{40}\text{Ar}$ cooling dates collected across the CCSZ. The complexity of the CCSZ in terms of deformation and mineralization events is well documented and we will focus on differences in deformation extent and style as we cross the CCSZ. These observations and data pose interesting challenges to existing models for the role of the CCSZ and relationships between the Adirondack Highlands and Lowlands Terranes. One major area of controversy is the exact timing of juxtaposition of the Adirondack Highlands and Lowlands Terranes. Critical to this discussion is the nature and timing of widespread metasomatic alteration of rocks in both the Lowlands Terrane (hanging wall) and Highlands Terrane (footwall) near to the CCSZ detachment surface. This event is marked by widespread scapolite replacement of plagioclase feldspars, and the emplacement of hornblende + scapolite and scapolite veins in both the footwall (Highlands) and hanging wall (lowlands) of the CCSZ. This metasomatism is critical to understanding the relationship between the Highlands and Lowlands Terranes during late Ottawan time because it marks a common event for both terranes. In the Dana Hill Metagabbro (Highlands), scapolite growth corresponds with the injection of thousands of hornblende veins into the gabbro which is constrained by U/Pb dating to occur prior to 1020 Ma. In the Diana Syenite Complex (Lowlands), scapolite growth occurs in shear zones dated to 1040-1052 Ma. These data and observations argue that the Adirondack Highlands and Lowlands Terranes were near to a common structural level as early as 1050Ma. At this time, these two terranes would be at very different temperatures requiring a pronounced thermal gradient (100°C) exist across the CCSZ at least until 1000 Ma.

At several locations, we will examine late syn-orogenic granitic intrusions that decorate the footwall (Highlands) along the CCSZ. These granite bodies are variably deformed and belong to the 1050 Ma Lyon Mountain Suite (McLelland et al., 2001). The abundance of these granite bodies near to and along the CCSZ suggests a causal relationship may exist between CCSZ movements and granite emplacement.

A NEW TECTONIC MODEL

Field, isotopic, and petrologic data from the CCSZ are tantalizingly similar to those reported from recent studies of rapidly exhumed granulite cores in the modern day Himalayan Mountains (Wobus et al., 2003). Zeitler et al. (2001) describe these rapidly exhumed granulites (Nanga Parbat) as tectonic aneurisms triggered by orogenic compression coupled with rapid surface denudation. Pronounced (100°C+) thermal gradients exist across the bounding shear

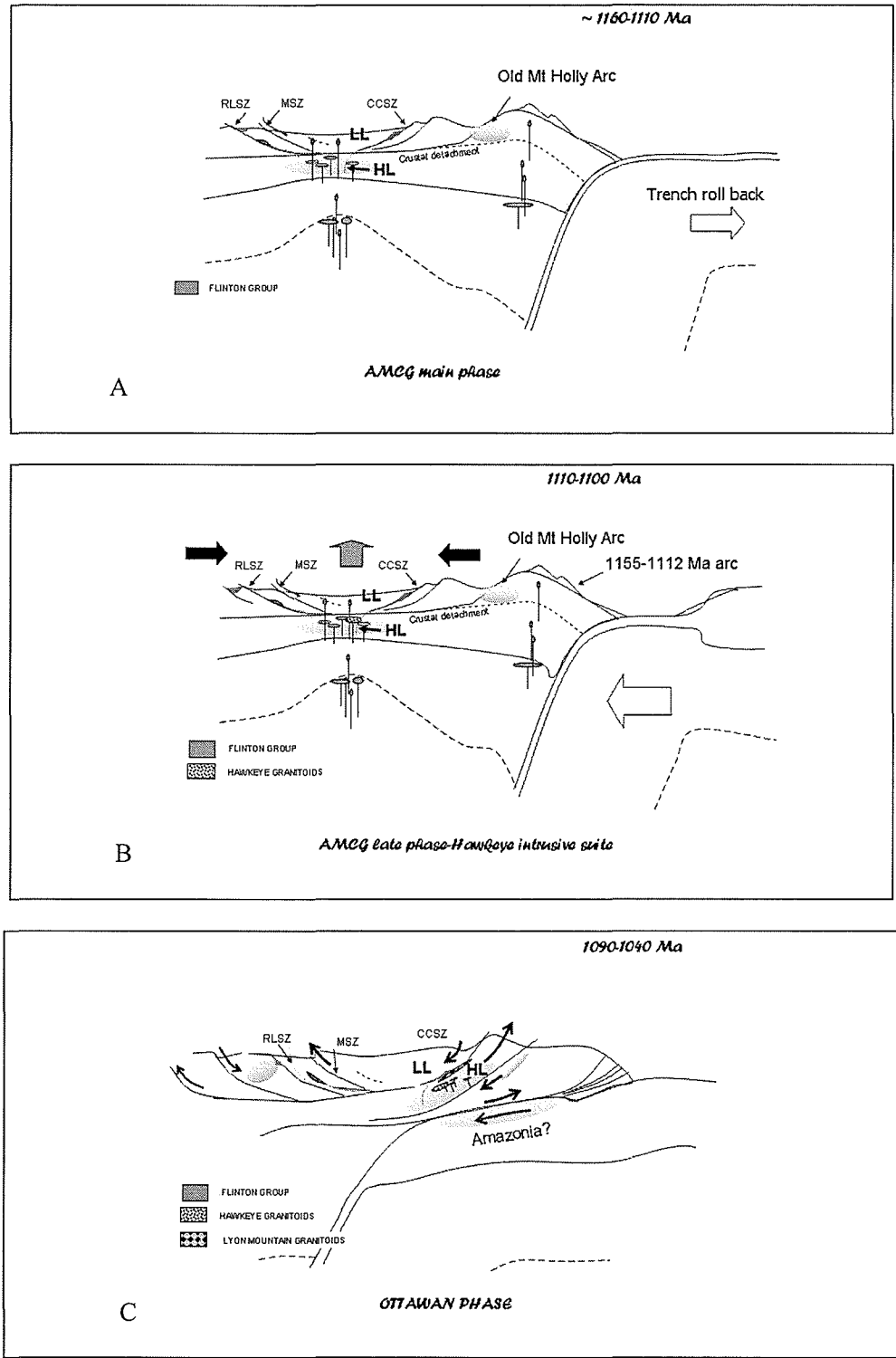


Figure 2. Tectonic cross-sections showing the development of a crustal channel. LL=Adirondack Lowlands Terrane; HL = Adirondack Highlands Terrane. All other abbreviations as in Figure 1.

zones, and the exhuming granulite core undergoes pressure release melting forming A-type granites. These granites intrude along the bounding shear zones (Zietler et al., 2001). Because of

the rapid exhumation, rocks across the bounding shear zones record very different thermal histories. This is a very similar scenario to what we will observe along the CCSZ on this trip and I propose that we may be looking at the top of a crustal channel that developed during peak to post peak Ottawa time. Tectonic cross-sections (figure 2a-c) show the basic elements of how the crustal channel model is applied to the tectonic development of this portion of the Grenville.

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ROAD LOG

Downtown Harrisville: Field trip members assemble at the public parking lot adjacent to the old Scanlon's Bakery.

Travel south on NY route 3 to the intersection of Rt. 3 and Hermitage Road.

3.9 miles

STOP 1 Valentine Wollastonite Mine: Discuss field relationships between the Diana Syenite Body and lowland marbles. Basic goal here is to demonstrate that the Diana Syenite intrudes into lowlands marbles and contact metamorphism drove formation of the Wollastonite.

Note that much of the wollastonite body is at best weakly deformed and so lacks Ottawaan deformation.

Return to the vehicles and travel north on NY route 3

4.6 Miles

STOP 2 Big Crop Diana Syenite: Look at pegmatites and shear zones that cut the body. These shear zones vary to greenschist facies formed during the end of CCSZ deformation.

OPTIONAL

STOP 3 Contact Metamorphism of marble at the Diana Contact (route 813). Once again show a lack of a strong Ottawaan deformation. Note that this type of grain coarsened marble can be found in many locations at or near to Diana Syenite contacts.

9.6 Miles At the north end of the town of Pitcairn turn east on Jayville Road.

STOP 4 Jayville Road: Here we will cross into the Adirondack Highlands for the first time. Variations in the orientation of stretching lineation will mark our passage across the CCSZ. In the Lowlands, stretching lineations are more steeply dipping and oriented to the NW, but once we cross the CCSZ, stretching lineations rotate to near strike parallel orientation (NNW).

13.3 Miles

STOP 4A Fault Zone in Diana Syenite. This zone shows both strong ductile and brittle deformational fabrics. The Diana Syenite Body is vertically stacked by several small thrust faults. (Lowlands)

STOP 4B Contact between Diana Syenite and the Border Granite (Lyon Mountain?) Along RR tracks near Topa-da-Hill Road. Is this the Highlands-Lowlands Boundary?

STOP 4C Long Lake Fault Zone (look up the lake at this major lineament). This structure is a brittle normal fault that offsets the CCSZ detachment (SEE FIGURE 1). We will encounter this fault once again at STOP 10. At this location, the Long Lake Fault vertically truncates the CCSZ detachment.

STOP 4D Road south of Jayville Road (ROD and TODD outcrop); note that while to the North of Jayville Road we have passed into the Granite, but here to the south and east, we are still in the Diana Syenite Body. A small east-west trending (strike-slip?) fault offsets the CCSZ (Highlands-lowlands boundary) at this location. This fault passes directly

through the Jayville Mine (STOP 4E) and continues (at least in topographic expression) to the east passing through the Benson Mine.

STOP 4E Jayville Mine (stop to look for vonsenite ore) Here we can visit the mine shaft and discuss the amphibolite matrix for the vonsenite ($\text{Fe}^{2+}\text{Fe}^{3+}_2\text{BO}_5$) ore and the origin of the boron. Discuss the Lyon Mountain Granite at this local and the presence of felsic quartz-albite facies dikes.. Examine the location of the mine in terms of known brittle and ductile features.

Reset odometer to 0.0 miles Travel NORTH on NY route 3 for 4.5 Miles

STOP 5 Faulting in the Diana Syenite Body. Classic mixture of rock types that characterize the faulted contact between the Diana Syenite Body and lowlands paragneisses including the feldspathic quartzite, marble and diopsidite. Note the strong ductile fabric of these rocks that is overprinted by later brittle faulting.

5.1 miles

STOP 6 Outcrop of diopsidite skarn. Contact skarn between the Diana Syenite Body and the Balmat Edwards (?) marble. This friable green colored rock is primarily made up of green diopside and grey calcite. (mapped as Tia)

6.1 miles

LUNCH Greenwood Falls Picnic Area. Look at the Diana Syenite Body.

8.4 miles

STOP 7 Diopsidite contact rock (Dia/Tia). Note on the map that these diopsidite contact skarns are found in the middle of the Diana Syenite Body and along its eastern edge, at the CCSZ detachment. This unit is associated with the contact between the Diana Syenite and the Balmat Edwards Marble.

9.6 miles

STOP 8 Once we pass the last outcrop of green diopsidite, we have left the Adirondack Lowlands and entered the Adirondack Highlands Terrane. Pink leucogranite and hornblende granite outcrops underpin the ridge. Our stop is near the intersection of Route 3 and Sykes Road. The contact between the Leucogranitic gneiss and the Irish Hill Gneiss is well exposed in this outcrop. The Irish Hill Gneiss (Whippoorwill Corners Gneiss of Hall, 1981) consists of calc-silicate gneiss (containing calcite + diopside +/- tourmaline) and quartzite with abundant concordant and cross-cutting pegmatites.

10.9 miles

STOP 9 Hornblende granite. This stranded small body of granite differs from those that we have seen on Jayville road. Larger exposures of a similar granite can be found to the north in the South Edwards Quadrangle (Eastern Granite Gneiss of Hall 1981). The granite is moderately deformed at this location.

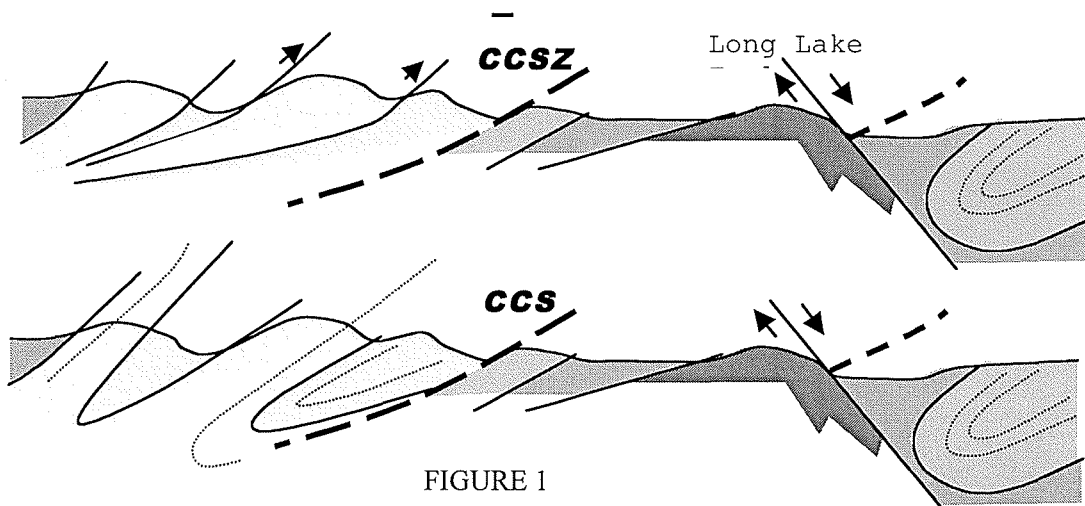


FIGURE 1

11.2 miles

STOP 10 A Faulted Block of the Lowlands: Intersection of NY Routes 58 and 3. Park in the small lot at the intersection of Routes 58 and 3. Directly to the north of the parking lot is a small mine adit. We will start by heading north to the old bridge over the Oswegatchie River. Outcrops to the west (down the slope) are of green Irish Hill Gneiss. The outcrops along the road show a strong brittle deformation and a mixture of rock types. This outcrop contains marble (looks very much like Balmat Edwards Type), bleached syenite-granite, and even some diopsidite. Fluorite crystals have been found in vugs and tension gashes in the marble. This outcrop lies on the trace of the Long Lake Lineament (Fault) and movements on this lineament are the logical cause for the strong brittle overprint observed in these rocks. The intriguing thing about this series of outcrops is that the rock types are more like those of the Lowlands Terrane even though we have crossed the CCSZ and are well into the Highlands at this location. Just 100m west one can find outcrops of Irish Hill Gneiss (Highlands) and to the east (on Route 3) we find pink granite (Highlands Rock) with a strong brittle overprint. This outcrop may represent a block belonging to the Adirondack Lowlands that has been down faulted along the Long Lake Fault (see figure 2).

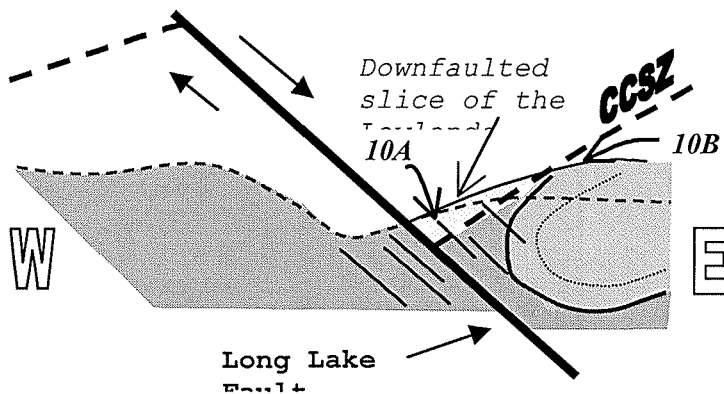


FIGURE 2

STOP 10 B Route 3 Granite gneiss and breccia (Long Lake Fault): Calcite filled breccia in highlands granite gneiss and Irish Hill Gneiss. Both sides of the road.

Return to the vehicles and proceed WEST on Route 58. We will pass several large outcrops of Irish Hill Gneiss and of pink leuco-granitic gneiss. The leuco-granitic gneisses are highly deformed. As we proceed west on Route 58, we will pass through outcrops of hornblende granite gneiss (Eastern Granite Gneiss of Hall, 1981). The Highlands/Lowlands boundary is constrained between the last outcrop of Eastern Mountain Granite Gneiss and the first outcrop of Diana Syenite (which along Route 58, is also a pink granitic gneiss). The Diana Syenite can be identified by the presence of abundant rounded augens of grey plagioclase feldspar.

13.3-13.4 miles

STOP 11 Two large road cuts expose (or nearly expose) the contact between the pink leuco-granitic gneiss and the calc-silicate Irish Hill Gneiss. Here the Irish Hill Gneiss is cut by many coarse pegmatite bodies. Stop 11a: Irish Hill Gneiss. Stop 11b: Leuco-granitic gneiss. We are now nearly due north of STOP 8 (IHG/Lg contact on Route 3).

14.7 miles

STOP 12 Outcrops of strongly deformed leuco-granitic gneiss (Highlands).

16.2 miles

STOP 13 Roadcut into Diana Syenite. The Diana Syenite (granitic phase) shows strong ductile deformation with well developed c/s fabric. Note also the strong brittle overprint as marked by the abundant and closely spaced joints sets. We have once again crossed the Highlands/Lowlands boundary. Here we will look for kinematic indicators.

18.3 miles Turn right onto Harmon Road.

Continue west on Route 58 to the intersection with Harmon Road (to the right). Turn right on Harmon road and continue east until the road crosses the creek. Park the vehicles off to the right at the junction of Harmon Road and Stammerville Road. Proceed to the small outcrops on either side of the roadway.

19.0 miles

STOP14 Shear Zones in the Diana Syenite Complex: The outcrop on the north side of the road show numerous anastomosing shear zones. Sheared Diana contains Hornblende (Cl-rich) + biotite + plagioclase (An) + perthite + quartz + titanite +/- Fe-Ti oxide minerals. Relict clinopyroxene rimmed by amphibole and amphibole + chlorite is common as is scapolite replacement of some plagioclase crystals.

Samples SE-TF-8 and SE TF-11 have been dated by the author using U/Pb titanite and $^{39}\text{Ar}/^{40}\text{Ar}$ for hornblende. The intrusion age for the Diana Syenite Complex has been dated to 1155 +/- 4 Ma (Grant et. al. 1986).

In shear zones, titanite replaces Fe-Ti oxides probably via a reaction involving plagioclase feldspar, and calcic amphibole. Titanite is also found in the syenite outside of these shear zones but it is rare. Away from the shear zones, Fe-Ti oxides are common while they are nearly absent in the shear zones. These observations suggest that sphene growth accompanied recrystallization during shearing, and since the recrystallization conditions during shear zone formation range only to the lower amphibolite facies and probably well below the 600-650°C closure temperature for lead in titanite, U/Pb ages are interpreted to represent growth ages and hence the time of shearing.

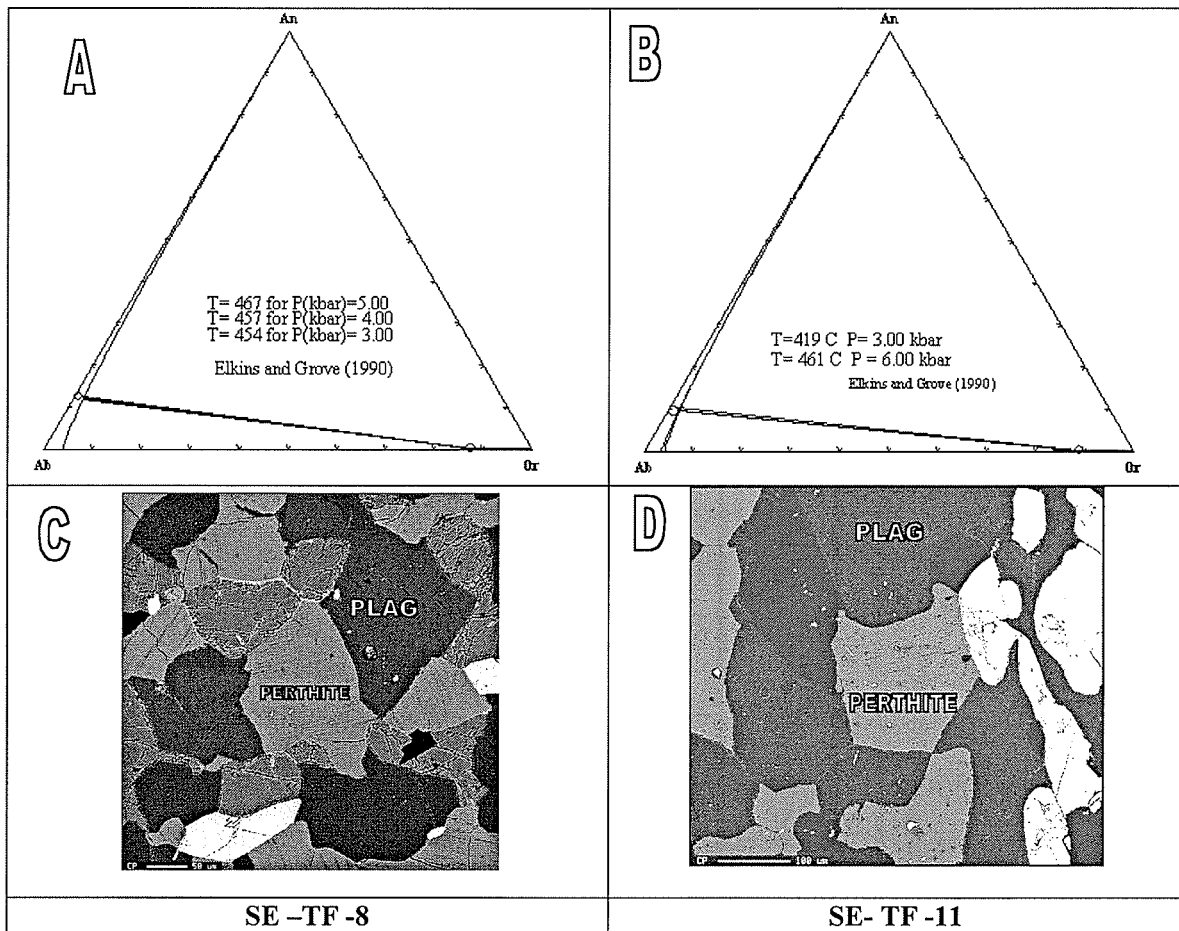
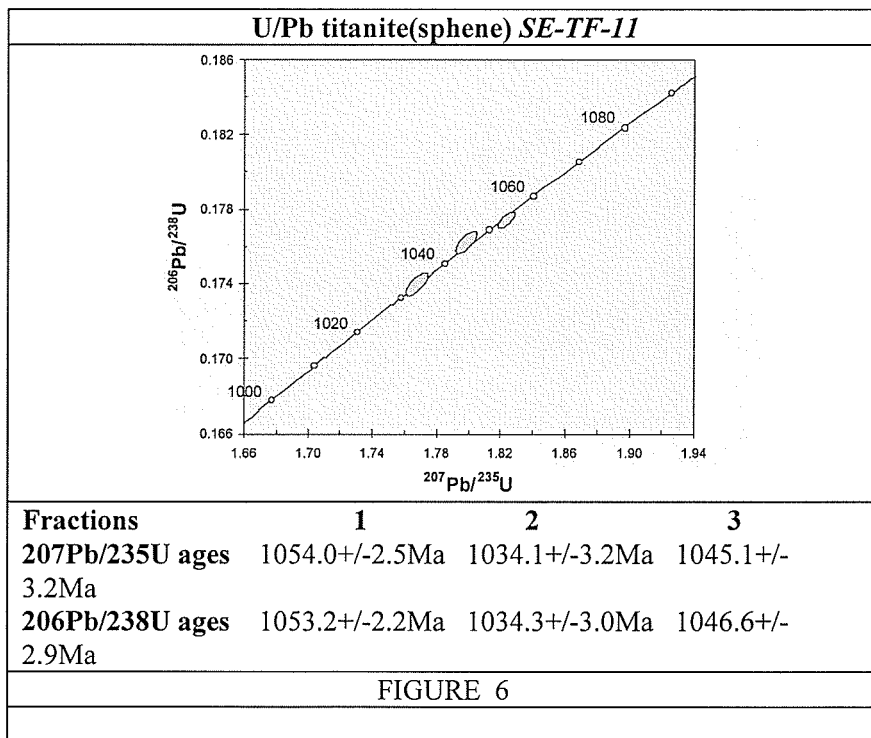
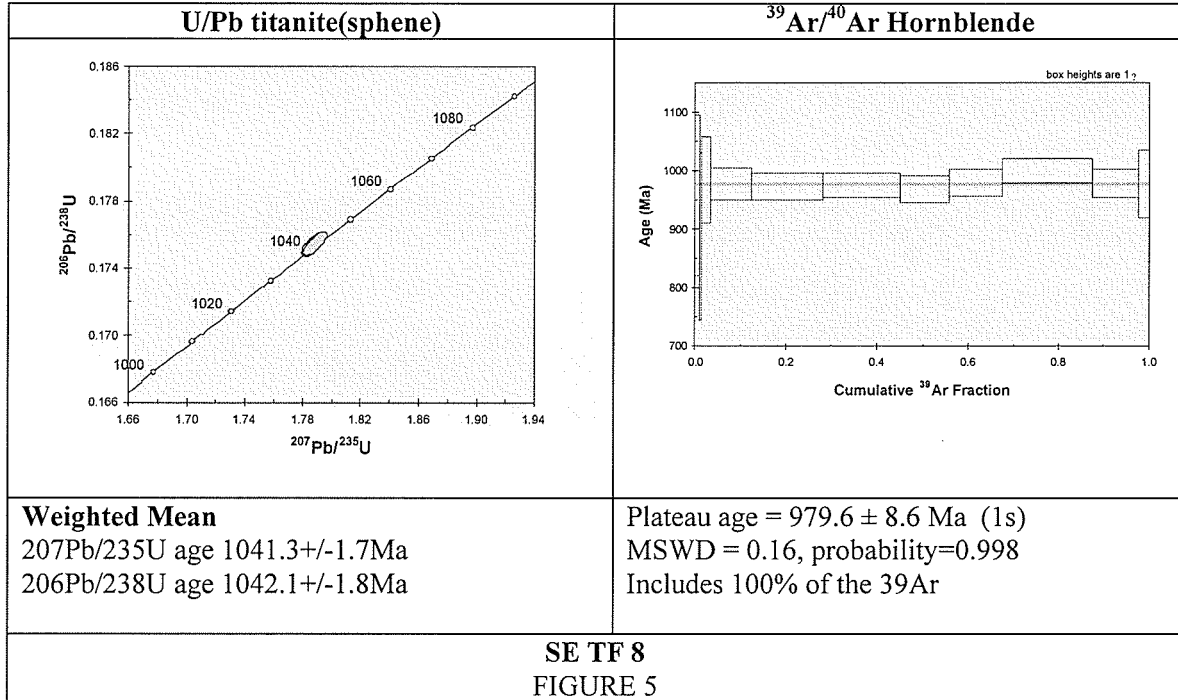


FIGURE 4

Figure 4c and 4d show backscatter electron images of feldspar pairs used for two feldspar geothermometry. Both samples (SE-TF-8 SE TF-11) were collected from the cores of shear zones in these outcrops. Re-integration of the perthite was accomplished using electron microprobe analyses using a 5 micron (SE-TF-8) and 10 micron (SE-TF-11) beam size over an analyses grid. The 150 analyses (grid points) were used to reintegrate the composition for SE-TF-11 and 45 analyses (grid points) were used for SE-TF-8 (note scale differences, figures 4c and 4d). Temperatures were calculated using SOLV CALC and the thermodynamic model of Elkins and Grove (1990). Temperatures calculated for reintegrated feldspar compositions are 454-467°C for sample SE-TF-8 and 419-461°C for sample SE TF 11 (for pressures of 3-6kbar). These results are similar to those reported by Lamb (1993) for shear zones in the Diana Syenite Complex to the south near Harrisville, New York. Two feldspar geothermometry is plagued by resetting and so these temperatures are considered to represent minimums. The presence of biotite and chlorite which is not retrograde to the deformation in these shear zones indicates that shearing took place at upper greenschist to lower amphibolite facies.

The U/Pb age for titanite are concordant and constrain the time of titanite growth during shearing to ~1041 Ma (see figure 5). $^{39}\text{Ar}/^{40}\text{Ar}$ data for amphibole from this sample yield a flat spectrum with a plateau age of 979.8 +/- 8.6 Ma. The closure temperature for hornblende (Ar) is 500-550°C, and these ages are interpreted to represent cooling ages.



Sample SE-TF 11: (Same outcrop as SE-TF-8) Geochronology data for the SETF-11 is shown in figure 6. Three fractions prepared from this sample all yield concordant ages that range

from 1054 to 1034 Ma. These ages are interpreted to represent multiple generations of titanite (sphene) growth in the shear zone.

Return to the vehicles and drive east on Harmon Road. The road turns sharply to the south and ends at a gate. Park in the turn around at the end of the road and walk back up the road (30m) to the outcrops.

STOP 15 Ultramylonite zone in the Diana Complex. The small shear zone exposed here shows extremely sharp strain gradients. The core of this shear zone is ultramylonitic and yet within 2-3 meters, the host Diana Syenite retains some igneous texture. It is interesting to note that strain recorded throughout the Diana Syenite Body is highly variable. The DSC is everywhere deformed ranging from coarse-grained augen gneisses with distinct igneous textures preserved (most common) to ultramylonite. Against this deformational backdrop, the Diana Syenite is cut by sub-meter width shear zones that record low recrystallization temperatures (greenschist-amphibolite facies). In many locations, a strong brittle deformational event is also evident.

Return to Route 58 and continue West

20.6 miles

STOP 16 Famous Green Diopside skarn outcrop. This skarn body marks the contact between the granitic gneiss, which exhibits a strong lineation, and the marble. It is interesting to note that the skarn does not show a deformational overprint.

Continue on Rt. 58 west for 0.1 mile and turn right onto Maple Avenue. Follow Maple Avenue into the town of Edwards. At the intersection in town, turn north on NY Route and follow this route to Dana Hill Road.

21.0 miles

Leucogranitic Gneiss (Lowlands)

26.0 miles

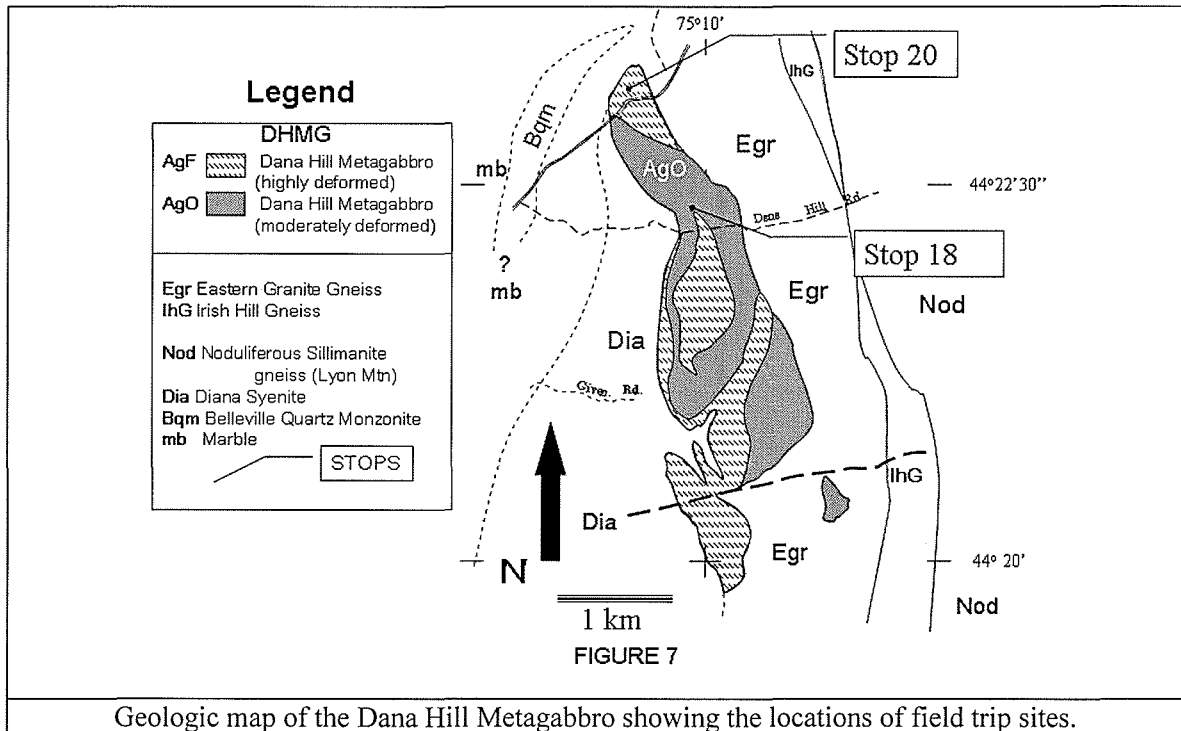
Turn right onto Dana Hill Road.

26.3 miles

STOP 17 Freshly blasted small outcrop of leucogranitic gneiss. This granite gneiss body outcrops along the eastern margin of the Diana Syenite Body. This granite body is, therefore, a part of the Adirondack Lowlands. Just around the next corner, we will encounter the Diana Syenite.

DANA HILL METAGABBRO

The Dana Hill Metagabbro preserves multiple deformation and veining events ranging from granulite facies ductile to sub-greenschist facies brittle events (see appendix). In many cases, cross-cutting relationships allow for the determination of a sequence of events. To date, six major deformational/veining events have been identified (Johnson et al., 2004; Streepey et al., 2001). At STOP 18 we will examine EVENT 4 shearing. Events 1 through 6 will be examined at stop 20.



27.3 miles

STOP 18 The “Zebra” rock outcrop of Dana Hill Metagabbro (Adirondack Highlands). The gabbro is cut by multiple cm to sub meter wide EVENT 4 (see appendix) shear zones. The zones typically dip steeply and shear sense, which varies from shear to shear, can be determined by rotation of a preexisting foliation into the zone (see appendix and figure 8).

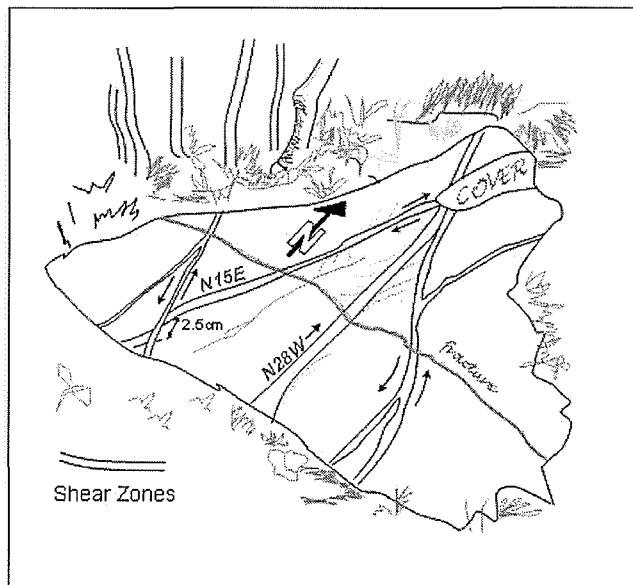
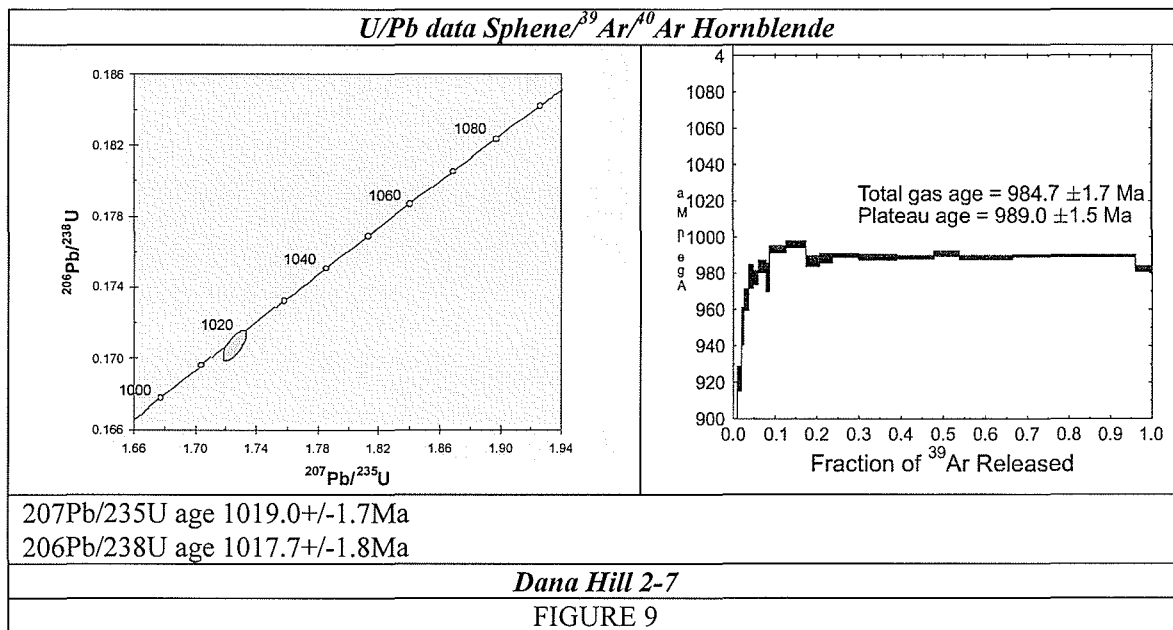


FIGURE 8

Sketch of a portion of the Dana Hill “Zebra Rock” outcrop showing multiple generations of small (cm-wide scale) EVENT 4 shear zones. Note that shear zones show both dextral and sinistral shear sets and that shear zones cut and offset one another.

The typical assemblage consists of amphibole +/- clinopyroxene + scapolite + plagioclase + Fe-Ti oxides. Plagioclase compositions are consistent within individual shear zones but range from An₀₅ to An₃₂ between shear zones. Polygonal scapolite forms distinct halos about amphibole and original ilmenite is replaced by titanite in the shear zones. Geochronologic data for this outcrop are presented in Figure 9.



Sphene (titanite) growth is constrained to occur during shearing and U/Pb ages are considered to be cooling ages off of peak Ottawa temperatures of 680-720°C (Streepey et al., 2001). These shear zones are similar in size and type with those found in the Diana Syenite Body (STOP 14) but shearing in these zones takes place at considerably higher temperatures. Sphene (titanite) U/Pb ages for shear zones in the Diana Syenite are considered to be growth ages marking the time of shear zone formation at ~1054-1034 Ma. Shear zones in the Dana Hill Metagabbro at this location record cooling temperatures at 1020 Ma so it is not unreasonable to suggest that the shear zones found in Dana Hill Metagabbro were active at the same time but at very different temperatures. ³⁹Ar/⁴⁰Ar cooling ages for these shear zones and similar style shear zones in the Diana Syenite Body overlap indicating that both units cooled through 550°C closure temperature for hornblende at the same time.

Continue east on Dana Hill Road. The ridge that we are passing over is cored by the Dana Hill Metagabbro. We will encounter hornblende granite, Irish Hill Gneiss (NoD) and Lyon Mountain Granite Gneiss (with sillimanite nodules) to the east of the Gabbro Body. Outcrops, however, are far and few between unless we track off into the woods. Excellent exposures of these rocks can be found along County Road 17 and along Plumb Brook (at the NY State Fishing access site). Next we will examine a small outcrop of Lyon Mountain Granite on Silver Hill Road.

29.1 Miles End of Dana Hill Road. Turn right (south) along County Road 17.

30.6 Miles Turn right (west) onto Silver Hill Road.

31.5 Miles Bear right at the Y intersection and continue down the dirt road (Cook Road).

32.2 Miles

STOP 19 Sillimanite + quartz + magnetite shear zones in the Lyon Mountain Granite Gneiss.

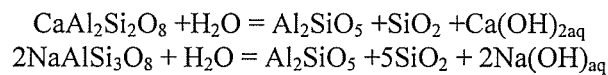
Sillimanite + quartz + magnetite is a common assemblage in the Lyon Mountain Gneiss (McLelland et al., 2001). At this location, one can see the formation of this assemblage as a consequence of deformation and post deformational fluid flow through the shear zones. In the shear zones, sillimanite needles are both aligned along the developing folia and as radial splays that clearly cross-cut the foliation. In the shear zones, plagioclase feldspar is only present as albite lamellae in exsolved perthite. Bulk and trace element chemistries of this rock both in and outside of the shear zones show some interesting variations (see table 1 RL).

Bulk and Trace element chemistries for Lyon Mountain Granite Gneiss

Oxide	<i>SRCH1</i>	<i>SRCH2</i>	FRED	DH	AM-86-11	AM 86-4	AM 86-10
SiO ₂	71.83	71.96	68.86	68.3	69.98	70.1	69.8
TiO ₂	0.27	0.287	0.63	0.56	0.46	0.69	0.62
Al ₂ O ₃	13.46	13.34	14.36	14.61	12.37	12.63	12.3
FeO	na	na	na	na	5.13	1.76	2.05
Fe ₂ O ₃	3.45	3.61	4.35	4.31	1.11	3.77	3.05
MnO	0.01	0.01	0.03	0.03	0.01	0.02	0.03
MgO	0.26	0.27	0.66	0.74	0.08	0.01	0.47
CaO	0.01	0.04	1.03	0.96	1.25	0.94	0.71
Na ₂ O	0.81	0.73	3.68	3.32	3.99	2.05	2.13
K ₂ O	9.19	9.16	5.08	5.92	4.91	7.56	6.84
P ₂ O ₅	0.03	0.03	0.16	0.12	0.04	0.17	0.11
Total	99.32	99.437	98.84	98.87	99.33	99.7	98.1
Rb	320	305	155	167	190	315	210
Sr	257	268	183	203	20	73	60
Zr	499	505	471	448	1230	414	620
Nb	9	10	35	21	30	18	20
Y	13	15	73	65	120	66	80
Ba	1294	1216	616	863	nd	840	600
Eu	nd	nd	nd	3			

Table 1 RL. Bulk and selected trace element chemistry for Lyon Mountain Granite Gneiss samples. Data for the shaded fields are from McLelland et al. (2001) and are presented here for comparison. Samples in bold italic are from sillimanite-bearing shear zones.

Samples from sheared sillimanite-bearing Lyon Mountain samples (SRCH1 and SRCH2) show marked depletions in Ca, Na, and enrichments in K, Rb, and Ba. The proposed mechanism for quartz-sillimanite formation is via the incongruent dissolution of plagioclase feldspar via the reaction:



REACTIONS 1 AND 2

Slight enrichments in SiO_2 Al_2O_3 can be accommodated by these reactions and the simple removal of Na_2O and CaO , but K_2O enrichments cannot be caused in this fashion. It appears that potassium was indeed introduced to these samples during and after shearing.

The timing of this fluid infiltration event is constrained to post date emplacement of the granite during syn to late-Ottawan time (~1050 Ma).

Turn around and retrace the route back to the intersection of Dana Hill Road.

36.9 Miles

Turnoff for the DEC Plumb Brook Fishing Access Site.

37.5 Miles Whippoorwill Corners. (**Jct. County Routes 17 and 24**) Note the large outcrop of Irish Hill (Whippoorwill Corners) Gneiss.

Follow County Route 24 South to STOP 20.

38.4 Miles Roadcut of pink granitic gneiss

39.3 Miles Roadcut into pink granitic gneiss (hornblende granite protolith)

39.4 Miles DANA HILL METAGABBRO Park the vans and climb the hill on the north side of the road. On the trail up the hill we will pass several sub-meter width EVENT 4 shear zones.

STOP 20 We return to the Dana Hill Metagabbro to examine the complex deformation of the body. This outcrop along with the outcrops at the top of the hill across the road, exhibit all 6 deformational events (see appendix and fig.10). We will start at the far end of the outcrop and examine the deformational sequence of events recorded. From the oldest to the youngest, this outcrop preserves EVENT 1 mega-shearing, EVENT 3 hornblende veining, EVENT 4 sub-meter shearing, and EVENT 6 folding and brecciation. EVENTS 2 and 4 can be observed at the top of the hill across the road. Events 3 through 5 take place in the presence of a fluid or fluids that drive scapolite replacement of original plagioclase feldspar in the host metagabbro. In the Diana Syenite Body (Lowlands Terraine), sub meter wide shear zones (dated to 1052-1034 Ma) also exhibit scapolite replacement of plagioclase feldspar. This scapolitization event is widespread in and around the CCSZ from just north of Harrisville to Colton and is present in both the Highlands and Lowlands Terranes. It therefore marks a common event for both terranes.

The goal of this stop is to demonstrate that the Dana Hill Metagabbro Body acted as a rigid block during deformation. In some instances, cumulate igneous textures have been completely preserved while in others the gabbro ranges to ultramylonitic in texture. The resistance to deformation in the Dana Hill Metagabbro resulted in an episodic response to the applied stress leading to discrete pulses of deformation. This body preserves individual and distinct events that record the entire deformational history of the region. The earliest shear zones are massive (30m wide) and mylonitic to ultramylonitic. These shear zones record recrystallization temperatures in excess of 700°C. Subsequent shearing events are dramatically different, forming sub-meter wide anastomosing shear zones at recrystallization temperatures at or below 700°C. The last deformation events to affect the Dana Hill Metagabbro transition to brittle failure at low to sub greenschist facies conditions. The deformational history is one of an exhuming footwall with deformation beginning in the granulite facies and eventually passing through the brittle-ductile transition at greenschist to sub greenschist facies conditions. We will examine these events and the available geochronologic data for this complex outcrop.

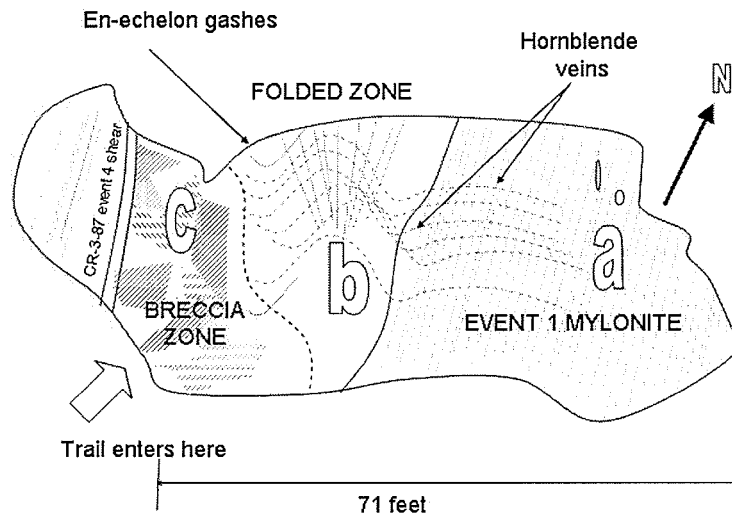


Figure 10. Map view of the outcrop at stop 20. We will begin at the western edge of exposure in zone a. The small oval shapes in zone a represent feldspar (albite)+quartz veins and tension gash fills that are undeformed internally.

EVENT 1 shearing accounts for the mylonitic character of the outcrop as a whole. The foliation here dips steeply yet transport lineation orientations plunge shallowly to the north-northwest. Kinematic indicators yield dextral shear sense. These mylonites contain recrystallized clinopyroxene + amphibole + sphene + plagioclase (An_{45-51}) along with accessory minerals (apatite, zircon, +/-quartz). Amphibole compositions for these samples range from ferroan pargasite to magnesian hastingsite. Chlorine contents are high for all amphiboles studied ranging from 2 to 18% hydroxyl site occupation. Amphibole and plagioclase chemistries are presented in Johnson et al. (2004). All samples exhibit a well-annealed polygonal fabric with perfect 120° triple junctions between grains. Grain sizes show a narrow range of variation for these samples averaging in the range of 100-300 microns for polygonal plagioclase. Re-crystallization temperatures for event 1 samples using the quartz-free geothermometer of Holland and Blundy (1994) range from 744 to 770°C (for 6kbar). Scapolite replacement of plagioclase is not present in **EVENT 1** shears at this location.

Hornblende veins cut the foliation at high angles in zone a. Hornblende veining belongs to **EVENT 3** (we do not see **EVENT 2** shear zones in this outcrop.). The hornblende veins are surrounded by reaction halos where scapolite replaces plagioclase feldspar in the host metagabbro. These halos can extend several mm into the surrounding metagabbro. In zone b (see figure 10), the metagabbro is folded and the open to nearly chevron folds are marked by **EVENT 3** hornblende veins. What looks like a rotated cleavage fanning across the folds are in fact the old **EVENT 1** mylonitic foliation surfaces. This zone transitions into the chaotic breccia zone (**EVENT 6**; zone c).

THE BRECCIA ZONE (EVENT 6)

Brecciation was accompanied by the growth of actinolite, biotite and chlorite after hornblende, and the breakdown of scapolite to a mixture of albite, epidote, and calcite. Breccia sample H-6A preserves rafts and clots of scapolite-rich mylonitic metagabbro with an invasive matrix of fibrous mats of chlorite, epidote, and actinolite. Hornblende (ferroan

pargasite) that has not suffered alteration to actinolite is fluorine-rich (average F = .75 wt %; average Cl = .57 wt %).

At the eastern margin of the breccia zone, an **EVENT 4** sub-meter scale shear zone is exposed. This shear (sample CR-3-87 Johnson et al. 2004; Streepey et al. 2001) preserves deformation textures (little annealing) and contains the assemblage hornblende + recrystallized clinopyroxene + plagioclase An₃₂ + Fe-Ti oxides + scapolite (minor). Plagioclase-amphibole equilibrium pairs where present yield re-crystallization temperatures for event 4 shearing in the range of 730°C to 680°C +/-50°C for a pressure of 6 kbar .

Geochronology of STOP 20.

Figure 11 shows the U/Pb isochron data for shear-zone grown sphene (titanite) for this outcrop. U/Pb data presented represent EVENTS 1 and 4, and yield a tightly constrained age of 1020.7 +/- 3.1 Ma. Since recrystallization temperatures for events 1 through 4 occur at temperatures above the closure temperature for U/Pb in sphene (titanite), these dates represent cooling ages for the body. The consistency of U/Pb titanite ages for samples throughout the body indicates that all (Events 1-5) shearing and veining occurred prior to 1020 Ma.

U/Pb titanite data for STOP 20

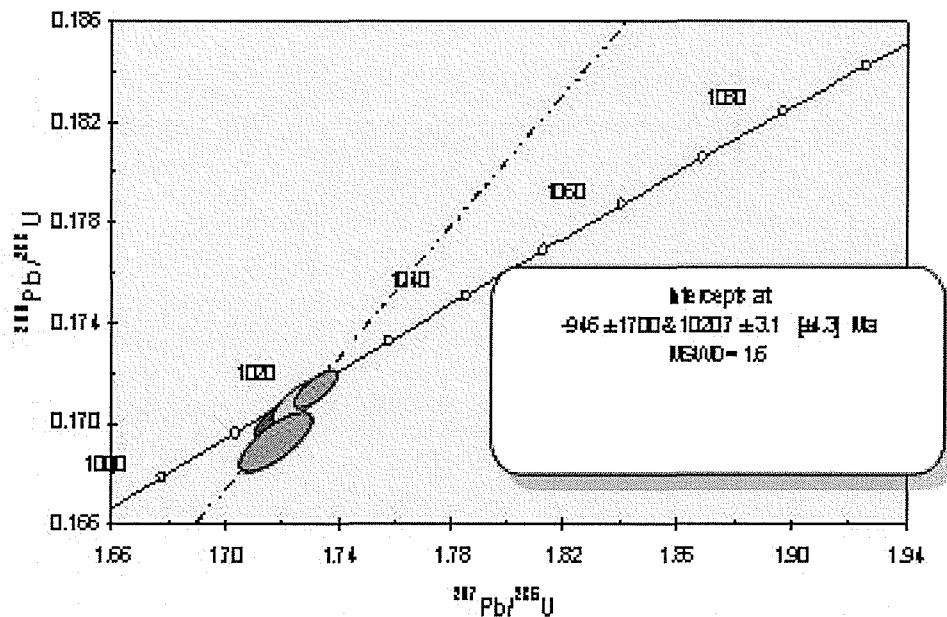
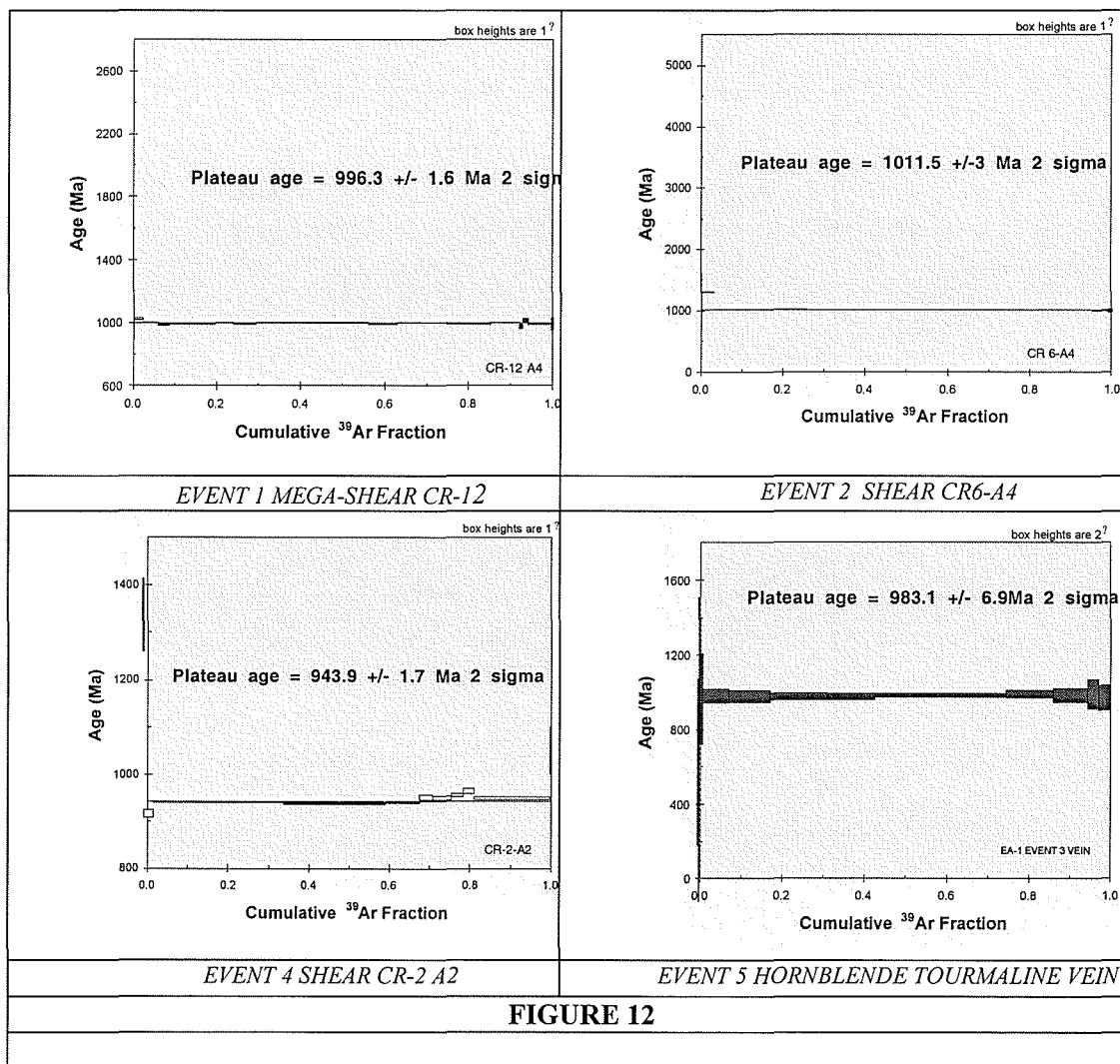


FIGURE 11

The $^{39}\text{Ar}/^{40}\text{Ar}$ results for hornblende in these samples is presented in figure 12. These data mark the date at which these samples cooled through the 500-550°C closure temperature for hornblende. The data from this and outcrop A-4 (opposite side of the road) are quite interesting. The results yield two cooling ages: one at ~985-1000 Ma and a second (recorded in two shear zones) of ~935-940 Ma. The latter and younger ages were determined from two samples at this outcrop. The 945 Ma age was used by Streepey et al (2001) to constrain the timing of the last stage of movement along the CCSZ. Only one of these samples (CR-2A2) yields a statistically clear plateau. Both shear zones are overprinted by the later brecciation event and, therefore, may have suffered some Ar loss during this event. Conversely, hornblende overgrowths on undeformed cumulate-textured Dana Hill Metagabbro sample from the outcrop across the road also yield a 945 Ma age, indicating hornblende growth at this time. Whether or not the 945 Ma age represents renewed deformation remains a point of controversy. The bulk of the shear zones and veins studied in the Dana Hill Metagabbro and surrounding Diana Syenite Body record $^{39}\text{Ar}/^{40}\text{Ar}$ hornblende cooling ages of 985-1010Ma. The generally flat spectra for $^{39}\text{Ar}/^{40}\text{Ar}$ data indicate rapid cooling with little to no post-closure disturbance.



The Dana Hill Metagabbro outcrops visited today provide an overview of the deformational and thermal history associated with movement along the CCSZ. Since this body is located at the CCSZ detachment, it records the entire deformational history. During exhumation of the footwall (highlands

side), the width of the deformation zone narrows with falling temperature and confining pressure, and eventually deformation is confined to regions directly adjacent to the detachment surface. Due to its resistance to strain, the Dana Hill Body did not completely overprint pre-existing deformational fabrics, leading to the complexly deformed body that we see today. Deformation in the Dana Hill can be broken down into three distinct regimes with falling temperature and pressure: 1. mega shearing, 2. sub-meter width shearing, 3. brittle failure. Early veining episodes may have been driven by fluid infiltration into the body, driving scapolite-forming reactions. The origin(s) of these fluids (CO₂ and HCl/NaCl rich) is unknown, but a likely source is from exhalation/mobilization of evaporite deposits in the adjacent lowlands hanging wall block. This origin for the metasomatic fluids fits well with the observed and widespread scapolite veining and scapolite replacement of original plagioclase feldspar in the lowlands near Pierrepoint (Tyler, 1981; Selleck , pers. comm.)

SUMMARY

The CCSZ is a west to northwest dipping and complex zone of strong ductile deformation. The style of deformation and the width of the deformed zones differ between the Highlands (east) and the Lowlands Terranes. In the Fine Quadrangle to the south, a marked change in the orientation of stretching lineation from NW trending down dip to NNW trending along strike coincides with crossing the detachment of the CCSZ. I believe that the nearly ubiquitous CCSZ deformation recorded in the Lowlands (Diana Syenite) coincides with early movements on the CCSZ. This earlier deformation fabric records both reverse and normal movement sense with reverse movement sense being most common. The later movement history is recorded in thousands of low temperature sub-meter width shear zones. These shear zones were active at upper greenschist to lower amphibolite facies conditions during Ottawa to late Ottawa time (1060-1030 Ma) and mark minor offsets in the bodies that they cut. These zones record primarily oblique normal movement sense. The Lowlands (Hanging Wall) rocks near to the CCSZ detachment cool to 500-550°C by ~980 +/- 9 Ma. In the Highlands Terrane, the CCSZ deformation extends several kilometers into the footwall and takes place at considerably higher temperatures. On the Highlands side, the shear zone is intruded during Ottawa to late Ottawa time by a series of granite bodies belonging to the Lyon Mountain Suite. Deformation in these granite bodies is variable reflecting their late injection into this evolving shear zone. The deformational history for the Highlands Terrane is well preserved in the Dana Hill Metagabbro Body which preserves granulite –amphibolite ductile shearing through greenschist facies brittle faulting and brecciation. Early high-temperature (700°C+) shearing produced broad mylonitic to ultramylonitic shear zones that were subsequently invaded by hornblende veins which, in turn, are cut by sub-meter width shear zones. Deformation terminates with folding and brecciation of the body. Shear sense is primarily dextral and oblique with stretching lineations plunging gently to the NNW. Early mega-shear zones dip steeply to the WNW and displacement sense is oblique normal.

All generations of ductile shearing and hornblende veining cooled together through the 600-650°C closure temperature for sphene (titanite) by 1020 Ma and the bulk of the shear zones and veins cool through the closure temperature for argon in hornblende by ~500-550°C. Scapolitization of original plagioclase feldspar is common in both the Highlands and Lowlands Terranes and marks a common event for both. In the Dana Hill Metagabbro, scapolite formation is directly tied to event 3 hornblende veining. With the exception of brecciation, all subsequent veining and shearing involve scapolite formation. Sub-meter width scapolite-bearing shear zones in the Diana Syenite are dated to have formed over the interval of 1054-1034 Ma and scapolite bearing sub meter width shear zones in the Dana Hill record U/Pb cooling temperatures of 1020 Ma (off 680-720°C peak temperatures). Based on these dates and the fact that both terranes are recording the same fluid driven scapolitization event, juxtaposition of Adirondack Highlands and Lowlands Terranes at or near a common structural level is constrained to have occurred between 1054-1020 Ma.

At 1020 Ma, the Dana Hill Metagabbro Body is cooling through 600-650°C, which is at least 100°C hotter than the Lowlands Diana Syenite Body, requiring a thermal discontinuity across the CCSZ that survives to as

late as 1010-985 Ma. Since thermal discontinuities typically cannot survive in the crust for more than 14 Ma, additional heat source(s) are required. This heat may be supplied by continued adjustments along the CCSZ or the intrusion of late quartz+albite pegmatites into the region.

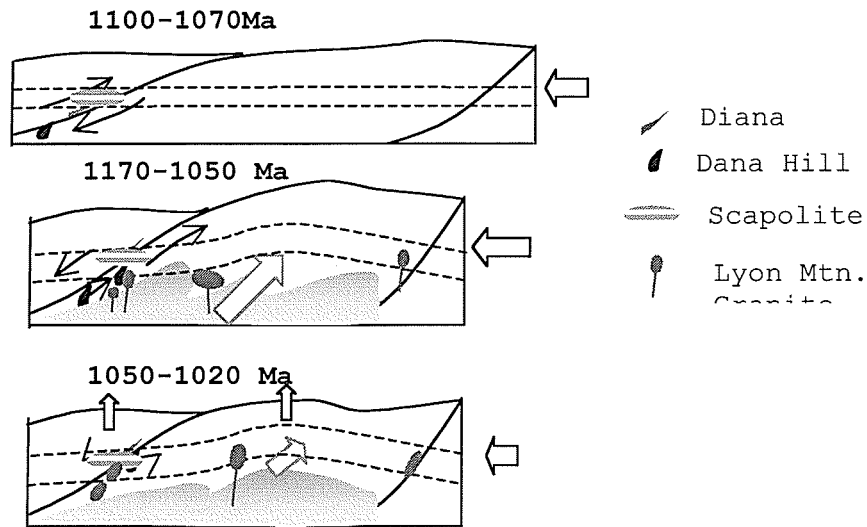


FIGURE 13 The proposed sequence of events for the CCSZ through the Ottawa Orogeny. 1100-1070 Ma: Initial Ottawaan compression leading to shortening and activation of the CCSZ as a reverse fault. 1170-1050 Ma: higher temperatures in the core of the Highlands Terrane lead to lower crustal viscosity and the extrusion of a crustal channel. The CCSZ acts as the roof of this developing channel and movement sense is normal. Decompression of the extruding Highlands leads to granitic melt generation forming Lyon mountain magmas. Along the CCSZ, deformation in the Dana Hill Metagabbro transitions from mega shears to sub-meter shear zones as temperatures fall due to exhumation. Highlands and Lowlands Terranes are juxtaposed by 1040 Ma and both share a common fluid driven scapolitization event. 1020-980 Ma: both terranes cool through 550-500°C. Post 980 Ma: transition from ductile to brittle deformation, formation of the Long Lake Fault?

Recent models of crustal channel formation in the Himalayas (see Hodges et al., 2003, and references therein) fit well with the observed movement history along the CCSZ. In the Himalayan case, crustal channels form in response to mobilization of a low viscosity granulite core that, driven by compression and surface denudation, undergoes syntectonic (syn-compression) exhumation. In the Himalaya, this exhumation is accommodated along a basal (thrust) shear zone. The roof of the exhuming crustal channel is marked by large ductile to brittle normal shears. In the Himalayan case, these bounding shear zones support long-lived thermal gradients due to the rapid exhumation of the still hot granulite core of the channel. Although both the roof and channel rocks are involved in the same orogenic episode, they record very different thermal histories. This is exactly the case for the rocks on either side of the Cartage Colton Shear Zone. Crustal channels and their bounding shear zones in the Himalaya are decorated with A-type Granite Bodies that form as pressure release melts in the exhuming granulite core. The A-type Lyon Mountain Granite Bodies that run the length of the CCSZ provide an excellent analog. In this model, the Adirondack Highlands Terrane is transported up and to the east against the “cover rocks” of the Adirondack Lowland Terrane (figure 13).

END OF TRIP

APPENDIX Deformational and veining events for the Dana Hill Metagabbro Body.

Outcrop event	Sample #	Orientation	Mineral assemblage	⁴⁰ Ar/ ³⁹ Ar date* U/Pb date (see Streepey et.al. , 2001)	T(°C) (6kbar)
Undeformed metagabbro	Cr-9 A4	na	Plag + Cpx + Fe-Ti Oxides (amph rims on cpx)	Amph rim: 943.8+/-1.7	NA NA
1. 30+m shear zone	Cr-7,Cr12 Cr-6 A4 CR-11A4 H-1A	FOL: N51W 59W LIN: 05 N54W	Cr-7, Cr6,Cr 11* and Cr-12* cpx+ amph+titanite+plag H-1A Cpx + plag + amph + titanite * scapolite replaces plag near amph. veins.	Cr-6A4 1005 +/- 1.9 Ma	1021 -1023Ma 718-744
2. 3m shear zone	Cr-5,4,3,2	FOL: N47W 76W LIN: 29N55W	Cr-5 amph+plag+titanite+qtz		NA NA
3 Parallel amph veins.	Cr-12	Vein orientation: N09E 67W	Cr-12 vein: amph + cpx + scapolite Matrix: well defined halo of scapolite replacing plag near to the vein walls. Vein is .3cm wide.	Cr12-A4 Matrix cpx mylonite: 996.3 +/- 2 Ma No date from vein	1021 Ma NA
4. cm wide shear zones	Cr-3 87; Cr2-A2 Cr 10A4	Cr3: FOL: N44W 74W LIN: 47 N61W Cr-2 FOL: N35E 57W LIN: 57 N55W	Cr-3 87: plag + amphibole + cpx +Fe-Ti oxides* Cr 2 A2 amph + plag+ scap+ titanite + biotite +qtz+ Fe-Ti oxides (replacing titanite)	Cr-2-A2 944+/- 1.9 Ma Cr-3-87 940.9 +/- 3Ma	NA 715°C
5. Folded mylonitic gabbro	NA	na	Folded mylonite with CR-7 assemblage (addition of scapolite near amph. veins)	NA	NA NA
6. Brecciated gabbro	H-6A H-87 5B	Na	Matrix: albite + chlorite + actinolite + calcite epidote	NA	NA NA

Outcrop event	Sample #	Orient-ation	Mineral assemblage	⁴⁰ Ar/ ³⁹ Ar date /Pb date see Streepey et.al, 2000)	T (C)
1. 30+m shear zone	RW-H1	FOL N09W 82 W LIN 30 346	Amphibole + plagioclase + scapolite	976+/- 2Ma	771°C
Amph-Tourm vein parallel to RW-H1 Foliation	EA-1	Foliated amph-tourm vein FOL N30W 90	Amphibole + tourmaline +quartz+titanite	983+/- 2 Ma	
2. 3m shear zone	RW-S3 (A,B,C)	FOL N60W 90 LIN:	Plagioclase (granular) + amphibole +scapolite (as corona on amphibole)	1009 +/-3Ma	
3. Amphibole Vein	RW-AVS3	Trend N65E 85S			
4. cm wide shear zones	RW-S1 RWS-2 CR-1DH1 CR-7DH1 CR-6DH1	Dextral shears S1 :FOL: N01W 87E LIN: NA S2: FOL N09E 70E LIN:NA CR-1: FOL N80W 90 CR-7 FOL: N53W 44NE	RW-S1 amphibole + scapolite +plagioclase (polygonal) + titanite (minor) RW S-2: CR6-DH1: Scapolite + plag + amphibole+biotite+Fe/Ti oxides CR-7 DH1: Scapolite + amphibole + biotite + plag CR-1 DH1: amphibole + scapolite +plag +Fe-Ti oxides	RW S1 1000+/- 2Ma CR-1 DH1 989 +/-1 Ma CR-7DH1 985 +/- 2Ma	718°C
5. Veining event	LHV-1	late amph vein	amph + tourmaline		
6. Brecciated vein	MV-1	ductile to brittle shear.	Highly altered: amph to chlorite.		

Trip A-6

CORDIERITE-BEARING GNEISSES IN THE WEST-CENTRAL ADIRONDACK HIGHLANDS

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INTRODUCTION

Cordierite-bearing gneiss is uncommon in the Adirondack Highlands. To date, it has been described from three locations, one near the village of Inlet (Seal, 1986; Whitney et al, 2002) and two along the Moose River further to the west (Darling et al, 2004). All of these cordierite occurrences are located in the west-central Adirondacks, a region characterized by somewhat lower metamorphic pressures as compared to the rest of the Adirondack Highlands (Florence et al, 1995; Darling et al, 2004).

In the Fulton Chain of Lakes area of the west-central Adirondack Highlands, a heterogeneous unit of metasedimentary rocks, including cordierite-bearing gneisses, forms the core of a major NE to ENE trending synform. Cordierite appears in an assortment of mineral assemblages, including one containing the uncommon borosilicate, prismaticine, the boron-rich end-member of kornerupine (Grew et al., 1996). The assemblage cordierite + orthopyroxene is also present, the first recognized occurrence of this mineral pair in the Adirondack Highlands (Darling et al, 2004).

This field trip includes stops at four outcrops containing cordierite in mineral assemblages that are characteristic of granulite facies metamorphism in aluminous rocks. Stops 1, 3 and 4 are from those previously described (Seal, 1986; Whitney et al, 2002; Darling et al, 2004) whereas Stop 2 is described here for the first time. Our intention is to consider the different parageneses in cordierite gneisses, and to consider the metamorphic pressure-temperature controls, as well as compositional controls, on the formation of these assemblages. We will also discuss the utility of these low variance assemblages for characterizing the pressure-temperature path of metamorphism (as well as formation conditions for prismaticine) and the implications of their moderate pressure conditions of metamorphism for our understanding of the geologic history of this portion of the Adirondacks.

STRUCTURAL SETTING

The Fulton Lakes Synform is a major structure that extends from the small community of McKeever on the southwest to beyond Raquette Lake in the northeast (Whitney et al., 2002). The axial trend passes through the Fulton Chain Lakes, so that one travels approximately parallel to it while driving along Route 28. Various rock units, most of sedimentary origin, occur in overturned, southeast verging folds that are bounded to the northwest and southeast by charnockitic gneisses. Abundant rock units within this synform include quartzite, biotite-quartz-plagioclase gneiss, and calcsilicate rocks. Also present, but less abundant, are Mg-rich gneisses, amphibolites, biotite-sillimanite schist, and calcite marble. Tight-to-isoclinal folding of these units has pervasively deformed compositional layers. Foliation parallels compositional layering. Centimeter scale gneissic layering is common, as are fine scale laminations in quartzite and ubiquitous, prominent mineral lineations.

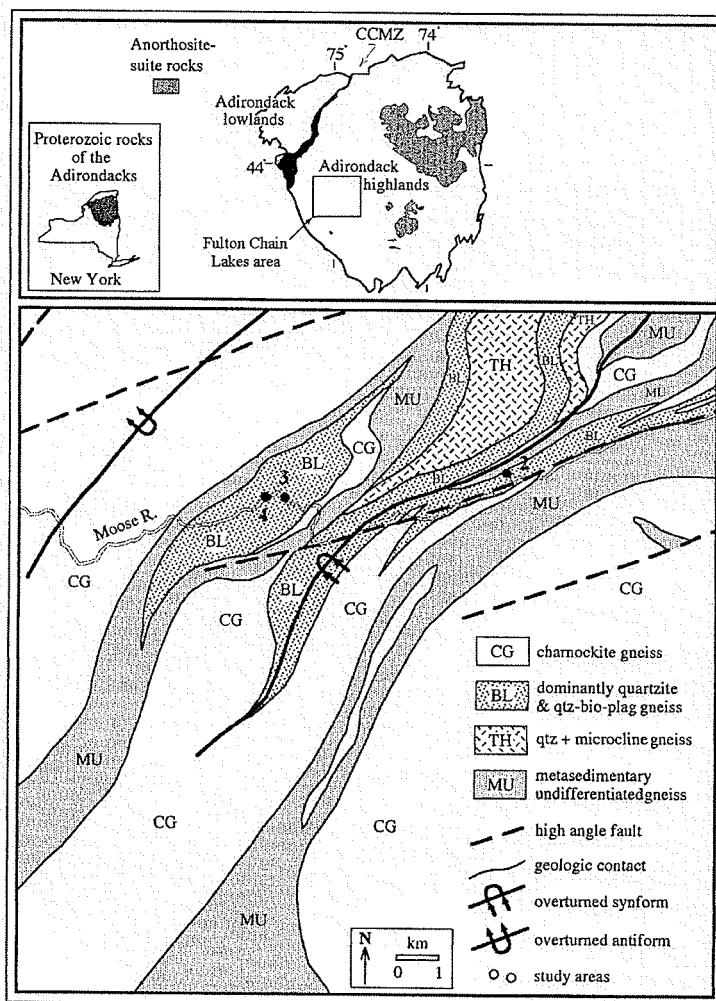


Figure 1. Location map showing the area of the field trip. Geologic map shows the map units, and structures from Whitney et al. (2002) and the last three field trip stops. Stop 1 is to the northeast near the village of Inlet. Its location is described in the road log.

LITHOLOGIES

The following are general features of the rocks we will visit on this trip.

Quartzites: Outcrops of quartzite are some of the most readily recognized metasedimentary lithologies of the Fulton Lakes Synform. They occur throughout the synform, often interlayered with calcsilicate rocks (e.g., Stop 1) and in the vicinity of the Moose River, adjacent to the Mg- and B-rich gneiss containing prismatic (Stops 3 and 4.) Layers vary in thickness from centimeters to tens of meters. Green diopside is a common accessory mineral, especially in calcsilicate layers within the quartzites. Other associated phases include pale needles of tremolite, phlogopite, and tourmaline. Whitney et al. (2002) report the presence of scarce wollastonite in the quartzite in the vicinity of the Moose River.

Metapelites: Medium- to coarse-grained biotite-quartz-plagioclase gneisses are found throughout the area, commonly interlayered with quartzites. Garnet and sillimanite are common accessory minerals in these rocks and are sometimes locally abundant. Alkali feldspar, typically, perthitic, may also be present. Anatectic leucosomes are found in these rocks, both parallel to and cross-cutting foliation. Presumably, these formed through fluid-absent melting involving biotite breakdown, as reported for similar rocks in the Port Leyden area, on the western edge of the Adirondacks (Florence et al., 1995.)

Calcsilicates: Fine grained, generally equigranular calcareous rocks are abundant throughout the synform and occur both as thick outcrops and as thin layers within the quartzites. These rocks contain abundant diopside, and often include quartz, tremolite, phlogopite, and titanite. Calcsilicates throughout the synform also contain variable amounts of andradite garnet, epidote, scapolite, enstatite, biotite, pyrite, pyrrhotite, and graphite. Layers of calcite marble are less common, but are observed associated with the calcsilicates in the vicinity of the Fulton Lakes Synform.

Mg-rich gneisses: Outcrops and layers of dark, Mg-rich gneiss are scattered throughout the synform, either as layers within quartzite units or in close proximity to quartzite. Stop 1 contains distinctive layers within quartzite that contain garnet, cordierite, sillimanite, biotite, and quartz (Seal, 1986). Different horizons within the biotite-quartz-plagioclase gneisses seen at Stops 3 and 4 contain the following assemblages: (1) cordierite, garnet, sillimanite, and spinel; (2) cordierite, orthopyroxene, and biotite, (3) cordierite, garnet, sillimanite, microcline, prismatic, and tourmaline; and (4) garnet, orthopyroxene, and microcline. The presence of prismatic ± tourmaline in assemblage (3) attests to abundant boron, in addition to magnesium, and Whitney et al. (2002) suggest that these rocks may have been metamorphosed from evaporite protoliths.

SUMMARY OF CORDIERITE-BEARING ASSEMBLAGES

Individual assemblages are discussed in the Road Log, but the following list compares the different mineral association containing cordierite.

Cordierite + Garnet + Sillimanite + Biotite + Quartz + Plagioclase (Stop 1).

Cordierite + Biotite + K-feldspar + Plagioclase ± Quartz ± Magnetite ± Garnet (Stop 2)

Cordierite + Garnet + K-Feldspar + Plagioclase + Quartz + Prismatic ± Biotite ± Sillimanite (Stops 3, 4)

Cordierite + Garnet + Sillimanite ± Spinel + Biotite + Quartz + Plagioclase (Stops 3, 4)

Cordierite + Orthopyroxene + Biotite + K-feldspar + Quartz (Stops 4)

CONDITIONS OF METAMORPHISM

The presence of low-variance assemblages and a variety of mineral equilibria provide the means to determine the conditions of metamorphism for these rocks. Darling et al. (2004) applied a combination of net transfer and mineral exchange equilibria, along with constraints from petrogenetic grids, to the assemblages along the Moose River that are associated with the prismatic-bearing gneiss. While these results pertain specifically to the outcrops along the Moose River, and the conditions of prismatic formation, we suggest here that they are reasonable indicators for the metamorphic conditions that were experienced throughout the western portion of the synform.

The results for Fe-Mg exchange thermobarometry (Harley, 1984), in garnet-orthopyroxene gneiss, Al solubility in orthopyroxene (Fitzsimmons and Harley, 1994) from the same gneiss, and application of the petrogenetic grids for the formation of orthopyroxene in pelitic gneisses (Vielzeuf and Holloway, 1988; Spear et al., 1999) demonstrate that conditions for the equilibration of garnet-orthopyroxene assemblages correspond to 850 ± 20 °C and 6.6 ± 0.6 kilobars (Darling et al., 2004). These P-T ranges appear to represent the highest preserved conditions of metamorphism. The absence of any evidence of sillimanite in combination with orthopyroxene in these rocks indicates that maximum P-T conditions of metamorphism did not rise above 860 °C and 8.5 kilobars. Figure 2 shows the results of these equilibria calculations and petrogenetic constrains.

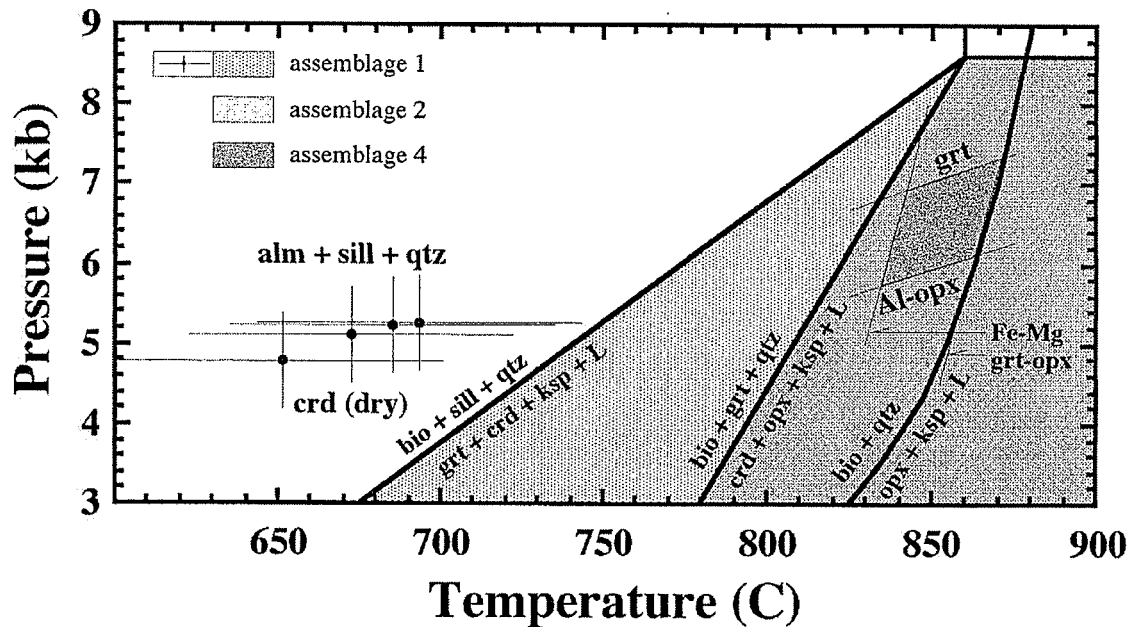


Figure 2. Pressure-temperature plot showing petrogenetic constraints, as well as results from net transfer and exchange reaction calculations based on mineral compositions found in assemblages along the Moose River. (From Darling et al., 2004)

Fe-Mg exchange equilibria and net transfer reactions for cordierite-garnet-sillimanite-quartz assemblages (Nichols et al., 1992) from the same outcrops as above reveal conditions of equilibration

of 675 ± 50 °C and 5.0 ± 0.6 kilobars. These results are also plotted on Figure 1. Darling et al (2004) interpret the thermobarometry of the cordierite-bearing assemblage to indicate the effects of retrograde re-equilibration. They point out that the stability of the mineral assemblage in the cordierite gneiss is inconsistent with the thermobarometry results. Fe and Mg diffusivities in cordierite are not well known, but have been estimated to be orders of magnitude more rapid than garnet (Lasaga et al., 1977.) Even after temperatures decreased to the extent that retrograde exchange reactions in garnet were effectively stopped, cordierite and biotite are presumed to have continued Fe-Mg exchange. Support for this interpretation comes from the garnet-biotite K_d values, which show Fe-enrichment in biotite.

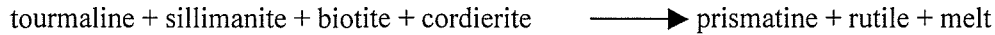
It should be pointed out that the pressure estimates obtained from the net transfer reaction used to equilibrium conditions for the cordierite-garnet assemblages are very nearly independent of temperature. As a result, it is reasonable to assume that even as retrograde Fe-Mg exchange during cooling altered cordierite compositions, no large uncertainty was introduced to the estimates of pressure conditions. Consequently, we favor the interpretation that the cooling path experienced by these rocks followed a nearly isobaric trajectory. This interpretation conforms to the retrograde cooling paths for the Adirondack Highlands that have been proposed on the basis of other petrologic studies, including Bohlen (1987), Lamb et al. (1991), Spear and Markussen (1997), and McLelland et al (2001).

DISCUSSION

Although generally rare throughout the Adirondack Highlands, cordierite is recognized in a variety of structurally related gneisses in the Fulton Chain of Lakes region. The bulk of the rocks in the Fulton Lakes Synform derived from sedimentary protolith suggesting that many, if not all, of the aluminous composition gneisses formed from pelitic or semipelitic deposits. At Stops 1, 3, and 4, the cordierite is found in distinctly Mg-rich layers that are associated with quartzites and calcsilicates. Whitney et al. (2002) have suggested that metamorphosed evaporite deposits are the likely protoliths for the calcsilicates in the area and argue on the basis of lithologic similarity that quartzites here can be compared to stromatolite-bearing quartzites in the Adirondack Lowlands. Mg- and B-enrichment, as seen in the prismatine-bearing layers, is consistent with the interpretation of evaporates at least locally present in the protolith. It is also possible that Mg-rich enrichment developed from dolomitization of layers within the original limestone. Cordierite seen at Stop 2 is found in pegmatitic, K-feldspar-, quartz-, and biotite-rich veins that appear to be the result of partial melting. Iron oxides and almandine garnets are also abundant in this exposure, indicating a bulk composition that is different from outcrops seen at the other stops.

It is clear that the cordierite gneisses reflect conditions of granulite facies metamorphism, but detailed analysis of the mineral assemblages suggests that cordierite had the role of either reactant or product in different melt-forming reactions as these gneisses reached conditions favorable for anatexis. In the assemblage cordierite + spinel + sillimanite + garnet, cordierite contains lenses of sillimanite needles and anhedral spinel grains in its core regions. Comparison of this relationship to similar features seen in contact metamorphism around the Laramide anorthosite complex in Wyoming (Grant and Frost, 1990) suggests that cordierite may have pseudomorphically replaced porphyroblasts of sillimanite or sapphirine. In the aluminous gneiss seen at Stop 2, cordierite is restricted to migmatitic leucosomes. Cordierite formed in contact and apparent textural equilibrium with orthopyroxene at Stop 4. Garnet and sillimanite are not present with this mineral pair, constraining the pressure-temperature conditions of formation of the assemblage (as discussed above) and suggesting that the reaction that formed this mineral pair involved biotite breakdown and melt formation. In nearby lenses containing orthopyroxene and plagioclase but without cordierite, orthopyroxene displays well developed ophitic textures.

Prismatine occurs in feldspathic lenses within biotite-quartz-plagioclase gneiss and these lenses extend out into the surrounding gneiss. Many prismatine blades lie randomly oriented within the plane of foliation of the surrounding gneiss, but other grains grew across foliation, suggesting that this mineral crystallized under pressure conditions that locally were close to hydrostatic. Tourmaline occurs in the gneiss away from these lenses and also is preserved as inclusions in garnet. Prismatine formation likely occurred at the expense of tourmaline and probably involved biotite breakdown. The proposed reaction of Darling et al. (2004) for prismatine formation also includes cordierite as a reactant:



An outstanding issue is the timing of cordierite formation for the rocks studied here. As seen at Stop 2, some cordierite formed as a result of partial melting. Anatexis has been recognized in other pelitic and quartzofeldspathic gneisses in the synform (Whitney et al., 2002), as well as in pelitic gneiss west to the area, near Port Leyden (Florence et al., 1995). A single crystal zircon age determination of 1031 ± 8 Ma from granitic gneiss at Agers Falls (Port Leyden area; Orrell and McLelland, 1996) and similar age monazite from the Port Leyden pelitic gneiss establish the timing of Ottawaan granulite facies metamorphism and partial melting in the west-central Adirondacks. Deformation of the cordierite-containing leucosomes at Stop 2 may reflect syn-tectonic anatexis during the Ottawaan. Initial cordierite formation elsewhere may predate Ottawaan metamorphism. This region has had a complex tectonic history, as demonstrated by the intrusion and deformation of charnockite and granitic gneisses. These rocks have not been dated in this area, but are geochemically similar to ca. 1150 Ma AMCG (anorthosite-mangerite-charnockite-granite) suite rocks that occur elsewhere in the Adirondack Highlands (McLelland et al., 2001; Whitney et al., 2002.) To what extent this earlier magmatic event was responsible for formation of cordierite is not clear.

More evident is the cooling path exhibited by these rocks following Ottawaan granulite facies metamorphism, which outlasted ductile deformation. Whether formed during the Ottawaan or re-equilibrated then, mineral compositions of cordierite, garnet, biotite, and orthopyroxene reflect the conditions near and subsequent to the thermal maximum of the Ottawaan event. The pressure-temperature evolution for the cordierite-bearing rocks followed a nearly isobaric cooling path from 850 ± 20 °C and 6.6 ± 0.6 kilobars to 675 ± 50 °C and 5.0 ± 0.6 kilobars. This path parallels the cooling trajectory identified for the Eastern Adirondacks by Spear and Markussen (1997), and shows a pressure that is lower by about 1.2 kilobars.

It is interesting to compare these thermobarometric results with an earlier study of the western Adirondack Highlands that also suggested lesser pressures here than in the eastern Adirondacks. De Waard (1965) observed that amphibolites in the western Adirondacks invariably lacked garnet, whereas those to the east were garnetiferous. He recognized that the transition from two-pyroxene amphibolites to garnet-bearing varieties was the result of the largely pressure-dependent net transfer reaction:



Development of this reaction is also dependent on bulk composition, but de Waard's suggestion that it indicates an overall westward decrease in pressure conditions of metamorphism across the Adirondacks is supported by the pressure determinations from the Moose River assemblages. Florence et al. (1995) also obtained moderate pressure-temperature estimates of 735 ± 25 °C and 4-6 kilobars at Port Leyden. Presuming these estimates also reflects Ottawaan conditions, this would appear to confirm a gradient of decreasing pressures across the Adirondack Highlands from the High Peaks to the western margin.

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ROAD LOG FOR CORDIERITE-BEARING GNEISSES IN WEST-CENTRAL ADIRONDACKS

CUMULATIVE MILEAGE	MILEAGE FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Town Park, Village of Inlet, on Route 28.
0.5	0.5	Stop 1. Outcrops on right side of road.

STOP 1. BIOTITE GNEISS WITH CORDIERITE

A long series of roadcuts is exposed along this section of road. The rocks immediately to the right are light gray outcrops of calcsilicates. Begin walking in the same direction as you were driving (to the N along this section of Route 28.) The next outcrops are garnet-biotite-quartz-feldspar gneisses containing abundant K-feldspar. Notice the color of these iron-rich garnets.

Proceed to the next outcrop to the north, containing darker gray quartzite and layers of biotite-quartz-plagioclase gneiss. Coarse sillimanite and lavender grains of garnet are found associated with biotite-rich layers. Bluish cordierite, ca. 1 cm in size, can be observed on fresh surfaces on the face of the outcrop or on top, towards the south end. Deformed leucosomes and pegmatite veining is also seen in outcrop.

11.2	10.7	Enchanted Forest, Village of Old Forge
11.6	0.4	Old Forge Hardware Store, downtown Old Forge
13.6	2.0	Thendara Station
21.8	8.2	Stop 2. Outcrops on left (east) side of Route 28.

STOP 2. CORDIERITE-BEARING OUTCROP

Pink and gray two-feldspar gneisses outcrop along both sides of the road and exhibit steeply NW dipping to nearly vertical layers. Coarse grains of bluish cordierite are visible within a deformed pegmatite vein at the southern end of the exposure.

These gneisses show strong evidence migmatization. There are numerous K-Feldspar-, biotite-, quartz- rich pegmatite veins parallel to foliation, some of which are deformed into isoclinal orptygmatic folds. Cm long, thin, discontinuous lenses of biotite and sillimanite (restite?) are abundant on the south end of the outcrop on the west side of Route 28, where it can be seen that the long axis of sillimanite blades are randomly oriented within the plane of foliation. The association of cordierite with the pegmatite veins suggests that its formation was the result of a melt-producing reaction.

These outcrops contain abundant oxides and the coloration of garnet implies a relatively high Fe content. Overall, the mineral abundances suggests that these rocks have a different bulk composition than the cordierite gneiss seen at Stop 1 and those that will be shown at Stops 3 and 4.

22.1	0.3	McKeever bridge across Moose River
22.2	0.1	Moose River Road. Turn right. Continue on Moose River Road
24.0	1.8	Lewis County boundary
25.4	1.4	Moose River in view to right
26.2	0.8	Stops 3 and 4. Pull into dirt parking area on right, adjacent to river.

The next two stops are along the Moose River and require a little more than a kilometer of walking to visit them both. The outcrops are exposed along the river's edge. Caution is advised during periods of high water. Please DO NOT USE HAMMERS at these outcrops. We request that sampling be restricted to collecting loose material.

From the parking area, follow an unimproved fishing trail that leads left out of the parking area and walk downstream on the bank above the south side of the river. Continue for approximately 100-200 m, past NW dipping quartzite beds containing tremolite needles, diopside, and other calcsilicate minerals. The trail passes through the old foundation of a former tannery. After another few 100 m, the river then bends to the north and the trail drops down to the river's waters edge.

Stop 3 consists of the first outcrops along the riverbank that are exposed downstream from the bend.

STOP 3. MG-RICH METAPELITES

This stop consists of a continuous bedrock exposure along the south side of the Moose River. The first exposures past the bend in the river contain large greenish-gray blades of prismatic that have formed in a biotite-quartz-K-feldspar gneiss containing massive, cm scale "lumps" of garnet. Cordierite was recognized in thin sections taken from these outcrops.

Continuing downstream, biotite-quartz-feldspar gneiss outcrops show elongate segregations of cordierite, sillimanite, and spinel in the layers adjacent to spectacular splays of prismatic. Prismatic is also well displayed in an isoclinal fold that can be seen on a 2 m high vertical face. Notice that prismatic needles grow both parallel to and across the plane of foliation. A little further downstream, outcrops contain zones with abundant small, black tourmaline crystals. Prismatic is also present here, immediately rimmed by tourmaline-free halos. Cordierite is present in this portion of the outcrop as well, sometimes as dark, pinitized (altered) grains and in lumpy-looking symplectite intergrowths with quartz.

The western end of the exposures at Stop 3 rises directly above the Moose River. To continue further west from here, walk directly upslope and return to the fishing trail. Continue in the downstream direction another 400 m to where quartz-rich outcrops are exposed along the river. Follow these outcrops for another 30-50 m. This is Stop 4.

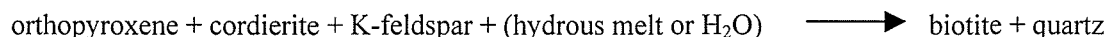
STOP 4. METAPELITES CONTAINING CORDIERITE + ORTHOPYROXENE

The first exposures along this section of outcrop contain occasional euhedral grains of prismatic in quartz-biotite-feldspar lenses in quartzite. Just downstream (ca. 10 m) from these are layers locally displaying large blue knots of cordierite and lavender garnets.

Another 10-15 m of downstream travel brings one to a few south dipping rocks that extend a little into the river. Here, cm long, dark green prismatic blades form radiating splays on surfaces of biotite-quartz-feldspar lenses within quartzite. Most grains lie within the plane of foliation but individual crystals are in fact arranged in random orientations with respect to foliation in what appear to be leucosomes. Sillimanite occurs in this assemblage only as anhedral grains included in prismatic, leading Darling et al. (2004) to suggest that sillimanite abundance was the limiting reactant in the melt-forming reaction leading to prismatic formation.

Other feldspathic gneiss lenses within these outcrops contain orthopyroxene, garnet, K-feldspar, and plagioclase in melt zones. In thin section, grains of orthopyroxene and plagioclase moderate to well-developed ophitic texture. As with the prismatic-bearing lenses, these mineral assemblages are considered to be the result of partial melting.

Adjacent biotite-rich layers contain bronze colored, weathered orthopyroxene megacrysts and cordierite knots. Grains of unaltered orthopyroxene were seen in thin section, where they appear in textural equilibrium with cordierite, biotite, quartz, and K-feldspar. Some grains of cordierite are rimmed by biotite and quartz symplectites. Presumably, the alteration and replacement of orthopyroxene and cordierite proceeded according to the reaction



It is not clear whether this reaction operated during the subsolidus portion of the retrograde path, presumably by the introduction of an aqueous phase, or it was brought on by melt-formation at or near the peak of metamorphic conditions.

From here, walk uphill to regain the fishing trail to return to the parking area.

Trip A-7

THE POWERS FARM UVITE LOCALITY: A DAY IN THE FIELD AT THIS CLASSIC MINERAL OCCURRENCE

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Once named pierrepontite (discredited name) the tourmalines from the Powers Farm occurrence in Pierrepont, New York can be found in private collections and museums world-wide. Amazingly this site can still be accessed by collectors looking for well crystallized uvites and other minerals.

INTRODUCTION

Introduced to the mineral collecting world of the 1800's as pierrepontite, the tourmaline crystals from the Bower Power's Farm, Pierrepont, St. Lawrence County, New York, USA, have achieved world-wide notoriety. Dana (1877) notes the occurrence of these unusual tourmaline specimens while Kunz (1892) describes the locality in his text Precious Stones of North America. To this day Pierrepont tourmalines are still noted and photographed in current editions (now in its 22nd edition) of the Manual of Mineral Science (Klein, 2002). Specimens of this aluminum-poor uvitic dravite (Dalton, 2003) and its accessory minerals can be found in many of the world's top museums and private collections. Though universally recognized as a classic tourmaline locale, the name of this mineral has been intensely debated. Based on recent chemical and x-ray analysis, the author believes the proper species name for this so called uvite may actually be in question. Henceforth, this tourmaline will be referred to as uvite, as it has been locally for many decades.

This field trip description will attempt to present an overview of what many have considered to be one of the world's classic tourmaline localities. Due to extensive coverage of the area's bedrock by Pleistocene glacial deposits, many aspects of the site's geology will remain speculative. Its minerals, however, are available for study and documentation, and the site remains open to collectors at the time of this writing.

DIRECTIONS

From Potsdam travel south on Rt. # 56 for approximately six miles to the intersection with the Brown's Bridge Road, also known as Country Road 24. Turn right onto County Road 24 and travel an additional 6 miles to the intersection with Post Road. Turn right onto this dirt lane and travel approximately one mile to where you will see a large garage/barn on your left. Continue straight into the woods along this jeep trail for one quarter of a mile until you reach Leonard Brook where the bridge is out. This is the parking area.

To reach the primary dig site, follow the foot path that travels north parallel to the stream for about one quarter mile. The site is in a wooded area on a small rise on the eastern side of the stream. Don't forget that this is private property and that the owner charges 5 dollars per person, per day to collect mineral specimens on his land. Arrangements to collect here should be made in advance or by contacting Bower Power, Jr. who lives in the first farm house on your left as you travel down Power's Road just north of Pierrepont.

GPS Readings are:

- Power's House 044 deg. 33' 5.40" N. Lat. by 075 deg. 01' 28.53" W. Long.
- DuFoe's Dig Site 044 deg. 33' 23.28" N. Lat. by 075 deg. 01' 20.56" W. Long; 624' elevation
- Parking Area 044 deg. 33' 16.08" N. Lat. by 075 deg. 01' 12.96" W. Long; 612' elevation
- Historic Dig Site 044 deg. 33' 23.03" N. Lat. by 075 deg. 01' 14.16" W. Long; 621' elevation
- Hillside Dig Site 044 deg. 33' 16.70" N. Lat. by 075 deg. 01' 03.98" W. Long; 624' elevation

A BRIEF HISTORY

An early mineral enthusiast of the area, Reverend Roselle Theodore Cross, of Richville had this to say regarding the Powers site:

"My Father took me with him once to a religious meeting twenty-five miles from home, up on the hills of Pierrepont. At the farmer's house where we stopped I saw a shining black crystal of tourmaline. In reply to my enquiry as to where it came from they said it was found in abundance near an old saw mill about a half a mile distant. The next morning they took us to the place. I dug the black brilliants for a half hour or so and then a thunderstorm drove us away. I remembered the place for years and often wished that I could revisit. I gave some to a farmer in a distant part of the county. Mr. Nims saw them and followed up the clue until he found the locality, and from that place also he sold wagon loads of tourmaline crystals. It had been a famous locality, for no blacker, or more brilliant, or more sharply cut crystals of tourmaline are found in this world." (Cross, 1903)

In the mid 1970's this site saw an increase in collecting activity due to its notation in an unpublished, yet widely available mineral collecting book by Robinson and Alverson titled, Minerals of the St. Lawrence Valley. Power's Farm appears as the first site described in this manuscript.

Extensive collecting has occurred at Power's Farm over the past 50 years. Tailings left by previous collectors can reach depths of ten feet or more. Thankfully, the occurrences of minerals on this property are widespread. Though it is unlikely in the present day to find "wagon loads" of crystals, there are good specimens to be had. Recent history has shown that every ten to fifteen years someone makes a major find at the site. This is usually the result of more than a single days work, however.

GEOLOGY

The geology at this location goes beyond complex to downright stupefying. To further confuse matters, much of the area bedrock is covered by overlying glacial till which sometimes reaches depths of 20 feet or more.

The area is obviously a complex metamorphic puzzle. Overly simplified, it appears to be a contact between regional Grenville aged marbles and Precambrian schists of mixed mineralogical nature. These schists vary in their mineral content, with most having large amounts of tourmaline, quartz and biotite.

MINERALS

Allanite: $(Ca,Ce)_3(Fe^{2+},Fe^{3+})Al_2O(SiO_4)(Si_2O_7)(OH)$ (EDS verified, 2003) is found as acicular inclusions and tuft-like bundles of crystals in association with quartz and calcite crystals from the adjoining DuFoe property (across stream from Power's property). It is currently unidentified as occurring on the east side of Leonard Stream on Mr. Power's land.

Apatite/Fluor-?: $Ca_5(PO_4)_3(F,Cl,OH)$ occurs in well formed translucent to opaque crystals up to 5 cm in length. They are usually green in color and typify the form seen in most New York State and Ontario, Canada apatite crystals. Crystals are usually small (less than a cm) and uncommon.

Calcite: $CaCO_3$, crystals from this location have only been recorded as coming from the adjoining property owned by the DuFoe family and the stream-side site on the Powers property. This site is on the western side of Leonard Stream and was once directly beside the trail leading into the main dig site up until the mid 1980's.

Chlorite: $(Mg,Fe)_6(AlSi_3)O_{10}(OH)_8$, occurs as coatings and inclusions within and on quartz and other minerals.

Goethite: $FeO(OH)$ appears as an alteration product of pyrite in small crystals to .5 cm and as coatings on other minerals.

Graphite: C, occurs as plates and aggregates of plates to 5 cm.

Magnetite: Fe_3O_4 , occurs as small, metallic, platy crystals up to several millimeters. (Personally observed in DuFoe specimens but none from Power's property).

Micas: at least 2 varieties as per S. Chamberlain, (personal communication). Phlogopite and biotite occur in large, well formed hexagonal books to 15 cm in diameter.

Pyrite: FeS_2 , occurs in massive form as a vein filling and rarely as poorly formed cubic crystals to 5 cm.

Quartz: SiO_2 , occurs in at least two generations with distinctly different appearances and crystal forms. The first generation quartz crystals form barrel shaped crystals with tapered terminations. These crystals are common and attain sizes to over 30 cm in length. They are almost always poorly formed, looking as if they have been partially melted, white to smoky in color and most commonly found in association with uvite or as floater clusters and individuals within calcite seams. They are commonly broken, sometimes showing minor rehealing of fracture surfaces. Some surfaces on these crystals will occasionally show a curvature to their prism faces. Seldom will this generation of quartz make for presentable specimens.

Second generation quartz crystals are very rare but spectacular in their form, clarity and luster. Many phenomenal specimens came from the stream-side site in the mid 1970's. This cut also produced some uvite quartz combination pieces that are rivaled by none. These quartz crystals exhibit more traditional and symmetrical development and are sometimes double terminated. They are exceptionally transparent, usually have a slightly smoky tint and can reach lengths up to 15 cm.

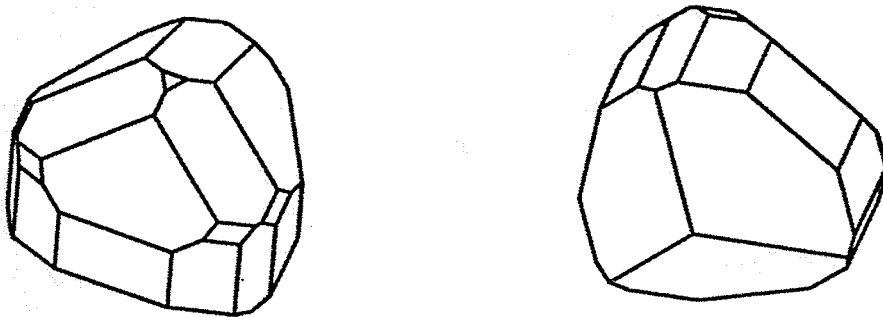
Scapolite: $3\text{NaAlSi}_3\text{O}_8 \cdot \text{NaCl}$ to $3\text{CaAl}_2\text{Si}_2\text{O}_8 \cdot \text{CaCO}_3$, occurs as blocky, low luster crystals to 15 cm in length.

Talc: $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$, occurs as a pseudomorph of uralite after diopside and as surface coatings on numerous other minerals. Rarely as pseudomorphs of scapolite or diopside in crystals to 6 cm. .

Tremolite, $\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$ occurs in well formed green crystals up to 8 cm in length. Clusters and plates of crystals are commonly associated with other area minerals.

Uralite occurs as a pseudomorph of a clinopyroxene, probably diopside, in green crystals up to 10 cm in length. Clusters and plates of crystals are commonly associated with other area minerals.

Uvite, $(\text{Na, Ca})(\text{Li, Mg, Al})_3(\text{Al, Fe, Mn})_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$ occurs in spectacular groupings and as individual crystals up to 20 cm in diameter (though any crystal over 4 cm is uncommon) and as vein filling in the area bedrock. Plates of uvite and associated minerals have been recovered up to 60 cm in maximum dimensions. Crystals appear black and opaque, although they can actually be



Idealized drawings of the typical uvite crystal form.

seen to be brown and translucent under intense light. The luster can range from flat to glassy. Occasionally, crystals are found which have broken in situ and partially rehealed. A great

degree of internal fracturing is present in most specimens. Calcite often acts as a cementing agent for such crystals leading to their destruction, in most cases, when they are etched from this calcite with acid. Specimens naturally weathered from calcite are more stable, yet less common.

Pockets to several feet in diameter containing uvite crystals are rarely encountered. More common are seams lined with uvite which have been subsequently filled by massive calcite through meteoric or hydrothermal deposition.

ACCESSIBILITY

This classic site is still available to collectors unlike so many others in the northeastern United States that have been closed. Mineral enthusiasts are encouraged to take advantage of the opportunity which exists to actually find their own specimens at this historic locality. Responsibility is also encouraged. The author has known this family for 35 years. They have no personal interest in mineral collecting, yet they do allow others to do so on their property for the small fee of five dollars per day per person. In the past the site has sometimes closed to collecting due to the irresponsibility of collectors who demand their money back or litter the property:
“Dear Sir,

This is just a note to inform you of the closing of another famous mineral locality: the uvite locality at Pierrepoint, New York. Apparently last winter the owner, Mr. Bower Powers (Senior) died and his son (Mr. Bower Powers Junior) heir to the property wants nothing to do with mineral collectors. Knowing him personally, I would say the prospects don't look too good for the future. Each year many mineral collectors visit the locality. Perhaps the Record can convey this message to those collectors who would otherwise be making the trip in vane.

George Robinson
Kingston, Ontario” (Robinson, 1978)

ACKNOWLEDGEMENTS

Thanks go to Scott Wallace for his careful editorial read of this field trip description.

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Workshop W-2

EARTHQUAKE WORKSHOP

Frank Revetta

SUNY Potsdam

Saturday, September 18, 2004

Room 120 Timerman Hall

Morning

- 8:00A.M. -9:30A.M. Potsdam Seismic Network and earthquakes in northern N.Y.
- 09:30A.M. - 12:00Noon Field trip to Potsdam and Lake Ozonia seismic field stations.

Afternoon

- 01:00P.M. - 5:00P.M. Field trip A-8 to Massena, New York, site of largest earthquake in New York State on September 5, 1944.

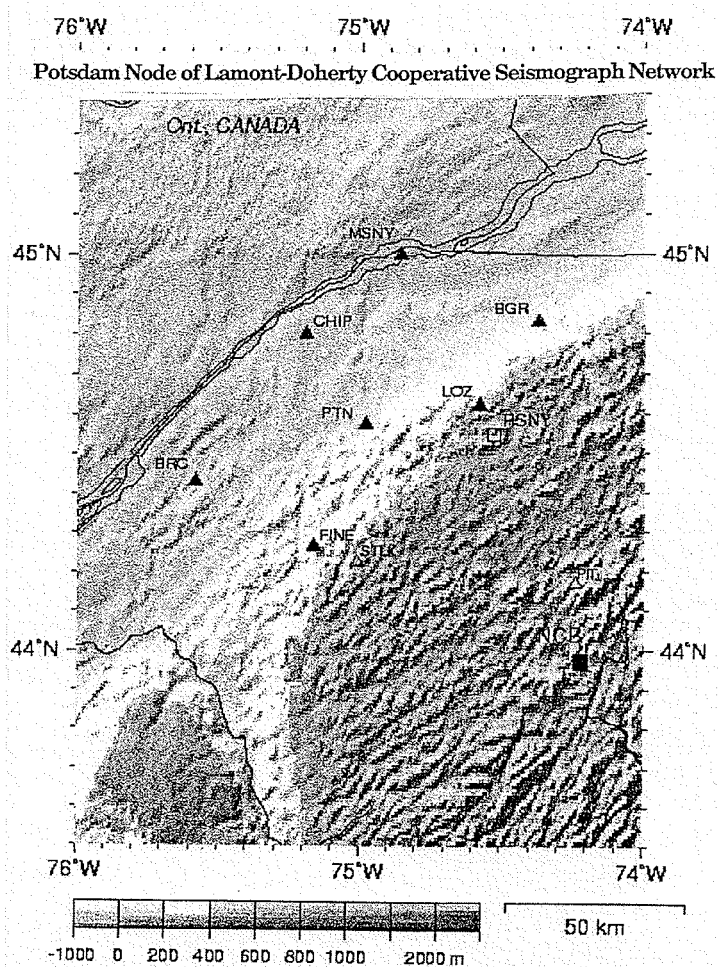


Figure 1. Location of seismic stations in Potsdam Network.

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- I. Lamont-Doherty Cooperative Seismographic Network (LCSN)
- II. History of Potsdam Seismic Network
- III. Seismic Field Stations
- IV. Seismic Recording Station
- V. Broadband Station
- VI. Earthquakes in Northeastern United States
- VII. Intensity Studies
- VIII. Applications of Potsdam Seismic Network
- IX. Information about Earthquakes

I. LCSN Seismographic Stations

The locations of the Nodes of the LCSN are shown in Figures 1 and 2. The Potsdam Node is located in the St. Lawrence Valley of northern New York and lies in the heart of the northern New York-Western Quebec Seismic Zone. This is the most active seismic area in New York State. The other nodes are Palisades at Lamont Doherty Earth Observatory, Delaware Node at Delaware Geological Survey – University of Delaware, and Lake Champlain Node at Middlebury College, VT. These stations monitor earthquakes that occur primarily in the Eastern United States.

II. History of the Potsdam Seismic Network

The Potsdam College Seismic Network consists of seven short period-vertical seismograph stations located in the St. Lawrence Valley in northwestern New York (Figure 1). The first station (PTN) was installed in October 1971 as a joint venture between Potsdam College and the Lamont-Doherty Geological Observatory (LDGO) of Columbia University. LDGO installed the seismic field station ten miles south of Potsdam and telemetered the seismic signals to Potsdam College where they were recorded on a seismograph jointly purchased by the Potsdam College and Alcoa Foundations. The seismic signals were transmitted by telephone lines to LDGO at Palisades, New York, for study by the LDGO seismologists. This was the first seismograph station installed in northern New York.

During the succeeding years, six more seismograph stations were installed in the area. In 1976 LDGO installed seismic field stations at the Long Sault Dam at Massena, New York, and at Bangor, New York. The Gulf and Alcoa Foundations provided Potsdam College with grants to purchase seismographs to record from these two field stations. From 1983 to 1988 Potsdam College purchased seismic equipment to install three stations at Lake Ozonia (LOZ), Star Lake (STLK) and Brasie Corners (BRC). The funds for the installation of these stations were received from the New York State Power Authority and Alcoa Foundations. In 1988 Plattsburgh State College donated one seismograph to Potsdam College. In addition, the Lamont-Doherty Geological Observatory has provided much detection and telemetering equipment.

In 1977 the Star Lake Station (STLK) site was moved to Fine, N.Y. In 2000 a three component broadband station was installed at the Lake Ozonia site (LOZ). The earthworm software was also installed, which enables us to study seismic data in the LCSN network from stations outside our Potsdam Network.

III. Seismic Field Stations

The detection of earthquakes occurs at the seven seismic field stations shown in Figure 1. The instrument that detects the ground motion produced by an earthquake is the seismometer (Figure 4). The seismometer is a coil of wire that is free to move back and forth in a magnetic field. All the seismometers are vertical short-period units which respond to the short-period seismic waves generated by local earthquakes. The seismometer is placed on bedrock inside a bottomless 55 gallon steel drum. The ground motion produced by the seismic waves is converted to an electrical signal and fed into a high-gain amplifier to increase the signal amplitude (figure 5). This signal is frequency modulated by a voltage-controlled oscillator (VCO). The VCO frequency is now in the audible range and its output frequency changes in response to the change sensed by the seismometer. The signal is modulated to the FM radio transmitter and then transmitted to the receiving station at Potsdam College. The power output of the transmitter is 100-350 milliwatts. The frequency is usually in the UHF government experimental band, however, a clear channel VHF frequency may be used for more critical propagation problems.

All stations are solar powered (Figure 6) except MSNY and PTN. The solar-powered station consists of a silicon solar collecting panel that provides DC current to the regulator during the daylight hours. When sufficient current is available, a regulator recharges the battery. The battery supplies the energy that is needed to power the radio transmitter. This results in a significant financial savings.

IV. Seismic Recording Stations

All seven of the seismic stations transmit the seismic signals to Potsdam College via FM narrow band telemetry except the station at Fine, N.Y., which is relayed through the Brasie Corners station (BRC). Antennas and receivers on Raymond and Timerman Halls pick up the signals and feed them into discriminators (Figure 7). The discriminator removes the FM carrier wave and feeds the signal into the amplifier for amplification. The output from the amplifier is recorded on the helicorder or seismograph.

The output from the discriminators also enters a computer which serves as an analog to digital converter. The computer supplies the digital information for the purpose of having a permanent record of all seismic events that have been detected by our network. This information is forwarded to the Lamont-Doherty Earth Observatory for study by their seismologists.

The entire system is "locked on" to a satellite receiver, which continuously monitors a GOES satellite, which transmits time signals from the National Bureau of Standards at Washington, D.C. The clock displays the number of the day and of the year, and hours, minutes and seconds in Universal Coordinated Time (UTC). Its accuracy is always within 12 milliseconds of true UTC time. The Potsdam College Seismic Network short-period seismometers are best suited for the detection of local earthquakes. Local earthquakes are those with epicenters within 1000 kms from the seismic station. However, distant

earthquakes (teleseisms) may also be recorded provided the magnitude of the earthquake is greater than 5 on the Richter Scale.

Table 1 shows station data for the seismic field stations of the Potsdam Network. The first column lists the station code. Presently we are recording from 7 field stations including a broadband three-component station at Lake Ozonia (LOZ). The Pitcairn (PIT) and Star Lake (STLK) stations have been closed. The latitude, longitude and elevation of each station is listed and their date of installation. The landowners of the station sites are listed below. We are grateful for their willingness to let us install the stations on their land.

John Fife	CHIP	315-322-5669
John Colt	PTN	315-265-9168
Raymond Hays	BRC	315-578-2535
Roger Fraser	FINE	315-848-2880
Bruce Monette	BGR	518-483-3835
Root Parker	LOZ	418-856-9277
N.Y Power Authority	MSNY	315-764-0226

V. Broadband Station

A three component broadband seismometer was installed at the Lake Ozonia Site in 2000. The seismometer rests on Precambrian bedrock. The instrument is well insulated. The station is located at a quiet site away from any extraneous noise. The station is solar powered with several solar panels to keep the batteries fully charged. Output from the broadband sensor is digitized with the digitizer and fed into a radio transmitter and antenna for transmission to Potsdam College. These signals are picked up by a radio receiver and fed into a PC with Windows NT running Earthworm and also into the Internet.

VI. Earthquakes in Northeastern United States

Most of the epicenters recorded by the Potsdam Network are located in northern New York in a seismic zone called the Northern New York-Western Quebec Seismic Zone. The Potsdam Network is located in the center of these epicenters. The epicenters trend northwestward, the same direction as fault plane solutions of the earthquakes. Most of these earthquakes are shallow and have their foci in the upper 8 kms of the Earth's crusts. No major fault is known to trend across the area and no surface faults have been observed that can be related to the epicenters. It is likely that the earthquake foci are due to reactivation of shallow fractures that do not reach the surface.

VII. Intensity Studies

Intensity surveys are conducted of the larger earthquakes (Mc 4-6) that are felt over a widespread area. The United States Geological Survey Earthquake Report is distributed to residents, schools, and news media throughout the area. Evaluation of the responses enables intensity at particular sites to be determined with the Modified Mercalli scale. The intensity values are plotted and contoured to construct an isoseismal map of the earthquake.

VIII. Applications of the Potsdam Seismic Network

The Potsdam Seismic Network provides significant services to the general public, education and research. The network keeps the people of the New York and eastern Canada informed about earthquakes in the area. The occurrence of an earthquake is verified by the network, and the location of the epicenter and magnitude are reported to the news media. The network helps to distinguish for the public whether the seismic event is an earthquake, quarry or mine blast, sonic boom or cryoseism. The college receives much publicity from the many calls and information provided to the news media after the occurrence of a local earthquake. A seismicity report is published listing all the earthquakes recorded during the year. Earthquake information in the area is also available over the internet at the web site: <http://www.ldeo.columbia.edu/lcsn>. This website lists the current earthquakes recorded as well as information about the network and earthquakes.

The network provides a valuable link between the college and other universities, government agencies and industries. The Potsdam Node is part of the larger Lamont-Doherty Seismic Network. We work closely with LCSN on the maintenance, repair and operation of the network to provide information about the seismicity of the region that will help us better understand the seismic hazard in the area. A close working relationship also exists with the Canadian Geological Survey and its Seismology Division, which includes a mutual exchange of the earthquake data. We also work closely with the New York State Geological Survey which has provided us with 7 portable seismographs for education use and for research dealing with aftershocks and crustal structure studies. Local industries and residents have also supported the network by providing funds for operation costs. The New York Power Authority provides funds for operational costs and the college supports its operation in its budget. A special thanks goes to Mrs. Valere Ricaud of Massena, N.Y. for her support of the network each year.

The seismic network provides services for education and research of our students. The seismograms of earthquakes recorded by the network are used to teach students seismogram interpretation in Seismology, Earth Science, Environmental Geology and Physical Geology courses. During the school year the network is operated, repaired and maintained by our students. They have the responsibility of changing the records and seismogram analysis to locate the epicenter of earthquakes. They often use the seismic data for undergraduate research projects and usually present their research projects at the Geological Society of America Meeting and Science Fair at the college. A number of undergraduate research topics are made possible by the network. Crustal structure studies by using the network data and portable seismographs given to us by the N.Y. State Geological Survey are in progress. Induced seismicity studies caused by water accumulation in closed mines have also been conducted.

IX. Where do I acquire information about earthquakes in northern New York?

Dr. Frank A. Revetta
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Potsdam, New York 13676
Office Phone: 315-267-2289
Home Phone: 315-265-2831
Email: revettfa@potsdam.edu

Canadian Geological Survey
613-995-5548

Janet Drysdale
613-992-0249
Email: drysdale@seismo.nrcan.gc.ca

Sylvia Lehmann
Email: lehmann@seismo.nrcan.gc.ca

Internet: <http://www.seismo.nrcan.gc.ca>

Lamont-Doherty Earth Observatory LCSN
<http://www.ldeo.columbia.edu/LCSN>

The Canadian Geological Survey lists all the current local earthquakes and monthly reports. The Lamont-Doherty Cooperative Seismographic Network (LCSN) lists all current earthquakes in Eastern United States and view of current seismograms.

The website for the National Earthquake Information Center NEIC is excellent for worldwide earthquake information. It is certainly worth accessing and exploring. The website is: <http://www.neic.cr.usgs.gov/>

The Lamont-Doherty Seismographic Network (LCSN) webpage:
<http://www.ldeo.columbia.edu/lcsm/eus.html>

This web page contains information such as an earthquake catalog, seismicity map, selected recent earthquakes in eastern United States, and other web sites for earthquakes in the Eastern United States.

X. Future Plans

Two more seismic stations are planned in the immediate future. A short period vertical seismometer is being installed at Mt. Arab, New York about 40 miles southwest of Potsdam. The seismic signals will be transmitted to Potsdam via an FM radio transmitter. This station is located near Tupper Lake, N.Y. and serves to expand the network toward the southeast.

A short period 3 component station is also being installed in the basement of Timerman Hall. The 3 component instrument will provide a complete record of the ground motion of local quakes and make possible more accurate locations of hypocenters of earthquakes.

MORNING FIELD TRIP

Stop I Potsdam Seismic Station (PTN)

This station was installed in October 1971 as a joint venture between Potsdam College and the Lamont-Doherty Earth Observatory. LDEO installed the seismic field station ten miles south of Potsdam and initially used telephone lines to transmit the signals to Potsdam College where the traces were recorded on a seismograph. The seismic signals were also transmitted to LDGO at the Palisades, N.Y. by telephone lines which eventually proved too expensive to operate. Later the signals were transmitted by high frequency radio transmitters to Potsdam College and to LDGO through the internet.

This station is a short period vertical seismometer best suited for detection of local earthquakes. The output from the seismometer is fed into a high gain amplifier to increase the signal amplitude. The signal is frequency modulated by a voltage-controlled oscillator (VCO). The VCO frequency is now in audible range and its output frequency changes in response to the change sensed by the seismometer. The signal is sent to the FM radio transmitter to transmit to the receiving station at Potsdam College.

The seismometer is mounted on Precambrian gneiss bedrock which produces the optimum signal. A site should be located on bedrock and away from any noise. The site must also be at an elevation so the line of sight enables the signal to be received at Potsdam. This site is powered by batteries since there are too many trees in the area to use solar panels.

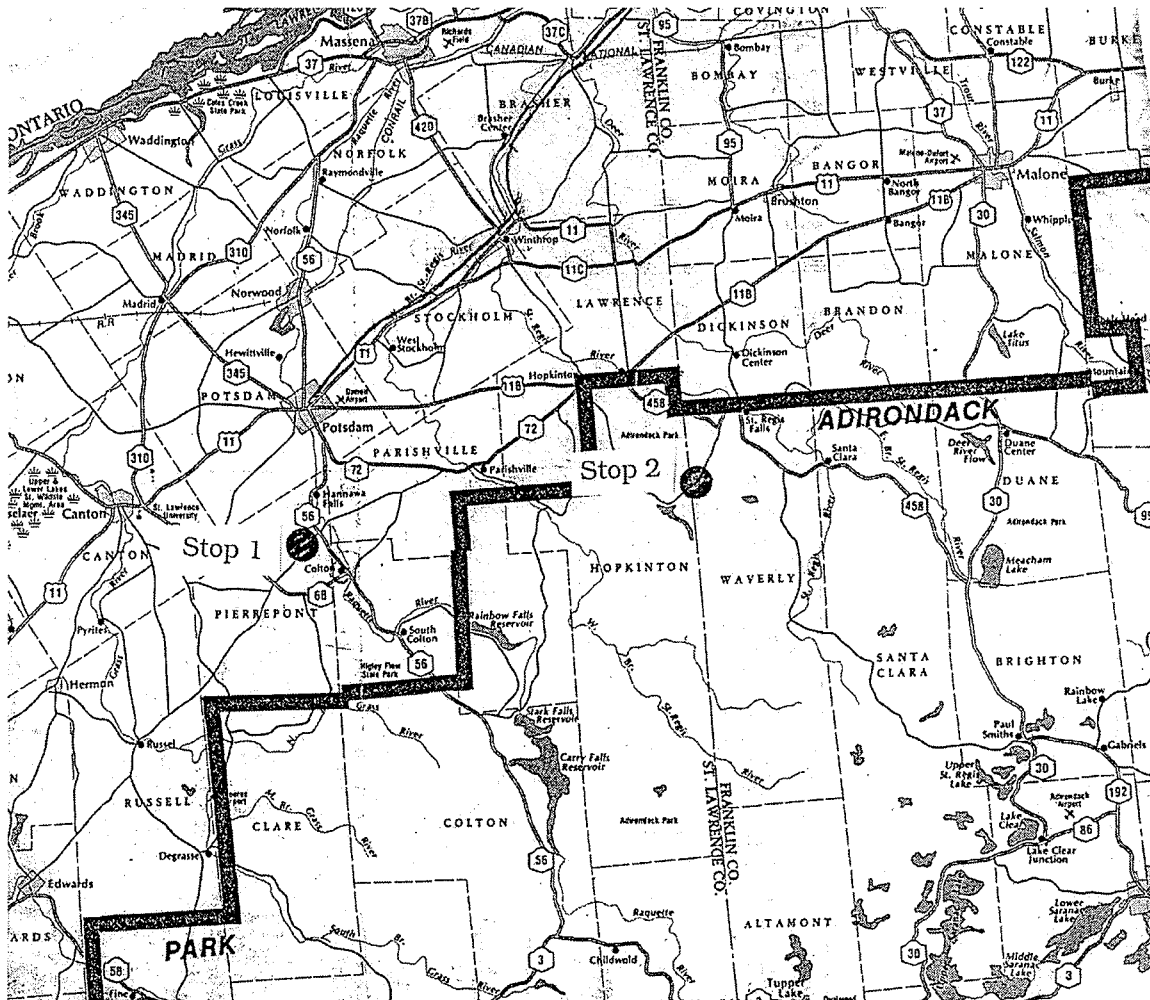


Figure 2. Location of morning field trip stops at the Potsdam (PTN) and Lake Ozonia (LOZ) seismic stations.

Stop 2 Lake Ozonia (LOZ)

The seismic station was installed in 1983. Two stations are located at this site a short period vertical seismometer and a 3-component broadband seismometer. The short period vertical is powered by non-rechargeable aircell batteries which must be replaced on an annual basis. The broadband seismometer is powered by solar panels which keep the rechargeable batteries charged for a long period of time. The 3-component instrument gives a better S wave arrival time which gives better depth control on the hypocenter. The S-waves show up much better on the north and east components and are easier to read. The broadband instruments are also less likely to go off scale eliminating the clipping problem so the entire earthquake waveform can be recorded and analyzed.

Table 1 - List of principal facts about seismic field stations in the Seismic Network

Station Name	Station Code	Latitude	Longitude	Elevation (ft)	Altitude (ft)	Altitude (ft)	Frequency (Hz)	Amplitude (µV)	Batteries	Seismometer	Distance (m)	Quadrangle	Land Owner
Pocahontas	PON	44.473	74.583	238	180	0	166.659	1700	Aircells	SP Vertical	8	Caton	John Cat
Massena	MSNY	44.998	74.862	55	80	180	167.809	1360	None	"	22	Massena	NYP&A
Bangor	BGR	44.929	74.374	326	80	250	416.806	1020	Solar Rechargeable	"	30	Bangor	Utah
Chippewa	CHIP	44.798	75.195	97	300	130	406.281	2720	Solar Rechargeable	"	14	Waddington	Montville
Lake Ozonia	LOZ	44.620	74.580	482	100	280	408.981	2040	Aircells	"	20	Lake Ozonia	Robert Packer
Fine	FINE	44.265	75.157	354	300	120	408.506	1700	Aircells	"	28	Fine	Koger
Brace Corners	BRC	44.428	75.583	126	240	65	408.506	2880	Solar and Aircell	"	34	Popes Mills	Frederic Raymond
McArdle	ARAB	44.212	74.590	776	150	330	461.075	1360	Aircell	"	40	Percival	Henry State Land

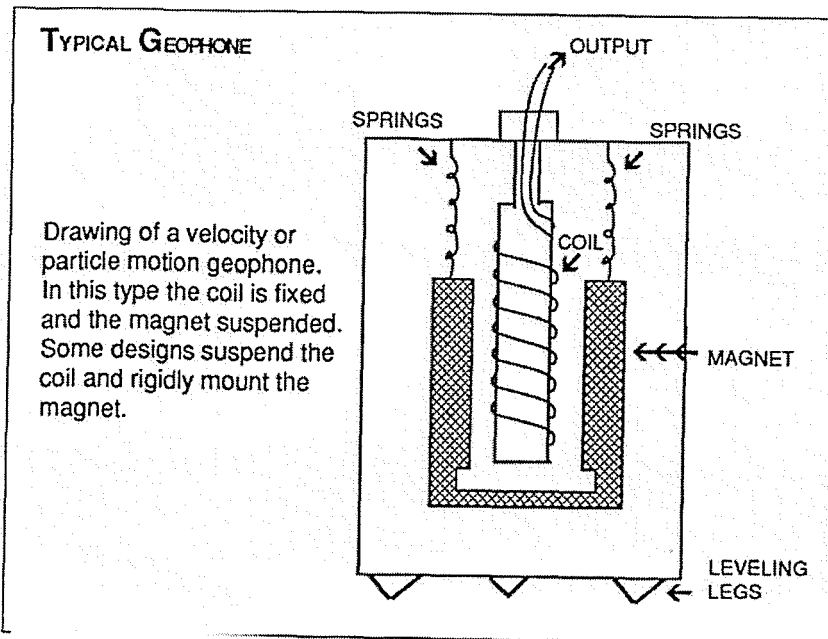


Figure 4 - Seismometer that detects earthquakes

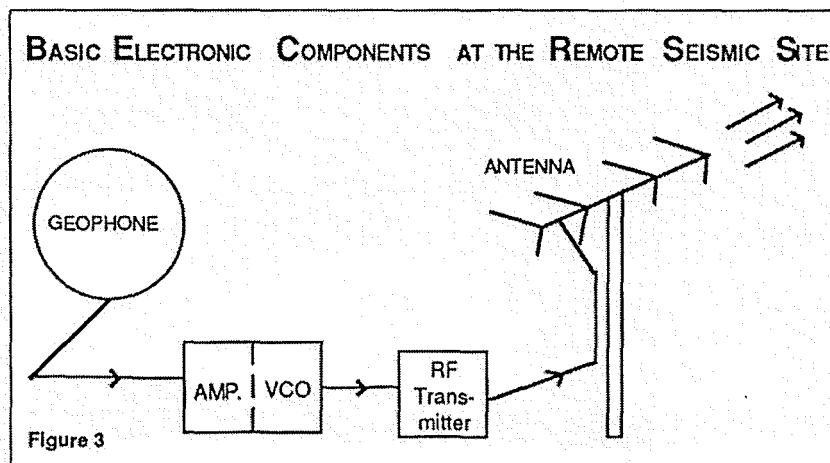


Figure 5 - Basic electronic components of a seismic field station

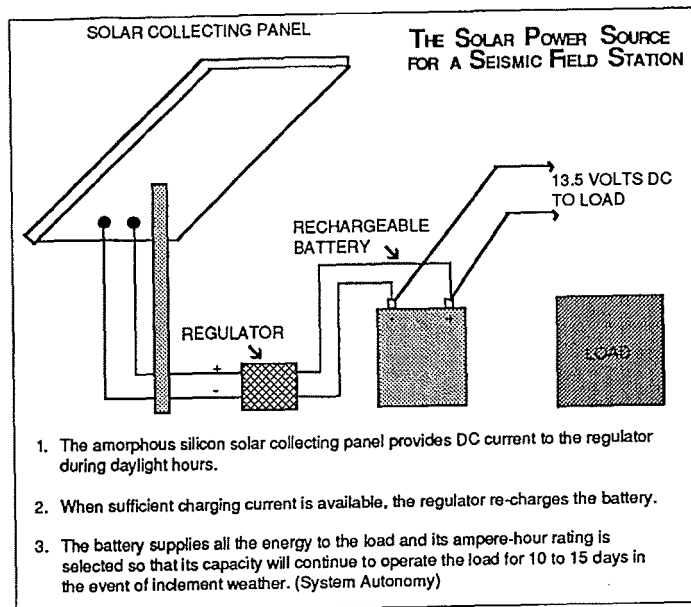


Figure 6 - Diagram showing basic components of a solar powered field station

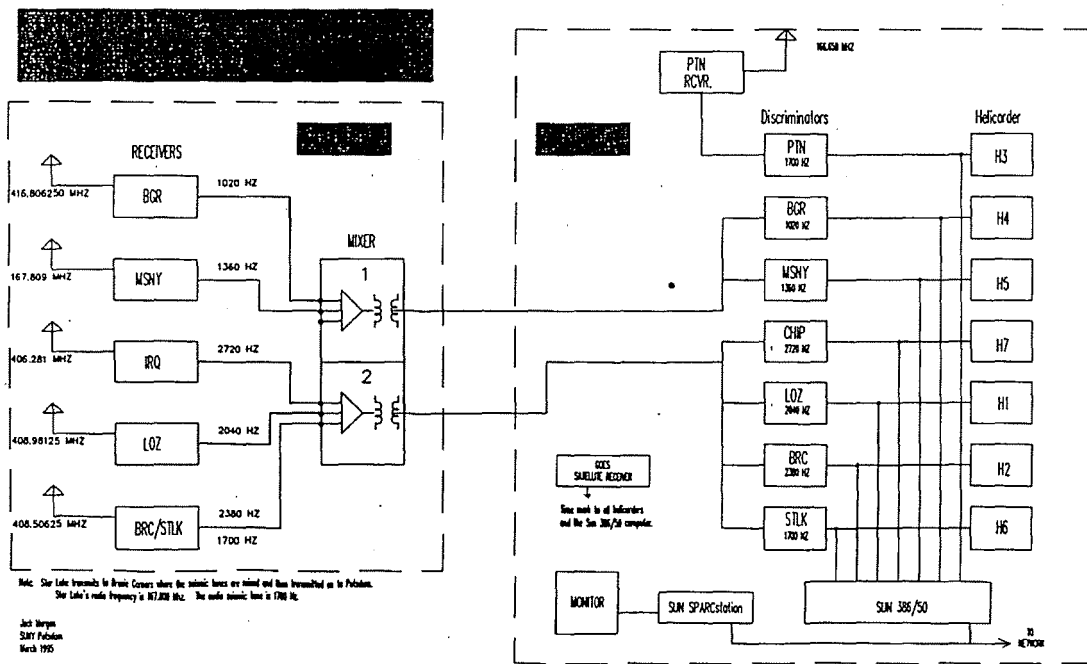


Figure 7 - Potsdam Seismic Network Components

TRIP A-8

A TOUR OF DAMAGE SITES AND A PROPOSED EPICENTER FOR THE CORNWALL-MASSENA EARTHQUAKE OF 1944

(This afternoon trip will follow Workshop W-2)

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INTRODUCTION

September 5, 1944. It was a warm late summer night in Massena, New York. World War II still raged. The local ALCOA plant was involved in the war effort with the manufacture of aluminum structural parts for the wings of American war planes. During the previous year, Nazi saboteurs had been caught near Long Island, New York with plans for the ALCOA plant. Many residents knew that. At 12:38 Eastern War Time (04:38 UTC), an ominous rumbling and hard shaking of the ground and buildings shocked the residents of Massena. The shaking lasted for what seemed like an eternity. Some had no idea what was happening. Others thought the Nazis had succeeded in landing a V-1 bomb on the ALCOA plant. Still others knew it was an earthquake. When the shaking was over, numerous homes, businesses, and other buildings along with their contents had been considerably damaged in the vicinity of Massena and Cornwall, Ontario. Many would never forget that night, and many, after more than 50 years, would call it the most upsetting night they had ever known, even those who fought in the war. During this fieldtrip we will visit some of the damage sites, recall what happened on that night in 1944, and consider a proposal for where the epicenter of the 1944 earthquake might have been.

ASPECTS OF THE MAINSHOCK

The Cornwall-Massena earthquake has been the largest known earthquake in New York State history. It took place within the southern end of the Western Quebec Seismic Zone which was identified by Basham and others (1982). This area of continuing activity (see Fig. 1) has produced large damaging earthquakes, such as the magnitude (M_w) 6.2 Timiskaming event of 1935. Depths determined for earthquakes in the seismic zone are known to reach between 20 and 25 km (Lamontagne and others, 1994), and in one case up to 31 km deep (Mohajer, 1992). A moment magnitude (M_w) of 5.8 ± 0.3 and a focal depth of 20 ± 2 km has been determined for the Cornwall-Massena earthquake by Bent (1996) with the modeling of regional waveform recordings of the event. The location of the epicenter is less precisely known.

An epicenter of 44.975°N and 74.898°W was computed by Milne (1949) using arrival times from seismograms of the earthquake. His epicenter lies roughly 5 km north of Massena. Later, Dewey and Gordon (1984) recomputed the epicenter along with those of two early aftershocks using a two-step relocation method. Their new mainshock epicenter lies at 44.958°N and 74.723°W , which is approximately 15 km east-southeast of the Milne epicenter. They found that this calculated location has an associated error of about ± 10 km. Given the magnitude of the event, it is reasonable to assume that the Cornwall-Massena mainshock and early aftershocks would have taken place in approximately the same area. If Dewey and Gordon's locations of the mainshock and two aftershocks along with their location errors are considered, it can be seen that all three events overlap a small common area with a radius of 3-5 km centered at 45.000°N and 74.692°W . This will be referred to as the Dewey and Gordon composite epicenter. The composite epicenter is positioned about 17 km east-northeast of the Milne

epicenter and 4 km northeast of the Dewey and Gordon mainshock epicenter. The locations of all three epicenters discussed are presented in Figure 2.

The modeling of the mainshock's regional waveforms by Bent (1996) resulted in a determination of its focal mechanism. Bent found that the event likely occurred on a northwest-striking fault with a rupture time of about 3 seconds and nearly equal components of thrust and strike-slip motion. This type of faulting is not unusual in the Western Quebec Seismic Zone.

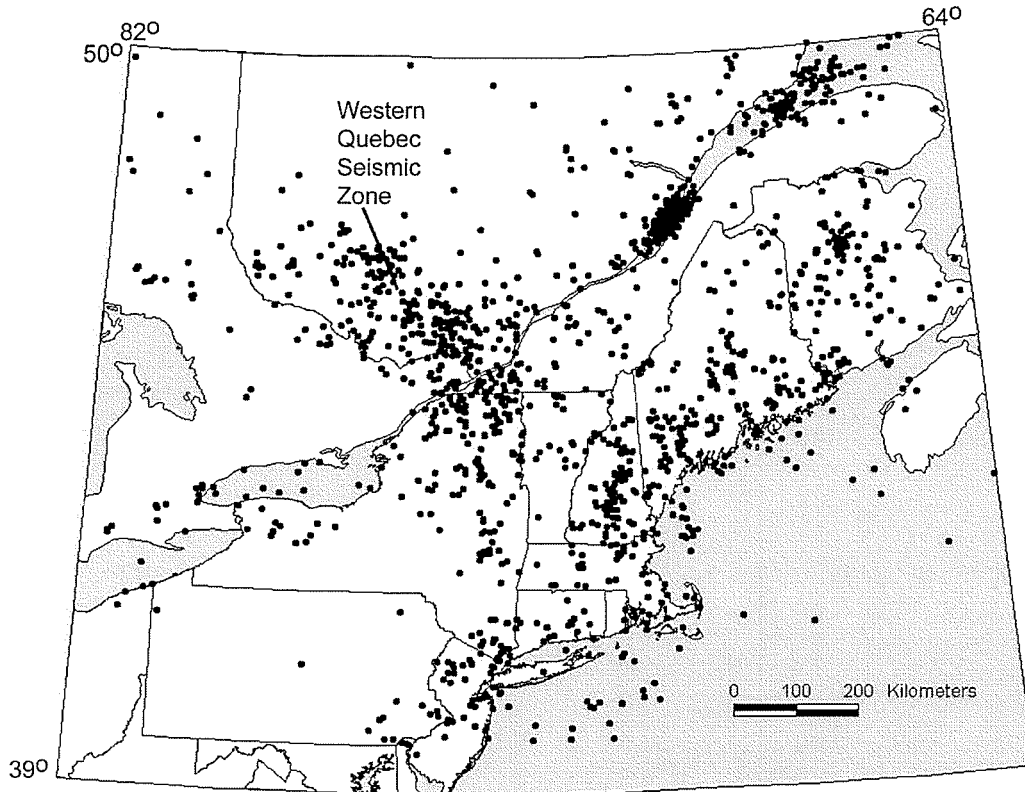


Figure 1. The location of the Western Quebec Seismic Zone as defined by instrumentally recorded earthquake activity in northeastern North America for the period of October 1, 1975 through December 31, 2002. The zone extends from northern-most New York State in a northwesterly direction along the western boundary of the Canadian province of Quebec.

FELT AREA AND DAMAGE ESTIMATES

The Cornwall-Massena earthquake was felt over an area of about 1.1 million km² (Stover and Coffman, 1993). Its vibrations were felt from New Brunswick in eastern Canada to as far west as Lake Michigan, and from James Bay in Canada to as far south as Virginia in the United States (see Figure 3). Bollinger and others (1993) estimated that the total damage area, felt effects of intensities VI (MM) to VIII (MM), covered 25,740 km². The area of considerable damage (intensity VIII [MM]), based on the observations of Berkey (1945), was confined to an elliptical area of 1,017 km² that included the communities of Massena, NY, Massena Center, NY, and Cornwall, ON. Estimates of the total property damage in the Massena and Cornwall area were reported by Hodgson (1945) as between \$1.75 and \$2.0 million 1944 dollars (\$18.9 to \$21.0 million in 2003 dollars).

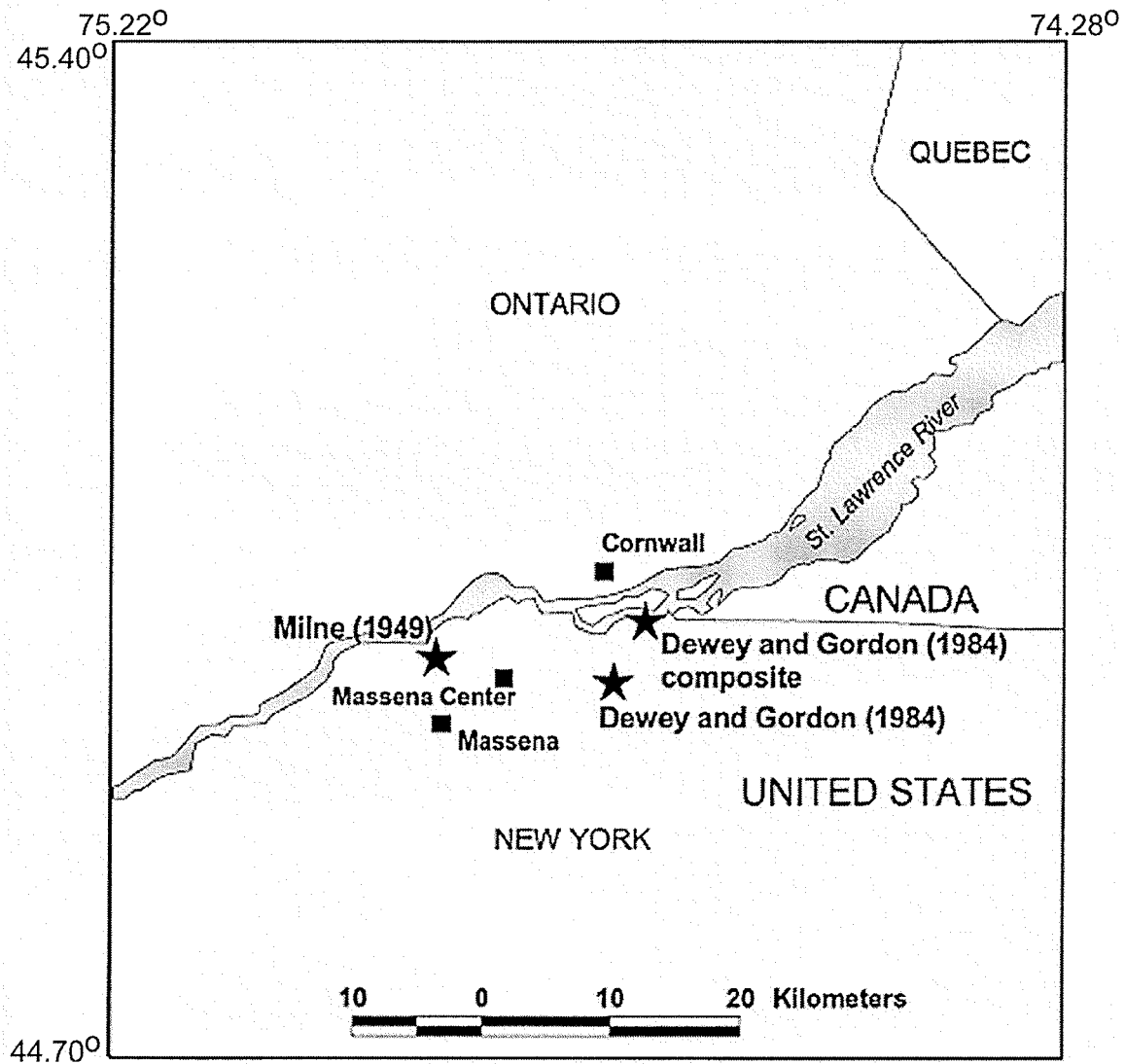


Figure 2. Positions of possible epicenters for the Cornwall-Massena earthquake as discussed in the text. Note also the locations of Massena and Massena Center in New York, and Cornwall in Ontario.

SUMMARY OF FELT EFFECTS IN THE EPICENTRAL AREA

The following damage descriptions were obtained from examination of newspaper microfilms for the *Massena Observer* (Massena, NY) and the *Daily Standard-Freeholder* (Cornwall, ON) over the period of September 5th through October 31st, 1944. Of equal importance in the composition of the descriptions was the information contained in the works of Berkey (1945), Hodgson (1944, 1945), and Webb (1944).

Non-Industrial Buildings

Residences. Residential damage in Massena, NY, Massena Center, NY, and Cornwall, ON was primarily of a non-structural nature. Approximately 2,500 to 3,000 chimneys in Massena and Massena Center, and nearly 3,000 chimneys in Cornwall lost bricks, collapsed down to roof lines, or peeled away from homes. Of particular note was the occurrence of up-bumped chimneys at Massena Center and

Cornwall. Those chimneys really did not lose bricks, but had their bricks separated and left in a loose pile at the top of the chimney. That type of chimney damage may be caused by upward traveling seismic waves. Many chimneys exhibited up-bumping in Cornwall while nearly all chimneys in Massena Center did so, implying that Massena Center was nearer to the epicenter of the mainshock than was Cornwall.

Residential chimneys not obviously damaged on the outside usually were damaged within the walls of residences. Damaged chimneys and fireplaces posed a significant fire hazard. Figure 4 shows an example of a damaged fireplace. In spite of the onset of cold weather following the earthquake, home owners were asked not to use their fireplaces until chimneys could be repaired or inspected. The mayors of both Massena and Cornwall were pressed to find enough materials and skilled workers to complete repairs of chimneys before winter.

Some residences in Cornwall and two residences in Massena had damage to both structural and non-structural brickwork. In those cases brick walls bulged outward, some bricks peeled away and fell from interior walls, or cracks opened in exterior walls that extended into the interior of the buildings. At least one two-family residence in Cornwall had to be condemned and demolished. Most residences in Massena and Cornwall suffered from damage to interior ceiling and wall plaster. Some of the plaster was merely cracked while in other cases large amounts fell. In a few cases, wood frame homes in Massena were shifted several inches on their foundations. Some home foundations in Massena and Massena Center, composed of field stone or unreinforced masonry, were cracked or severely damaged.

A few Massena residents reported that hot water pipes were snapped off at the point where they went through downstairs flooring. Most residences in Massena, Massena Center, and Cornwall had disruptions of interior contents. Some of the contents that moved, fell, or were broken included pictures, mirrors, books, bookcases, light to heavy furniture, dishes, and preserved foods.

Government Buildings. Several government buildings were damaged in the earthquake. Among those were the Town Hall and Post Office in Massena, and the Counties Building and Village Hall in Cornwall. At the Massena Town Hall the 12" stone veneer bulged outward on the lower front third of the building. The stones separated away from a 12" brick inner wall. Repair of the stone work necessitated that each stone was numbered and removed before the veneer was reconstructed (refer to Fig. 5). The building interior suffered damage when a main support was moved at its base by the earthquake. The plaster walls of the auditorium on the building's second floor were badly cracked as was some of the ceiling plaster, which fell. The United States Post Office in Massena, erected in 1936, suffered interior plaster damage and some minor damage to the exterior brickwork. No disruption to postal services occurred as a result of the damage.

The Counties Building in Cornwall developed a serious bulge on the east side, and the main building separated from its window frames by as much as 14" in some spots. The building's chimneys were damaged. Interestingly, two prisoners were trapped in their cells for 10 minutes following the mainshock because the cell doors were jammed in their frames. At the Cornwall Village Hall bricks were dislodged from exterior walls, and large cracks appeared in the sides of vaults which had walls about 1' thick.

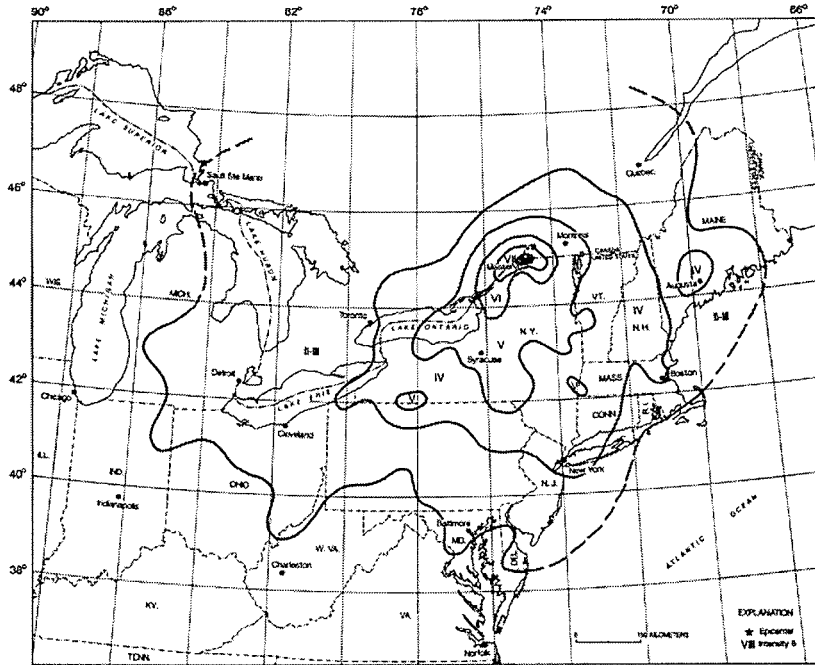


Figure 3. Map of the felt area and felt effects distribution for the September 5, 1944 mainshock as determined by Stover and Coffman (1993). Felt effects are described in terms of the Modified Mercalli Scale of 1931.



Figure 4. Damaged fireplace in the home of Mr. and Mrs. Charles G. Stubbs, 16 Danforth Place, Massena, New York (Tour Stop #2). The photo is from page 1 of the September 8, 1944 *Massena Observer*

Businesses. Businesses in both Massena and Cornwall generally had damage to plate glass windows, interior plaster, and large quantities of stock which were thrown down from shelves or displays. The most heavily damaged building used for business in Massena was the C-M (Cubley-MacDonald) building, next to the Town Hall. The building housed a dance studio, a barber shop, doctor's offices, dentist offices, insurance offices, and the Massena Observer newspaper offices. The south wall of the building buckled outward. It had to be completely rebuilt. The buckling of the wall caused large cracks to form in the plaster wall of the second floor dance studio. It is not known how the wall damage impacted the normal course of business in the affected offices.

In Cornwall the types of damages experienced by businesses was similar to that in Massena. Some business buildings did have damaged cornices and chimneys. The Orange Block in Cornwall, a three-story tall building which housed various businesses, suffered a 4" bulge in one wall. The wall was stabilized with ropes and cables and the building closed until repairs could be made. Unlike Massena, Cornwall businesses also had to endure the theft of goods from damaged window displays.

Hospitals. No damage was reported at the small wooden single story Massena Memorial Hospital. It did, however, have to operate for several hours with battery power for lights due to a power outage in Massena following the mainshock. The Hotel Dieu (Cornwall) and the Cornwall General Hospital did experience non-structural damage. At the Hotel Dieu there were broken lights at the entrance arch and fallen interior plaster. Similar damage occurred at the Cornwall General Hospital. Some minor damage to the brickwork at the top of the elevator shaft was also found at Cornwall General.

Schools. The schools in Massena, Massena Center, and Cornwall suffered significant damage. At Massena High School at least 150 window panes were broken. There was moderate to considerable plaster damage within the school. At nearby Washington School the chimney was damaged, blackboards popped-off of walls, and several truckloads of plaster fell. The fall of plaster in varying amounts appears to be the only damage reported for other Massena public schools and for the parochial school as well.

The unreinforced masonry school at Massena Center was so badly damaged that it was found to be unsafe for further use. School classes were thereafter held in the adjacent wood-frame Methodist Church. The school was eventually torn down.

In Cornwall the Collegiate and Vocational School and the Public School were extensively damaged. The Collegiate and Vocational School had structural and non-structural damage. Large portions of brick coping on the middle section of the school were shaken loose in the front and back. One section of brick coping broke loose and fell through the timber roof of the girl's gymnasium. That damage is shown in Figure 6. The school's main chimney was badly damaged, cracks developed in the brick walls, and considerable plaster fell inside the school.

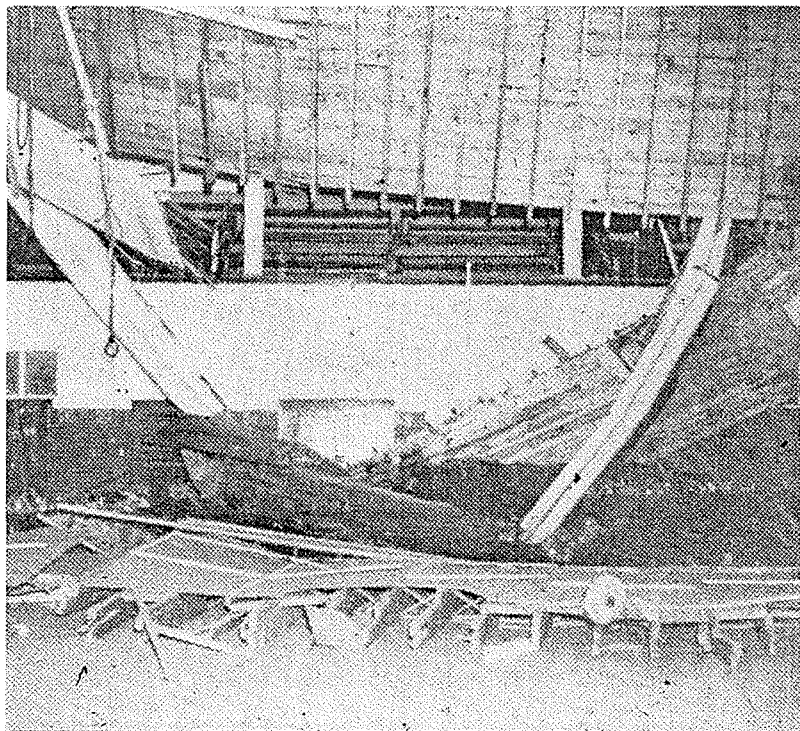
At Cornwall Public School portions of heavy brick coping fell outward from the building and inward through the roof into classrooms. The fallen coping exposed wall and roof connections. Cracks also developed in brick walls and there was considerable fall and damage of interior plaster.

The occurrence of the earthquake and the resulting damage caused the Massena public schools to be closed for one day for clean-up, inspections, and repairs. The parochial school did not close. The start of classes in Cornwall at the two damaged schools was delayed. In particular the Cornwall Public School did not open for classes until October 4, 1944. The school opened with limited classes. By October 17th most classes were in session using a staggered class schedule.

Figure 5. Repair work being done to the front stone work of the Massena Town Hall. The stone work bulged outward on the front bottom third as a result of the earthquake. The picture is from page 14 of the September 18, 1944 *Watertown (NY) Daily Times* (Tour Stop #10).



Figure 6. Destroyed timber roof of the girl's gymnasium at the Cornwall Collegiate and Vocational School in Cornwall, Ontario. A portion of exterior brick coping broke loose from the back of the school and fell through the roof. Photo is from Lamontagne and Bruneau (1993).



Churches. Most churches in the epicentral area had plaster and chimney damage as a result of the September 5th earthquake. The First Baptist Church in Massena had some minor cracking of the brick walls at various points (refer to Figs. 7 and 8). The majority of damage was confined to cracked interior plaster, especially bad in the sanctuary. St. John's Episcopal Church experienced glass and plaster damage along with damage to the marble altar. Brick supports within the altar collapsed and allowed the marble to shift. One church at Massena Center suffered structural damage and was eventually torn down.

In Cornwall the damage to churches was generally worse than in Massena. Trinity Anglican Church had ornamental stones at the peak ends of the roof and small minarets thrown down. A square Norman tower on the church was badly cracked above the roof line. Stones around the east stained glass windows were thrown out. Outer plain glass windows on the north side were broken. In addition there was interior plaster damage. St. Columban's Roman Catholic Church suffered from cracked walls, which in some cases showed signs of buckling. Three corner towers of the main altar were broken, the Tabernacle was damaged, and the main porch of the church was damaged. An organ loft was also damaged and its projection over the auditorium had to be braced. Further damage included a twisted east tower of the church and a great deal of fallen plaster. St. Columban's was closed for repairs and inspection, and was later reopened.

Other Cornwall churches that were impacted by the earthquake included the Knox United Church and St. John's Presbyterian Church. Besides significant interior plaster damage at Knox United Church, the inner walls of the steeple were weakened and had to be strengthened. Portions of the chimney fell, plaster fell, and the pipes of the church organ were damaged at St. John's. Knox United Church was closed for repairs until October 1, 1944.

Lifelines Electricity, domestic water, and telephones were impacted by the September 5th mainshock. Immediately following the earthquake power was lost in Massena for 1 to 2 hours, and for an unspecified short time in Cornwall. Homeowners reported numerous breaks in water line connections between residences and water mains in Massena. One 6" water main was reported to have broken in the northern portion of the village of Massena. Some 10", 12", and 18" underground water lines at the ALCOA plant in Massena were broken by the earthquake. Those lines also provided water for the public water system in Massena. While those lines were being repaired at the plant, the village experienced low water pressure for about two days.

Telephone service was disrupted in both Massena and Cornwall. With power out in Massena, the phones continued to operate through the use of either an emergency generator or batteries. No damage to phone equipment or lines was reported. However, in Cornwall about 50 phone lines were broken. That resulted in some phone service disruption for about 36 hours in some parts of Cornwall. The primary disruptions to phone service in northern New York and southeastern Ontario came from increased phone use by panic stricken residents wanting information about the mainshock. That increased usage overtaxed operators and phone circuits that created delays in obtaining dial tones and placing calls (up to 3 hours in Cornwall).

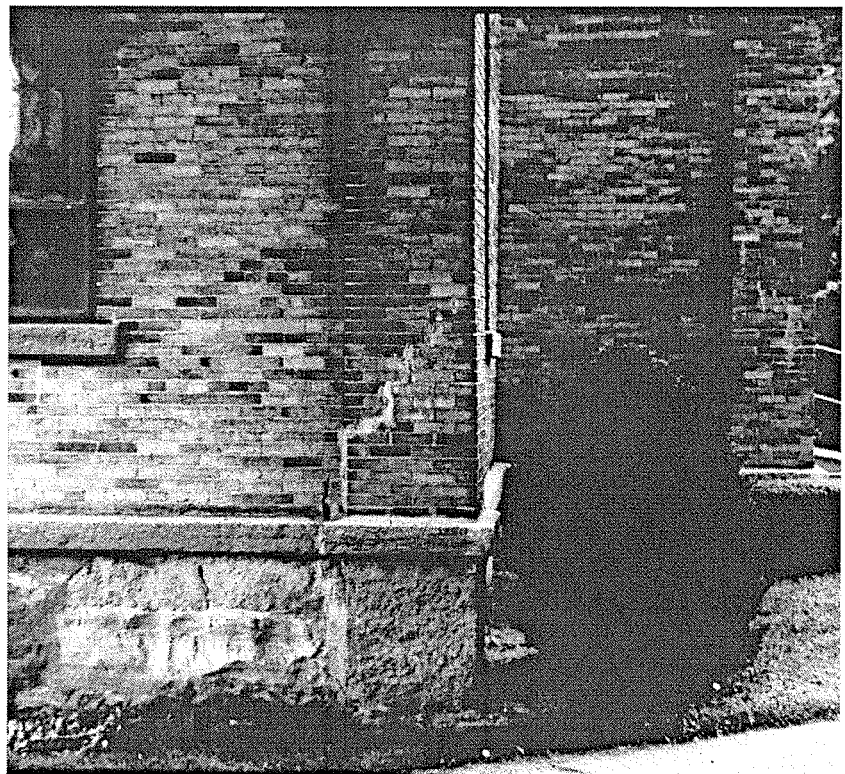
Industry Damage was reported at the ALCOA plant in Massena and at the following plants in Cornwall: (1) Canada Bread Company, (2) Canadian Cottons Ltd., (3) Canadian Industries Ltd., (4) Cornwall Chemicals Ltd., (5) Courtaulds (Rayon) Ltd., (6) Howard Smith Paper Company, (7) Ives Bedding Company Ltd., and (8) Powdrell and Alexander. It should be noted that Massena only had the one manufacturing plant.

Cracked tall chimneys, some of which required temporary reinforcement and repair, were noted at several of the plants. Those chimneys in a few cases were up to 220' tall and cracked from the top

Figure 7. Cracked brick work above the main door to the First Baptist Church in Massena, corner of Main Street and East Orvis Street in Massena (Tour Stop #9). The cracks above the entrance are about 1" to 2" wide. This photo was taken in 1993.



Figure 8. Cracked brick work on the lower north side wall of the First Baptist Church near the front of the building. The crack is generally 2" wide. Photo was taken in 1993.



down by as much as 35'. Some plants were found to have cracked brick walls and damaged plastering. At Canadian Cottons, bricks fell from exterior walls of the Stormont Mill, while at the Dundas Mill a wall moved outwards by as much as 1". At the Ives Bedding Company the plank roof of the main building was found to have shifted out of position. A large bread oven was cracked at the Canada Bread Company.

A testament to the force of the ground shaking from the earthquake lies in the fact that some large industrial equipment was moved from positions. At the ALCOA plant in Massena, seven out of eight 1" steel pins used to align the shaft of a 70 ton fly wheel sheared off, bent, or popped out of place. Three 200 KVA transformers on concrete mats shifted at Powdrell and Alexander. In the main building of that plant, 71 box looms had broken cast iron supports. A heavy safe in an office was also reported to have moved 6" there as well.

Transportation There were no reports of disruptions to automobile traffic, except perhaps in some spots where bricks or broken glass might have fallen in the streets. Street lights did go out in both Cornwall and Massena due to power outages. There was a report of humped-up pavements on Maple Street and North Main Street in the north section of Massena near the bank of the Grasse River. It is not known if this hindered traffic. Railroads and the street car system in Cornwall were also not impacted. Overall the transportation infrastructure was found to be unaffected.

Social Impacts Several minor injuries were reported in the newspapers as having occurred as a result of the earthquake. However, none of those injuries were treated at the Cornwall or Massena hospitals. One man did suffer severe electrical burns and was treated at the Massena hospital. The man was an employee at the ALCOA plant. When power was restored to Massena and the plant after the earthquake, a "pot" used to melt aluminum was damaged by a power surge. This resulted in the burns. The victim later recovered.

One of the greater social impacts of the earthquake was the occurrence of post traumatic stress. Shortly following the earthquake, residents of both Cornwall and Massena could not sleep and suffered from varying degrees of anxiety. Jittery, tired, and nerve-shattered were some adjectives used to describe people in Cornwall and Massena. For a number of people, these same symptoms continued for at least two months or more. Of note was a series of interviews conducted by the author in Massena in 1994. Several of the people interviewed 50 years after the earthquake still expressed some anxiety about the earthquake. One resident who fought during World War II noted that the earthquake had far more impact on him than did the battles he was in.

Cemetaries A number of cemeteries in the Cornwall and Massena area had damage to monuments or gravestones. Of 30 cemeteries visited by investigators following the earthquake, 13 had monuments that had markedly rotated, shifted, or fallen over. Figure 9 gives an idea of the distribution of the cemetery monument damage. Those monuments that were composed of more than one part sometimes had individual parts rotated in opposite directions. An interesting feature of the cemetery damage is that the majority of monuments on the Canadian side of the St. Lawrence River had counter-clockwise rotations, while those on the American side had clockwise rotations. It should be noted that the numbers of monuments damaged and the degree of damage generally increased as one approached the area containing Massena Center, NY and Cornwall.

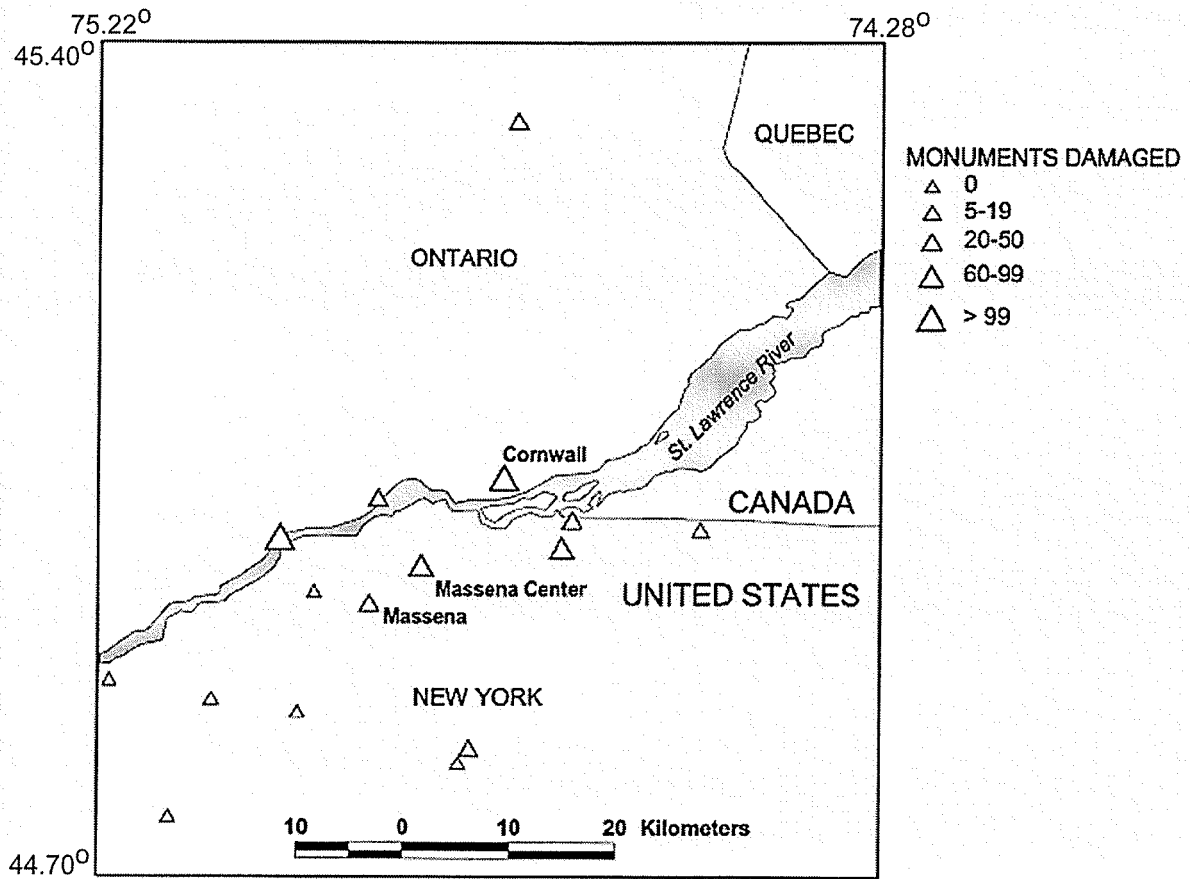


Figure 9. Distribution of some cemeteries investigated for damage following the 1944 Cornwall-Massena mainshock along with total numbers of damaged monuments at each locality. The numbers of monuments damaged and the degree of damage generally increased as one approached the area containing Massena Center, NY and Cornwall.

GEOTECHNICAL AND HYDROLOGICAL OBSERVATIONS

Influence of Local Surficial Deposits on Damage Distribution

Both Berkey (1945) and Hodgson (1944, 1945) noted that the locations of the most severe damage were controlled by surficial materials. Buildings constructed on outwash sands and gravels, and especially on silts and marine clays were greatly damaged. Those structures on boulder till were not significantly damaged. In Cornwall the greatest damage occurred on a belt of marine clays and associated silts that are situated in the central portion of the community. Massena's damage was found primarily in areas of glacial outwash. At Massena Center, marine clays with some outwash sands and gravels lay beneath the foundations of damaged structures.

Liquefaction

Earlier in this article it was noted that fairly large water mains in Massena and at the ALCOA plant were broken in the earthquake. Pavements were also humped-up in one part of Massena along the northern bank of the Grasse River. These locations seem to lie in deposits of marine clays with pockets

of sand and gravel outwash. The pavement and underground pipe damages were probably caused by permanent ground displacements as a result of liquefaction induced lateral spreading.

A definite occurrence of liquefaction took place at the W.G. Hooper Farm, about 2 km northwest of Massena Center. In the yard behind the farmhouse two north-south trending fissures of about 1" to 2" in width and up to 100' in length opened and white sand and water flowed out (Berkey, 1945). A third fissure from which sand and water flowed was found about 300' to the west across the local road. A back-hoe investigation of the farm site in the early 1990s by Tish Tuttle and Noel Barstow of the Lamont-Doherty Earth Observatory of Columbia University found sand dikes and diapers formed by the liquefaction of a 4' thick layer of white sand lying 8' beneath marine clays and silts. A photo of a sand dike at the Hooper Farm site is presented in Figure 10.

Impacts on Water Wells and Springs

Water wells in the vicinity of Massena, along the north shore of the St. Lawrence River, and particularly around Massena Center either dried-up or increased their flow following the earthquake. The same could be said of some springs near Massena Center (Berkey, 1945; Hodgson, 1945). Berkey (1945) found that most of the productive farm wells around Massena Center were shallow and dug into outwash sands and gravels. It was his opinion that compaction of the overburden by the earthquake might have caused the water flow changes.

AFTERSHOCKS

It is not unusual for large earthquakes in eastern North America to be followed by a series of aftershocks. The Cornwall-Massena earthquake was no exception. Smith (1966), in his earthquake catalog, lists 26 instrumentally recorded and 2 reportedly felt aftershocks from September 5, 1944 through November 10, 1949. The aftershocks had reported Richter magnitudes (M_L) of 2.0 to 4.6. A detailed catalog of felt aftershocks made by H.R. Horton, a Massena Center resident, lists 49 aftershocks for the period of September 5, 1944 through January 2, 1946 (Berkey, 1945). Additional reports of felt aftershocks were made in the pages of the *Massena Observer* and the *Daily Standard-Freeholder* (Cornwall, ON) from September 5th through October 31st, 1944. If aftershock reports are combined from all sources for September 5 through October 31 of 1944, then at least 43 aftershocks are known for that period.

The largest aftershock occurred on the morning of September 5th at 4:51 a.m. (08:51 UTC) and had an estimated body wave magnitude (m_{bLg}) of 4.5. It was generally felt in northern New York and southern Ontario. The second largest aftershock took place at 7:24 p.m. (23:24 UTC) on September 9th (Dewey and Gordon, 1984). That magnitude (m_{bLg}) 4.0 event caused further masonry damage in Massena and Cornwall.

Aftershock reports for September 5th through October 31st suggest that more aftershocks were felt in Massena Center than in either Massena or Cornwall. It appears that the newspapers in Massena and Cornwall made good efforts to report all felt aftershocks. Assuming their record keeping was as good as that of H.R. Horton at Massena Center, then a look at the distribution of felt aftershock reports between the three communities may provide a clue as to where the September 5th mainshock might have been. A consideration of the aftershock reports shows that 8 events were felt in Massena, 19 events in Cornwall, and 37 events in Massena Center. This distribution of felt reports is suggestive that the mainshock and the following aftershocks might have had a source between Massena Center and Cornwall, but closer to Massena Center.



Figure 10. Sand dike found in trench at the site of the former William G. Hooper farm, Massena Center, New York (Tour Stop #15). Shovel is for scale. Note disrupted soil structure defining the sand dike. Photo is courtesy of Tish Tuttle.

WHERE WAS THE EPICENTER?

Earlier in this article three possible epicenters from Milne (1949) and Dewey and Gordon (1984) were presented. The likely epicenter of the Cornwall-Massena earthquake should probably lie in the area most heavily impacted by the event and its aftershocks.

It is known that chimney damage took place in northern New York and southern Ontario, with considerable damage in Massena, Massena Center, and Cornwall (Hodgson, 1944; Berkey, 1945). Figure 11 depicts the distribution and degree of chimney damage in the region. The heaviest damage was at Massena Center. Recall that up-bumped chimneys, suggesting damage by upward traveling seismic waves, were found at Massena Center and Cornwall, with a higher number at Massena Center. Also recall from the description of cemetery damage that the largest number of impacted monuments and the highest degrees of damage were found in the Massena Center to Cornwall area.

Additional evidence suggestive of where the epicenter was comes from the location of impacted water wells in the vicinity of Massena Center, the fact that obvious evidence of liquefaction was found near Massena Center, and that most aftershocks were felt at Massena Center and Cornwall, with more felt at Massena Center than anywhere else.

If all of the evidence is considered, then it seems that the earlier named Dewey and Gordon composite epicenter (refer to Fig. 2) is the closest of the three discussed epicenters. To better fit the felt effects information described above, a new epicenter location of 44.99°N and 74.79°W is proposed. The position of that proposed epicenter is shown in Figure 12 along with the distributions and degrees of chimney and cemetery monument damages in the Cornwall and Massena area for emphasis.

CONCLUSION

The Cornwall-Massena earthquake of 1944 was the largest seismic event so far known in New York State. Based on damage distributions, liquefactions, water well disturbances, and a series of reported felt aftershocks, a new epicenter approximately 5 km northeast of Massena Center, New York is proposed. This magnitude (M_w) 5.8 event represents a good scenario earthquake for emergency planning. While typical large earthquakes in eastern North America originate at depths of 10 km, the Cornwall-Massena event, in spite of its greater depth (≈ 20 km), could be used as a model for much for New York State. Earthquakes of this size generally cause considerable damage in a somewhat limited area and can be felt widely. The impact of this earthquake would have been much greater if it had occurred near a larger population center. If it did so today, then damage estimates in a metropolitan area could easily run in the billions of dollars.

Figure 11. Distribution and relative numbers of chimneys damaged by the September 5, 1944 mainshock.

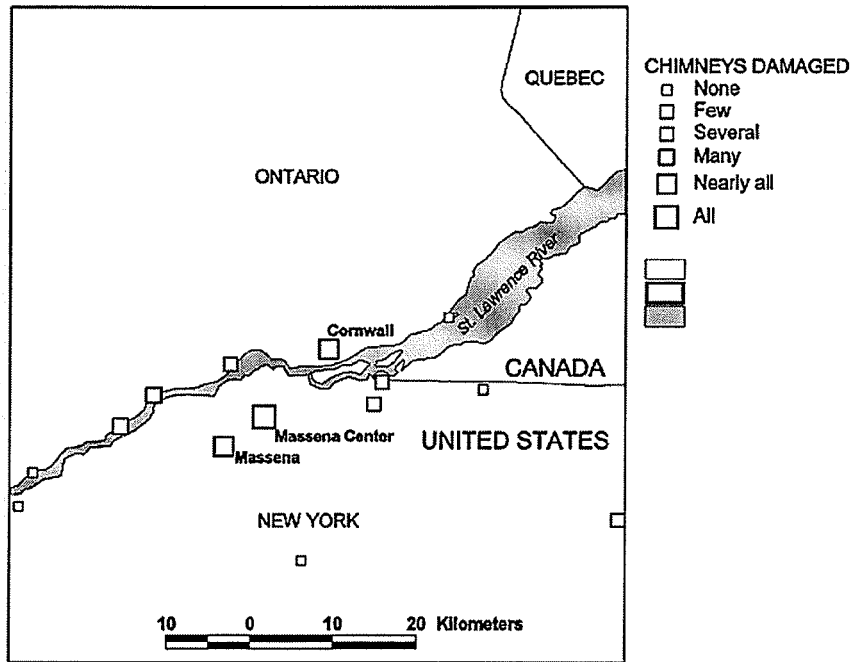
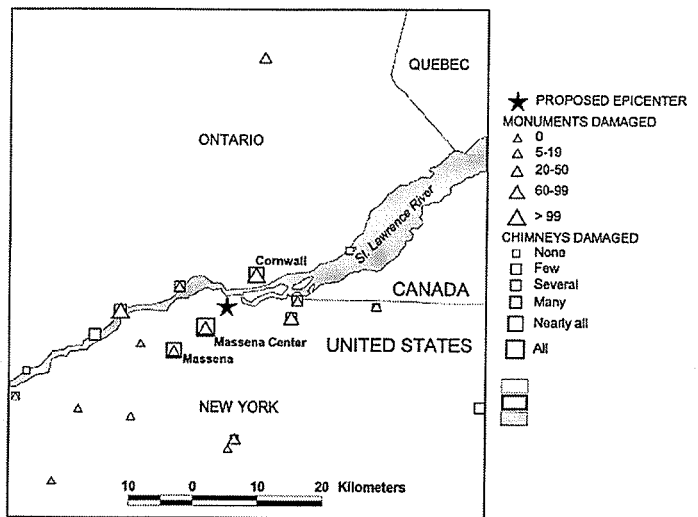


Figure 12. Proposed epicenter location of the Cornwall-Massena mainshock. The damage locations and degrees of damage for chimneys and cemetery monuments are shown as support for the proposed epicenter.



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**WALKING TOUR AND ROAD LOG FOR DAMAGE SITES IN
MASSENA AND MASSENA CENTER, NEW YORK**

This tour is actually a combined walking tour of sites in downtown Massena and a driving tour from Massena to the Eisenhower Lock of the St. Lawrence Seaway north of Massena Center. Travel to downtown Massena and park behind the Massena Town Hall on Main Street. Proceed south from there on foot to the northwest corner of Main Street and West Orvis Street. The walking tour, which is about 1.4 miles in length, will start there. A map of the walking tour, Sites 1-12, is presented on Figure 13.

Walking Tour

Site Number	Location	Purpose of Stop
1	Former Site of New York Telephone Company Office, 3 West Orvis Street	Discussion of communication disruption in the earthquake.
2	Former home of Mr. and Mrs. Charles Stubbs, 16 Danforth Place	Discussion of residential damages.
3	Old Cemetery on West Orvis Street.	Search for rotated cemetery monuments.
4	Former home of Mr. Herbert Hatch, 2 Ransom Avenue.	House has chimney repaired from the 1944 mainshock.
5	Former home of Mr. and Mrs. Leonard Prince, 61 Bridges Avenue.	Discussions of residential building contents damage and psychological trauma.
6	Former site of Massena High School, Bridges Avenue	Discussion of damage to the school, and other schools in Massena and Cornwall.
7	St. John's Episcopal Church, 141-143 Main Street	The chimney at this church appears to have repaired cracks from the earthquake. Marble alter was also damaged.
8	United States Post Office, 98 Main Street	Discussion of earthquake damage to the building and about unreinforced masonry buildings in general.
9	First Baptist Church, Corner of Main Street and East Orvis Street	Church exhibits repaired cracks in exterior brick work from the earthquake. Discussion of church damage in Cornwall and Massena.
10	Massena Town Hall, Main Street	Discussion of damage to this building.
11	C-M Building, 60 Main Street	Examination of north wall which was torn-out and replaced because of earthquake damage.
12	Former Site of the Sunshine Store, 10 Main Street	Discussion of damage to the former business here and the earthquake's impact on small business in the Massena and Cornwall area.

Please return to your vehicle at the Massena Town Hall and begin the driving portion of the tour.

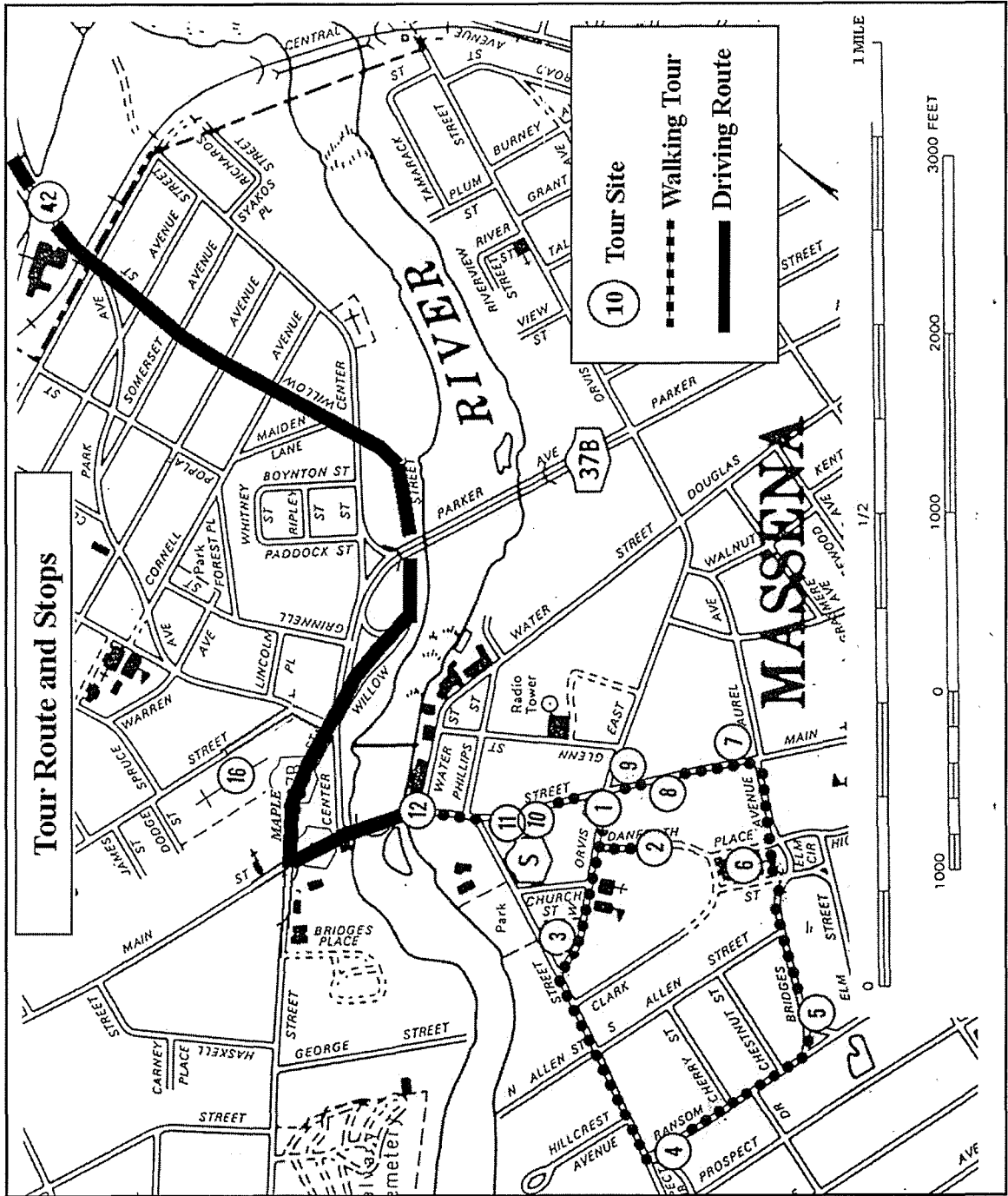


Figure 13. Map of downtown Massena, New York and the Walking Tour Sites.

Road Log

The route for this portion of the tour is shown on Figures 13, 14 and 15.

Approx. Cumulative Mileage	Approx. Miles From Last Point	Route Description
0.0	0.0	From the Massena Town Hall turn left and proceed north on Main Street over the Grasse River Bridge
0.2	0.2	Turn right (east onto Maple Street).
0.3	0.1	Continue east onto Willow Street (Route 42)
1.3	1.0	STOP 13 on right shoulder east of ALCOA Road.

STOP 13. OVERVIEW OF THE ALCOA PLANT.

This plant suffered minor cracking to brick walls and interior plaster damage. Five large chimneys ranging in height from 80' to 220' were cracked by the earthquake. The chimneys were cracked at points ranging from 8' to 30' down from the tops. It was on the plant grounds that 3 large water lines were broken by the earthquake due to apparent lateral spreading of the ground. One ALCOA employee was severely burned at the plant when a power surge damaged equipment after power was restored following an earthquake caused power outage. Return to the vehicle and continue on Route 42 to Massena Center.

3.4	2.1	Continue east on Route 42, past intersection with Route 131.
3.6	0.2	STOP 14 – Massena Center Cemetery

STOP 14. MASSENA CENTER CEMETERY

Many of the monuments in this cemetery were rotated, shifted, or knocked-down by the earthquake. At this stop please take some time to find some of the damaged grave stones. Just across the stream to the east of the cemetery is Massena Center. All of the chimneys in this area were up-bumped. The old Massena School, once located across the stream and north of the road was severely damaged in the earthquake and had to be demolished. Return to the vehicle. Turn left and return to the intersection of Route 42 and Route 131.

3.8	0.2	Turn right (north onto Route 131).
5.8	2.0	STOP 15 on access road next to Robinson Creek.

STOP 15. FORMER SITE OF THE WILLIAM HOOPER FARM

This is the site of the liquefactions or “sand boils” that occurred during the 1944 earthquake. The farm well also went dry here. A discussion of work done on the site, liquefaction, and the earthquake’s impact on local water wells will be conducted here. Please return to the vehicle and turn right (north) on Route 131. Follow the signs to the Eisenhower Lock.

6.3	0.5	STOP 16 – Parking lot of the Eisenhower Lock
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STOP 16. EISENHOWER LOCK

This stop is near the location of the H.R. Horton Farm where the majority of the Cornwall-Massena earthquake aftershocks were felt. The aftershocks will be discussed here as well as the evidence for the proposed epicenter.

END OF FIELD TRIP

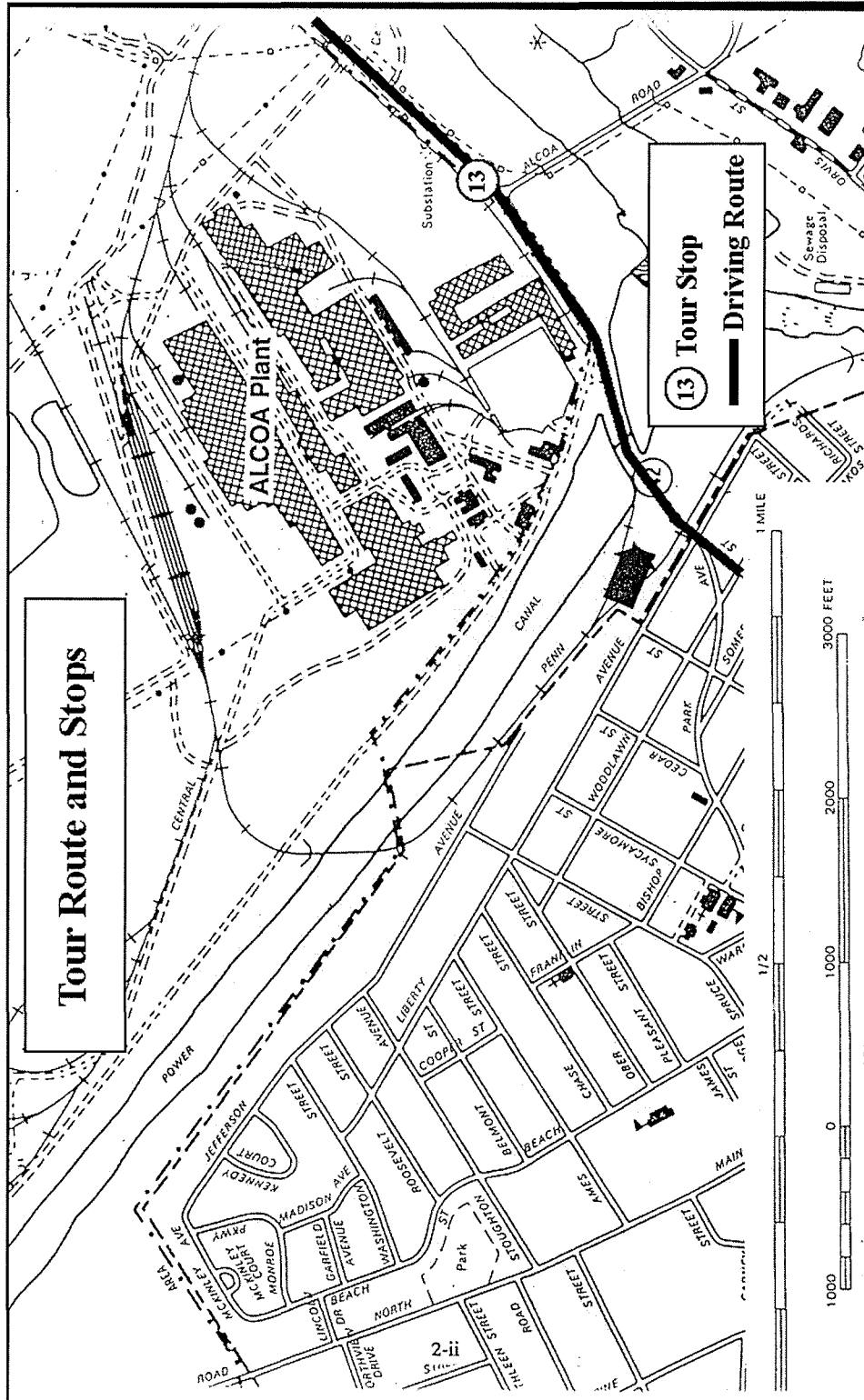


Figure 14. Driving Tour Route and Stops traveling from Massena towards Massena Center.

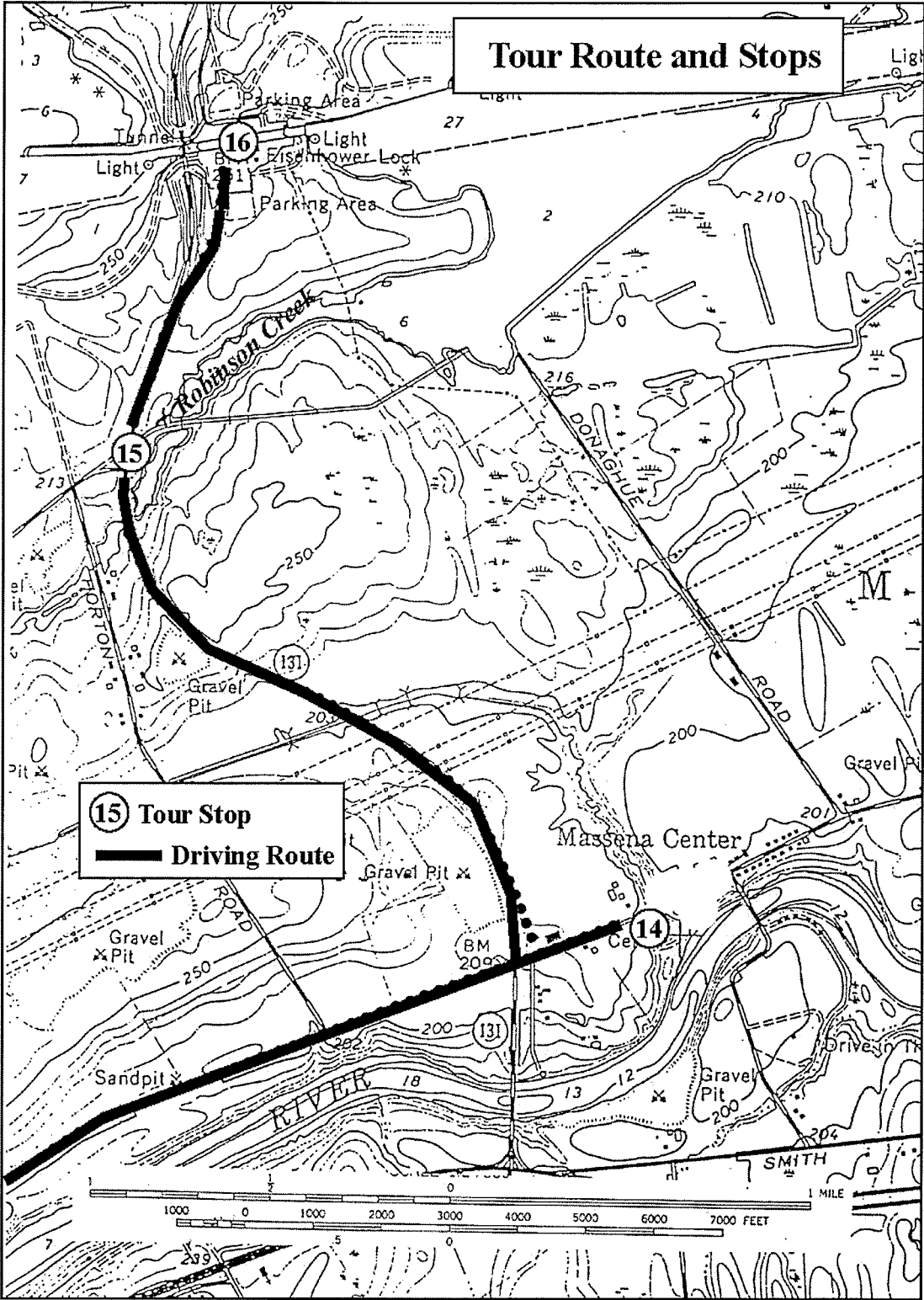


Figure 15. Driving Tour Route and Stops around Massena Center.

Trip B-1

L- VERSES S-TECTONITE FABRIC VARIATIONS WITHIN THE SOUTHERN ADIRONDACK SHEAR ZONE SYSTEM: PROGRESSIVE DEFORMATION ASSOCIATED WITH A SINISTRAL CONJUGATE TO A GRENVILLE SYNTAXIS

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INTRODUCTION

This field guide was prepared in tandem with a field guide for the 73th and 75th NYSGA field conferences, and synchronously with an article written for the Memorial Volume to Nicholas Rast, recently published in the *Journal of Geodynamics* (Gates et al., 2004). Therefore, some parts of this guide are directly related to work presented in the earlier field guides and some parts were prepared for multiple projects; however, the emphasis here is exclusively on new findings in the Adirondacks. We encourage the reader to examine our data presented in the earlier field guides (Gates et al., 2001; Gorrington et al., 2003) and summarized in Gates et al. (2004) for further details.

Transpressional strain is found to be related to a variety of tectonic environments. Transcurrent faults with restraining bends produce structures such as thrusts and conjugate faults (Woodcock, 1986). Oblique motion vectors between two tectonic plates result in oblique collision that produces zones of transpressional strike-slip deformation in the hinterland, and belts of thrusting in the foreland (e.g., Woodcock, 1986; Tappionier and Molnar, 1976). As well, zones of transcurrent strain can develop syntaxes in regions of the crust experiencing horizontal escape as the result of rigid indentors in the colliding lithosphere (Tappionier and Molnar, 1977). These structures have been almost exclusively described for rocks that were exhumed from intermediate to shallow levels of the crust. The distribution of strain and the location of faults can be controlled by the presence of pre-existing structures (Dewey and Burke, 1973), or by the juxtaposition of rock bodies with ductility contrasts such as decoupling of cover rocks over deforming crystalline basement (Gates et al., 1999; Valentino et al., 2004).

Dewey and Burke (1973) and Windley (1986) proposed a model for tectonism recorded in the Grenville Province rocks based upon the deep structure of Himalayas and the intensity of tectonism recorded there. Tappionier and Molnar (1977) proposed that the rigid indentation of India formed a syntaxis (abrupt bend in the general attitude of the orogen) containing conjugate strike-slip faults in the Eurasian continent during the Himalayan Orogeny. Northeast-striking sinistral, transcurrent shear systems accommodate tectonic escape (Tappionier et al., 1982) in China and southeast Asia, and these fault systems record hundreds to thousands of kilometers of offset over tens of millions of years. There are also smaller, northwest-striking, dextral systems that have been synchronously active with the sinistral zones that form the conjugate pairs to the larger sinistral zones of tectonic escape within the Himalayan syntaxis.

The Grenville Province forms one of the longest and most deeply exhumed areas of continental crust on Earth, extending from Scandinavia, through eastern Canada and inliers in the Appalachian chain, to Texas and Mexico, and perhaps beyond. Grenvillian basement massifs in the northeastern United States form a series of unconnected inliers along the Appalachian orogen (Figure 1). Because of the great spacing and high degree of tectonism associated with the Appalachian tectonic events, correlation of Grenvillian rocks among the massifs are difficult. In addition to widespread granulite-facies metamorphic conditions at about 1.0 Ga, these basement massifs all contain vast volumes of ‘A-type’ granite bodies whose magma had intruded (ca. 1150 Ma) into older supracrustal rocks (ca. 1250 Ma) of varied character prior to Ottawa deformation (ca. 1040 Ma; e.g., McLelland and Isachsen, 1986). The Grenville Province exposes the deep crustal roots of an ancient mountain range of immense portions, and records the assembly of one of the Earth's few recognized supercontinents, Rodinia. Consequently the Ottawa Orogeny (ca. 1070-1000 Ma) is often cited as a classic example of continent-continent collision and compressive thickening of the crust, with invocation of the Himalayas as a modern tectonic reference frame (Dewey and Burke, 1973; Windley, 1986; McLelland et al. 2001). However, refinement and testing of such a model must address many important components of the orogeny. One of the most significant components in the Himalayas is the massive amount of strike-slip faulting expressed in tectonic escape and the syntaxis (Tapponnier and Molnar, 1977). Whereas compressive tectonics is universally documented in the Grenville orogen, few workers have recognized analogous, large-scale, orogen-parallel deformation (cf. Baer, 1977). Some of the evidence for strike-parallel deformation is described herein, and is much of the basis for the sequence of outcrops listed in this guide.

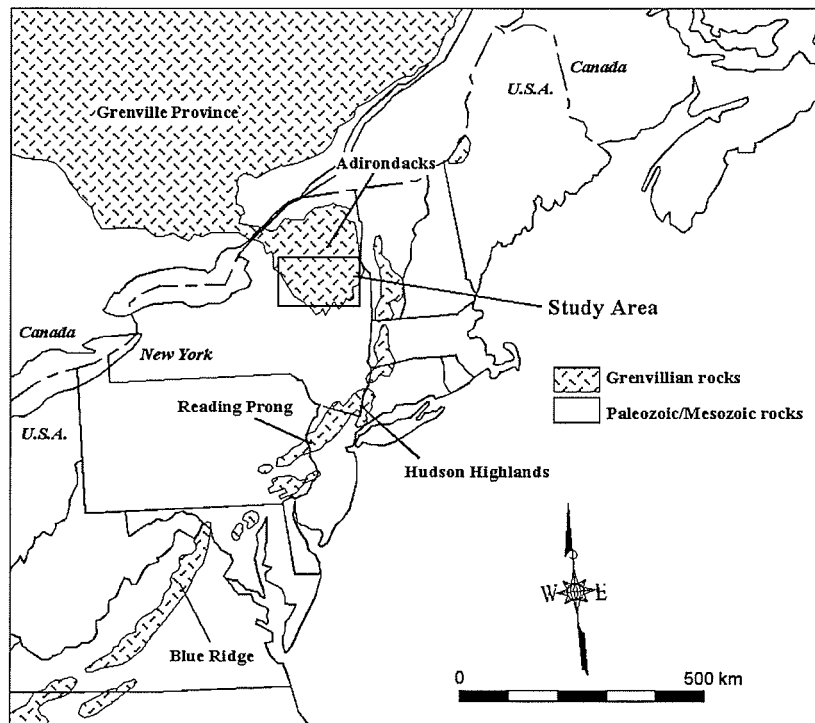


Figure 1. General map of the northeast U.S.A. and eastern Canada showing the distribution of Grenvillian basement rocks. The study area for this field guide is shown in the central and southern Adirondack Mountains, New York.

SINISTRAL SHEAR RECORDED IN ROCKS OF THE ADIRONDACK HIGHLANDS

In contrast to the overwhelming northeast trends throughout most of the Grenville Province, the structural grain of the south-central Adirondack Highlands is generally east-west (Figure 2). This broad

zone (>60-km wide) displays general parallelism of geologic contacts, fold axes, compositional layering, foliation, mineral lineations and an anastomosing system of mylonite zones. Several large (>20-km across) structural domes cored by rheologically rigid anorthosite lie within the zone. Kinematic investigations indicate that this zone is dominated by sinistral transpression (Chiarenzelli et al., 2000; Gates et al., 2004). There are a number of large-scale features (drag folds and rotated mega (gigga-) clasts) which are consistent with the abundant meso- and micro-scale kinematic indicators. Kinematic indicators include S-C fabrics, shear bands, and rotated porphyroclasts. The broad zone is bounded by shear zones that traverse portions of the southern Adirondacks. The structure of the south-central Adirondacks has been interpreted as the consequence of transpressional modification of earlier crustal-scale recumbent folds analogous to those exposed in the Adirondack Lowlands (Chiarenzelli et al., 2000). Widespread granulite-facies mineral assemblages within substantial volumes of supracrustal rocks are consistent with compressional tectonics; however, the southernmost bounding shear zone (the Piseco Lake shear zone) has mineral assemblages that indicate deformation outlasted high-grade conditions.

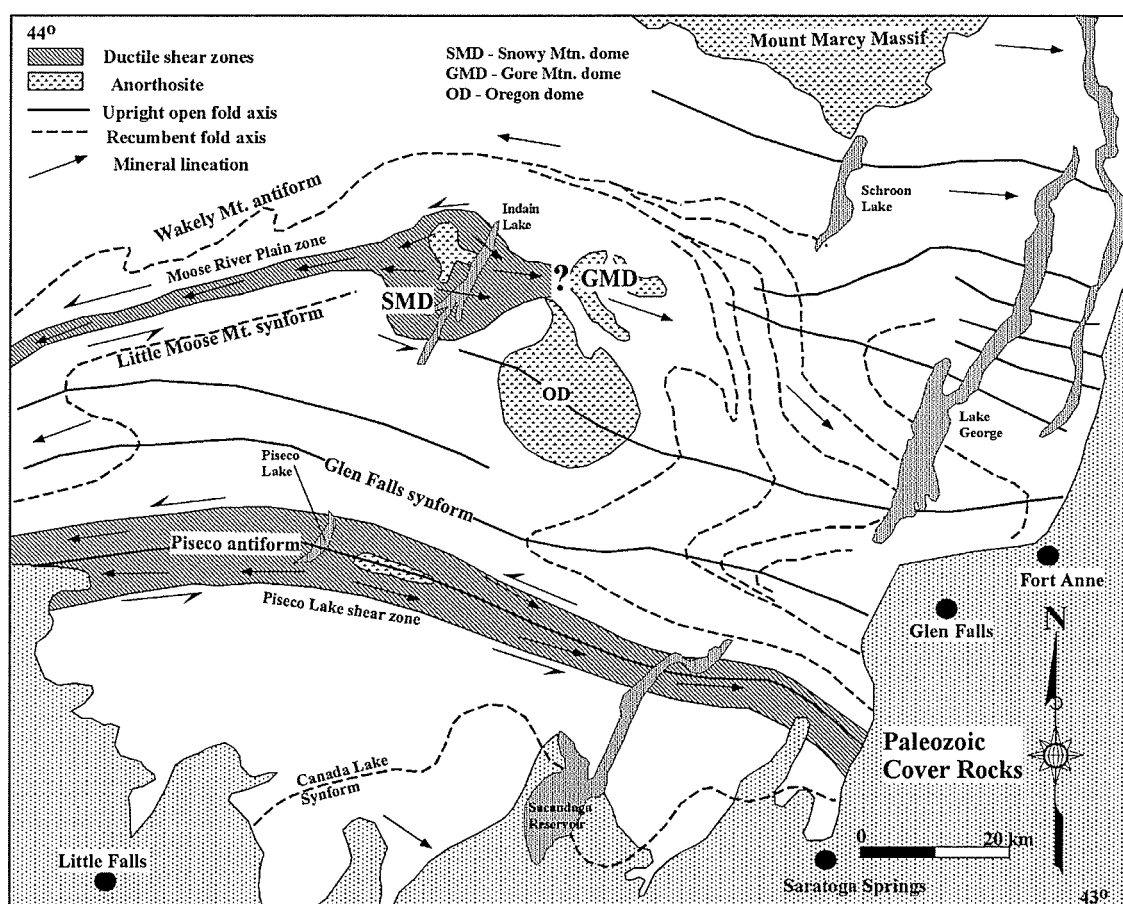


Figure 2. General geologic map of the central and southern Adirondacks showing the locations of major structures discussed in this field guide including the Moose River Plain shear zone, the Snowy Mountain dome (SMD) and the Piseco Lake shear zone.

MOOSE RIVER PLAIN SHEAR ZONE AND SNOWY MOUNTAIN DOME

A zone of high-grade intensely sheared rocks extends east-west through the Moose River Plain of the west-central Adirondacks and was thereby named the Moose River Plain shear zone (MRPSZ; Figures 2 and 3). This shear zone occurs between the Wakely Mountain antiform and Little Moose

Mountain synform (Wiener et al., 1984), and it experienced sinistral shearing under granulite-facies conditions. The eastward trace of the MRPSZ intersects and is deflected around the anorthosite-cored Snowy Mountain dome (DeWaard and Romey, 1969). East of the Snowy Mountain dome, the MRPSZ, traces toward the area of Gore Mountain, but the details are not as well documented.

Penetrative foliation occurs along a narrow belt (~2 km wide) that defines the MRPSZ. The foliation generally strikes 270° and dips moderately to steeply north (Figure 5A). It is defined by metamorphic mineral assemblages characteristic of granulite-facies conditions. Sheared charnockitic gneiss contains the assemblage plagioclase-clinopyroxene-hypersthene, pelitic gneiss contains biotite-K-feldspar-sillimanite-garnet, and gabbroic-gneiss contains augite-hypersthene-garnet-plagioclase. Local migmatite in the sheared charnockitic gneiss suggests anatexis during deformation. Within granitic and charnockitic gneisses, foliation is defined by planar aggregates of recrystallized feldspars and quartz. Foliation in pelitic gneiss is defined by recrystallized quartz and K-feldspar and parallel alignment of biotite and sillimanite. Mineral-elongation lineations are defined by linear aggregates of feldspar, pyroxene and garnet in charnockitic gneiss, and biotite and sillimanite in pelitic gneiss. The foliation and lineation in the gabbroic gneiss is mostly defined by alternating planar aggregates of plagioclase and pyroxenes. The eastern limit of the MRPSZ is structurally continuous with the penetrative foliation that mantles the Snowy Mountain dome (DeWaard and Romey, 1969).

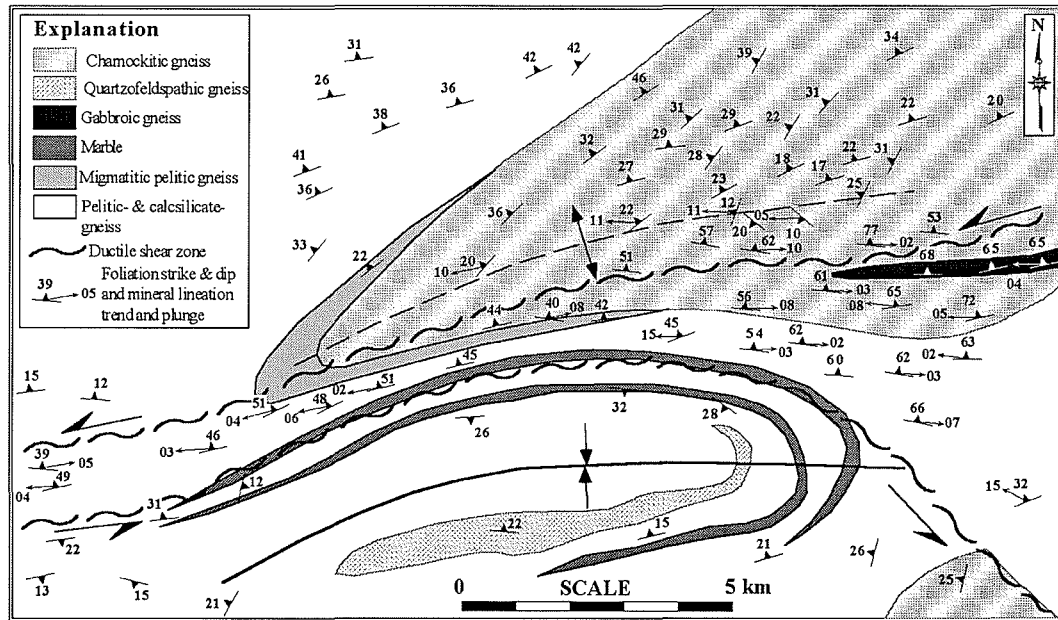


Figure 3. Detailed geologic map of the Moose River Plain shear zone in the area between the Wakely Mt. Antiform and Little Moose Mt. Synform.

The zone of deformed rocks in the Moose River Plain region was interpreted as the result of shearing between the lower and upper limb of the Wakely Mountain antiform and Little Moose Mountain synform (Wiener et al., 1984). Consistent subhorizontal mineral lineations throughout the Moose River Plain shear zone are indicative of a subhorizontal transport direction and inconsistent with earlier kinematic models based solely on map-pattern folds. Kinematic indicators throughout the shear zone are consistent with left-lateral shear. Kinematic indicators include σ - and δ -type porphyroclasts (cf. Simpson and Schmid, 1986; Passchier and Simpson, 1986) in pelitic and granitic gneiss, Type-I S-C fabrics (Lister and Snoke, 1984) in charnockitic gneiss, asymmetric foliation boudins often associated with local migmatite, and fish-structures comprised of broken garnet crystals, and small high-strain zones (Figure

5A). Locally the foliation is deflected at the margins of the MRPSZ consistent with map-scale left-lateral drag folds (Figure 3).

Large (15-20-km across) structural domes cored by anorthosite in the Adirondack Highlands are interpreted to have resulted from fold interference (McLelland and Isachsen, 1986) (Figures 2 and 5). The Snowy Mountain dome, located west of Indian Lake, is underlain by AMCG suite rocks with anorthosite in the core (DeWaard and Romey, 1969). The eastern extent of the MRPSZ foliation is structurally continuous

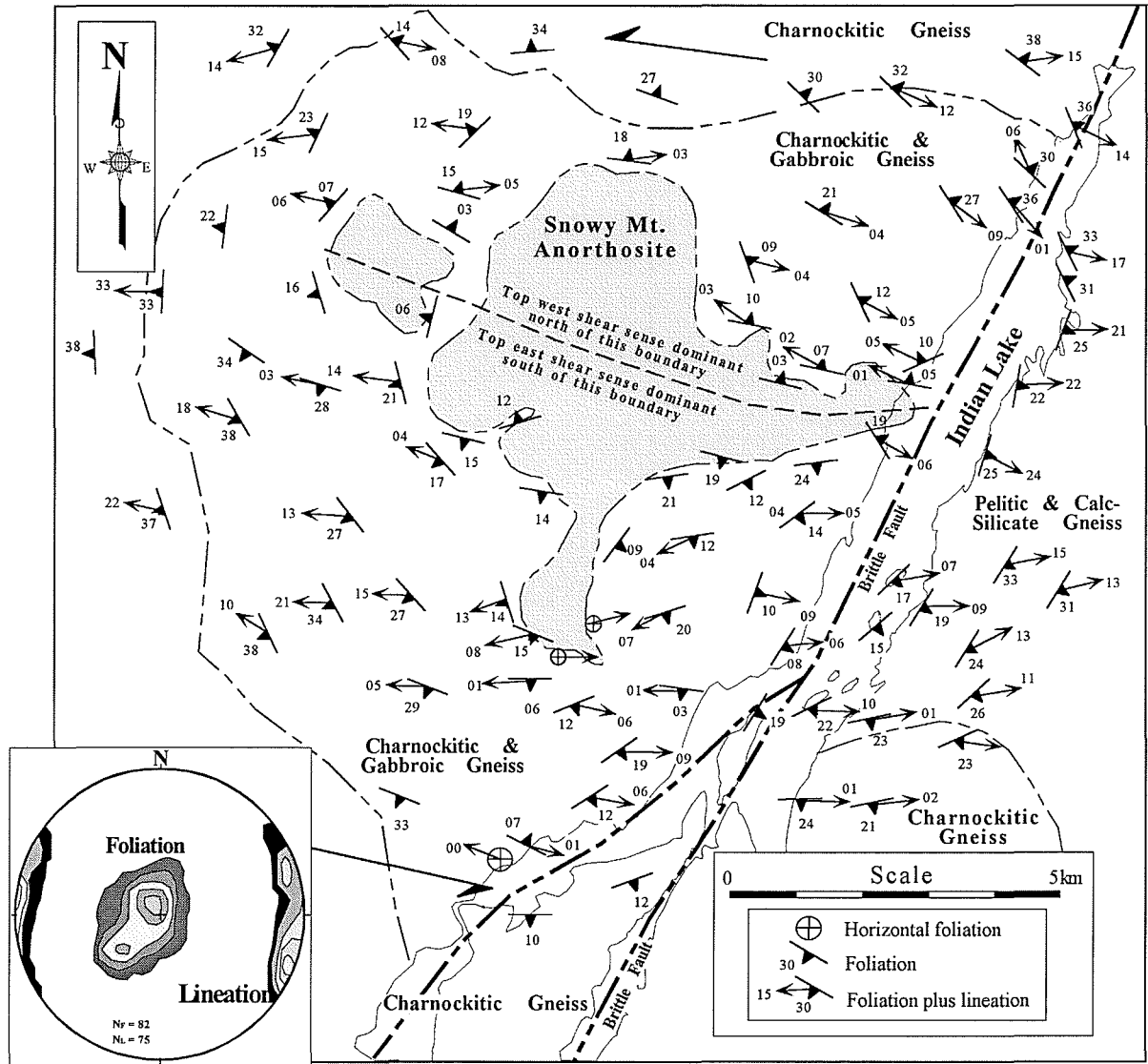


Figure 4. Detailed structure map of the Snowy Mountain dome, central Adirondack Mountains. Geologic contacts are modified from DeWaard and Romey (1964). The inset is a stereogram for poles to foliation and lineation for the eastern half of the dome.

with penetrative deformation fabrics that wrap around and define the Snowy Mountain dome. The core of the dome is underlain by megacrystic anorthosite with crystals commonly up to 20 cm. Anorthosite is mantled by gabbroic- and then charnockitic- gneiss forming a semi-concentric compositional zonation

(DeWaard and Romey, 1969). Although the central anorthosite is generally not deformed, the margins of the body contain dynamically recrystallized plagioclase that define well-developed foliation and lineation. As first described by DeWaard and Romey (1969), the transition from anorthosite to gabbroic gneiss is marked by more intensely developed deformation fabrics away from the dome core. Farther outward on the dome flanks, the foliation is penetrative in the charnockitic gneiss. The presence of relict plagioclase megacrysts in the charnockitic gneiss suggests a plutonic origin. Most of the unit consists of planar and linear aggregates of recrystallized plagioclase and anhedral, broken grains of clinopyroxene and hypersthene. Poles to foliation reveal that the dome has a dominant northwest-southeast-trending axis (Figure 4). The attitude of lineations vary about 30° around a general east-west trend that is roughly parallel to lineations in the MRPSZ.

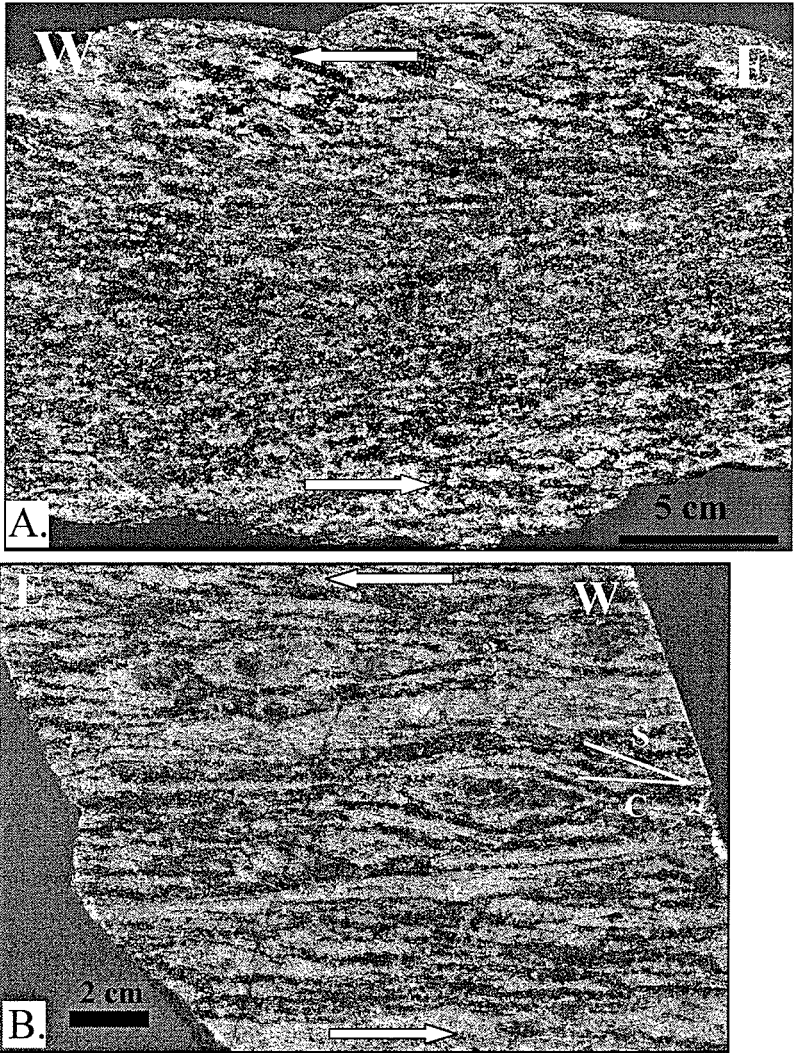


Figure 5. Examples of kinematic indicators from the Moose River Plain shear zone and the high strain fabrics that define the Snowy Mountain dome. A] Small high-strain zone from the MRPSZ showing sinistral shear; B] S-C fabric in gabbroic gneiss from the northeastern flank of the SMD.

Shear-sense indicators observed at the Snowy Mountain dome including σ - and δ -porphyroclasts (Passchier and Simpson, 1986), and type-I S-C fabrics (Lister and Snoke, 1984). Shear-sense indicators from the southern flank of the dome reveal top-to-the-east bulk shear, whereas the northwestern flank reveals top-to-the-west shear (Figure 5B). On the northwest side of the dome, where foliation dips moderately westward (Figure 4), the shear sense is locally dip-slip normal. On this basis, the dome can be divided into two domains as shown on Figure 5.

The axial obliquity of the dome with respect to the general east-west shear along the MRPSZ is consistent with development of the dome by sinistral transpression, and possibly large scale sinistral rotation. The dome does not appear to be a secondary fold defined by folded foliation as suggested in kinematic models for the Adirondacks (Weiner et al., 1984). In contrast, it appears to be a dome-shaped distribution of foliation developed in the less resistant rocks that mantle the more resistant anorthosite that cores the dome. The asymmetry of the dome axis relative to the general shear direction may reflect modification of the original dome geometry in the left-lateral shear couple. We propose here that the Snowy Mountain anorthosite and related rock suite, are part of an asymmetric giga-clast within a sinistral shear zone (Figure 6).

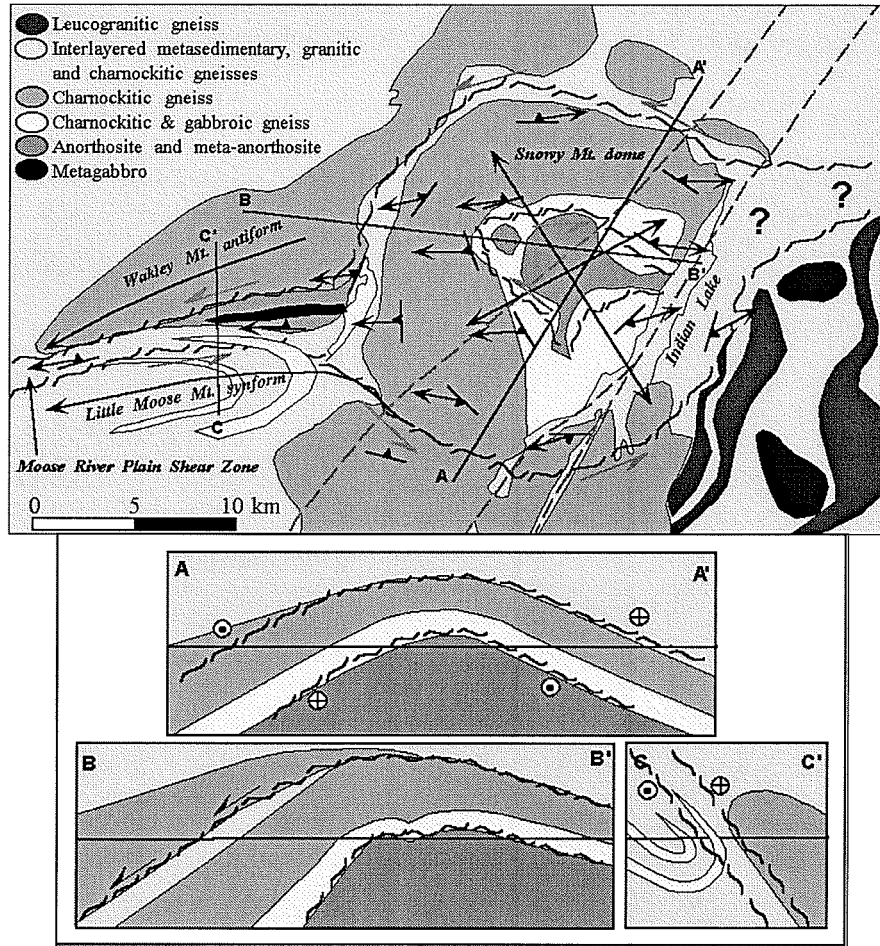


Figure 6. Schematic geologic map of the Snowy Mountain dome and the intersection with the Moose River Plain shear zone. The structure sections (A-A'; B-B'; C-C') are the same scale as the map and have no vertical exaggeration.

PISECO LAKE SHEAR ZONE

In the southern Adirondacks, there is a zone (10-20 km wide) of spectacular L-S and L>S tectonite with a general east-west map pattern, that extends across the entire southern Adirondacks (Figure 2). This deformation zone was designated by Gates et al. (2004) the Piseco Lake shear zone (PLSZ) based upon its inclusion of the Piseco dome and antiform of earlier workers (Cannon, 1937; Glennie, 1973; McLelland, 1984; Wiener et al., 1984), but also upon the extent of penetrative fabrics general shear fabrics found well beyond the core of the antiform. It is these fabrics, more than any other structure. Throughout the PLSZ, rocks of mostly granitic composition contain intense foliation and lineation, as described by Cannon (1937)

and McLelland (1984) in his paper on the formation of ribbon lineations. Penetrative foliation and lineation are defined by dynamically recrystallized quartz, K-feldspar and plagioclase, and alignment of muscovite, biotite and locally chlorite. Rocks within the zone consist dominantly of fine-grained aggregates of these minerals. Locally there are 2- to 6-cm-wide K-feldspar porphyroclasts supporting a plutonic origin for these rocks.

Foliation within the PLSZ defines an upright antiform (Cannon, 1937; Glennie, 1973; Weiner et al., 1984) with a subhorizontal axis that trends approximately 110° in the east, 090° in the central part, and 080° in the west. Foliation on the antiform limbs dips moderately to steeply both north and south. Lineations are penetrative in these rocks and are defined by dynamically recrystallized ribbons and rods of quartz, K-feldspar, plagioclase and streaks of chlorite, biotite, magnetite and muscovite. The plunges of the lineations are consistently shallow to subhorizontal. Overall the fabric in the antiform limb regions can be classified as L-S with the lineation and foliation both well developed. In the antiform crest, foliation is not well developed and penetrative lineations are defined by mineral rods, rods of mineral aggregates, and mineral ribbons. Lineations in the core area of the antiform are intensely developed, and in many places the linear fabric is dominant over the weak planar fabric ($L \gg S$; Figure 7) with grain-shape aspect ratios upward of 60:1 (in the L-parallel and S-perpendicular plane).

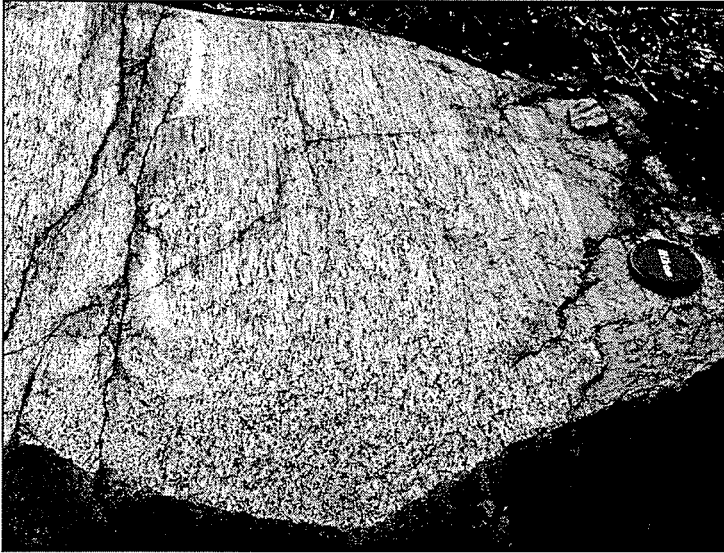


Figure 7. Outcrop of L-tectonite from the Piseco Lake shear zone. The view is looking west at an outcrop face that is subvertical in the foreground and subhorizontal in the background, revealing the ends and sides of mineral lineations respectively.

Metamorphic index minerals are not diverse in these rocks due to the overall granitic composition. The penetrative foliation and lineation is associated with diagnostic metamorphic minerals such as biotite, chlorite and muscovite, which are indicative of greenschist-facies conditions (Figure 8). Locally, anhedral grains of augite and hypersthene have overgrowths of hornblende, biotite or chlorite. The presence of hypersthene suggests these rocks experienced granulite facies metamorphism (McLelland, 1984), but the main fabric developed later during intense dynamic retrogression (Chiarenzelli et al., 2000).

McLelland (1984) suggested that the Piseco dome developed in the constrictional part of a regional west-directed thrust, but little kinematic data was presented. Shear-sense indicators are abundant in the PLSZ, and include Type I S-C fabrics (Lister and Snoke, 1984), σ - and δ -porphyroclasts of K-feldspar (cf. Simpson and Schmid, 1983; Passchier and Simpson, 1986), asymmetric polymineralic tails around porphyroclasts, and biotite- and muscovite-fish (Figure 9). These kinematic indicators reveal a consistent sinistral-shear sense on both the north- and south-dipping domains of the zone.

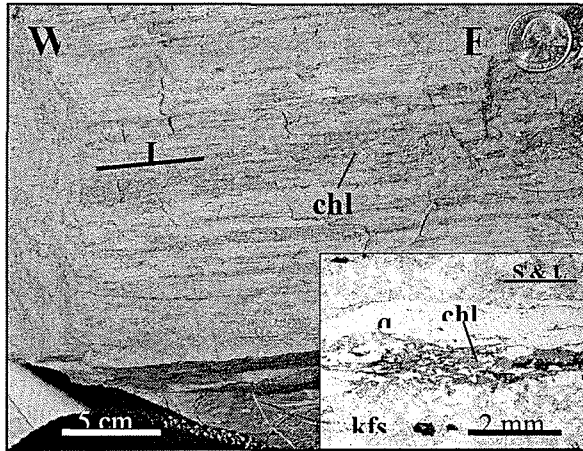


Figure 8. Outcrop of L-S fabrics in the PLSZ along Route 8 in the vicinity of Piseco Lake. The darker layers are linear aggregates of chlorite. The inset photomicrograph shows acicular chlorite (blades in three dimensions) oriented sub-parallel to the quartz ribbon.

NORMAL SHEAR ZONES

Geologic mapping of the PLSZ in the area of Speculator Mountain (southeast of the field trip area) revealed a cross cutting ductile normal shear zone with west directed displacement (Freyer et al., 2004). The area of Speculator Mountain is underlain by a sequence of granitic-, charnockitic- and gabbroic-gneisses that contain penetrative foliation and ribbon mineral lineations. The foliation texture varies from protomylonite to mylonite in a nearly vertical stack of rocks. Near the base of the mountain, protomylonite occurs in megacrystic granitic-gneiss. Moving structurally upward, the granitic-gneiss contains penetrative mylonitic foliation and lineation. Dynamically recrystallized quartz and K-feldspar, as well as core-mantle structure in K-feldspar are evidence for ductile strain. The mylonitic foliation dips gently to moderately (20-30 degrees) westward, but in some places the foliation is locally folded about a N-S axis. Mineral lineations associated with the mylonitic foliation are defined by ribbon-shaped aggregates of recrystallized quartz, and feldspars. Biotite forms mineral streaks that parallel the ribbon lineations. The lineations trend approximately due west.

In some minor mafic rocks, there are relict hypersthene grains with reaction rims and fringes of hornblende and biotite. The hornblende and biotite define a microscopic foliation and lineation that is parallel to the macroscopic mylonitic foliation and lineation, suggesting these index minerals formed during ductile deformation. These mineral textures also suggest that amphibolite facies metamorphism was associated with ductile deformation, and it was superimposed on rocks that were originally higher grade (presence of relict hypersthene grains). All the rocks are granitic in composition, with differences only in the mafic index minerals. The hanging wall rocks contain hypersthene, augite and hornblende. Within the shear zone, these mafic minerals show evidence of retrogression to biotite and/or chlorite, and there is good correlation between the occurrence of retrograde minerals and the level of fabric development.

Kinematic analysis of granitic mylonite revealed abundant shear sense indicators such as Type I S-C fabrics, δ - and σ -porphyroclasts, asymmetric tails around porphyroclasts, and shear bands. The shear sense indicators show that the direction of displacement was top toward the west, with the charnockitic-gneiss at the top of Speculator Mountain displaced over the megacrystic granitic-gneiss at the base. The presence of a large ductile normal shear zone was not previously documented in this area; however, small normal shear zones occur directly to the west in the PLSZ, and they have the same sense of displacement. These small normal shear zones consistently have hanging wall down toward the west (Figure 10). This is the same relationship observed at Speculator Mountain, but at the map-scale.

CONSTRAINTS ON TIMING

Geochronologic studies in the Adirondack Highlands constrain the timing of compressional deformation, peak metamorphic conditions, and late syn- to post-tectonic intrusives to 1090-1030 Ma after the intrusion of vast volumes of AMCG plutonic rocks from 1160-1100 Ma (McLelland et al., 1988; McLelland et al., 1996). Although sinistral shear along the MRPSZ and Snowy Mountain dome may have been active during the time of regional high-grade metamorphism (Ottawan orogeny), sinistral shear in the PLSZ clearly post-dates, and is superimposed on the granulite-facies mineral assemblages. A lower limit can be placed on sinistral deformation in the southern Adirondacks, at least locally, where an undeformed, 950 Ma, leucogranitic dike swarm intrudes strongly lineated gneiss (McLelland et al., 1996).

Recently published argon data ($^{40}\text{Ar}/^{39}\text{Ar}$) from biotite in samples collected near the Carthage-Colton shear zone in the Adirondacks suggest extensional movement occurred at 950-920 Ma (Streepey et al., 2000), well after the end of compression at 1030 Ma (McLelland et al., 1996). Given the nearly 100 Ma difference in timing between compression and extension, Streepey et al. (2000) suggested that movement on the Carthage-Colton shear zone was not related to orogenic collapse, but to an undefined, enigmatic extensional event.

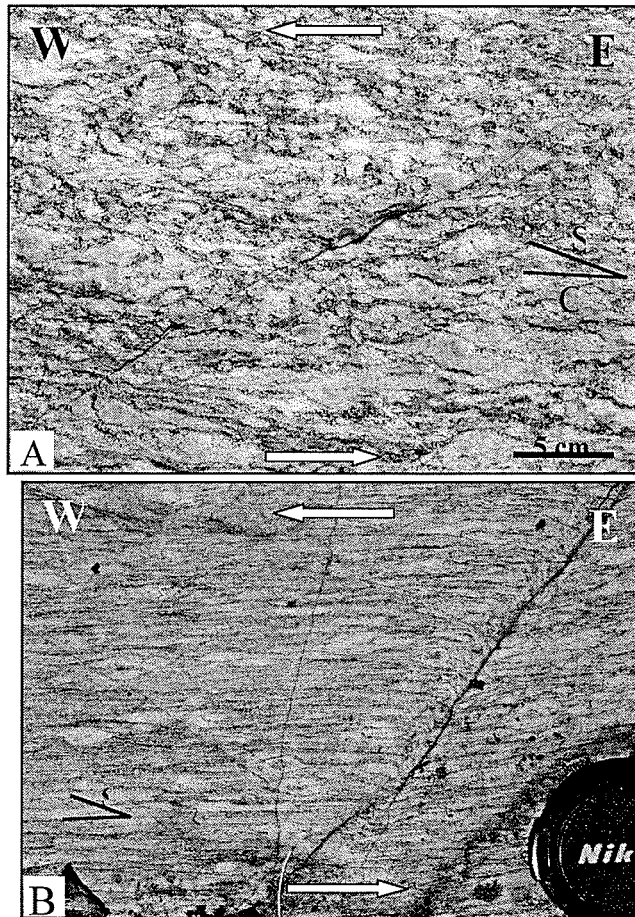


Figure 9. Outcrop photographs of kinematic indicators from the PLSZ. A] View is looking perpendicular to moderately north dipping foliation in western end of the Ohio Gorge on West Canada Creek. Type I S-C foliation is well developed in megacrystic granitic gneiss, and the shear sense is sinistral. B] Penetrative foliation developed in granitic gneiss along Route 10 south of the intersection with Route 8 (this is the pavement view on the top of the outcrop at STOP 12). σ -shaped porphyroclasts of K-feldspar and plagioclase indicate sinistral shear. These examples are from the northern and southern parts of the PLSZ respectively, and both show sinistral shear.

Interpretations suggest that the Adirondacks cooled at a rate of 1° - 2° C/Ma during a period of at least 100 Ma at this time (Mezger et al., 1993). The significance of extended periods of slow cooling is not yet fully understood; however, strike-slip deformation related to orogen parallel deformation after 1050 Ma provides a plausible mechanism for the slow uplift of the region over an extended timeframe. In the Adirondack Highlands, cooling rates are thought to have increased to 4° C/Ma at ca. 950 Ma (Streepey et al., 2000). The scenario proposed here, late strike-slip modification of Ottawaan compressional structures in a large sinistral zone, provides a realistic time frame for Rodinia assembly, a plausible mechanism for extension, and an explanation of otherwise enigmatic P-T-t paths.

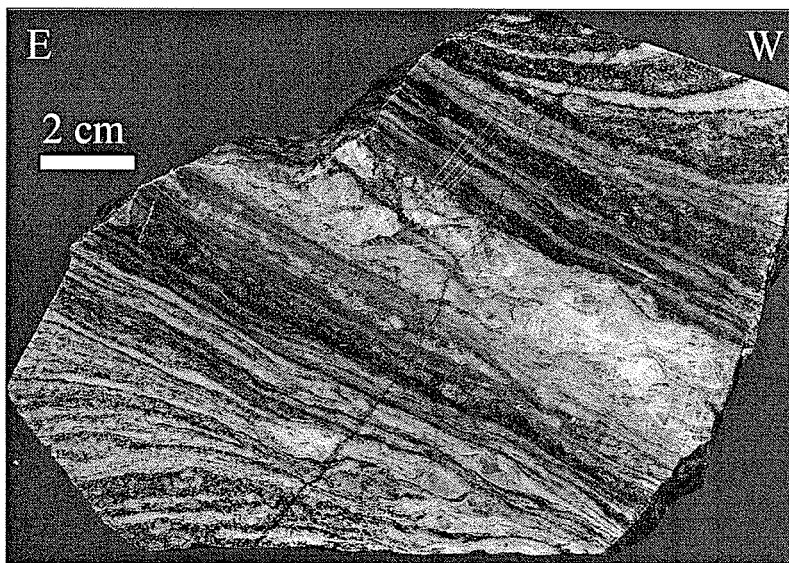


Figure 10. Polished rock slab of a small ductile shear zone that cross cuts the PLSZ fabric in the area of West Canada Creek. The view is looking south at a near vertical surface, and the shear sense is top down to the west. These small normal shear zones commonly contain parallel granitic pegmatite that is also plastically deformed.

TECTONIC MODEL AND CONCLUSIONS

Gates et al. (2004) proposed that dextral shearing in the Hudson Highlands of southern New York, and sinistral shearing in the southern Adirondacks occurred during the development of a conjugate syntaxis associated with the Ottawaan orogeny (Figure 11). Clearly, the limitations on this interpretation are the great distance between these two Grenville terranes that is covered by Paleozoic sedimentary rock and the potential modifications to the geometrical relations as the result of Paleozoic orogenesis. Nonetheless, the similarity in timing and character and evidence of numerous outcrop-scale, conjugate, shear-zone relations with similar orientations in both areas render the model plausible. Although the Adirondacks and Hudson Highlands are only a small portion of the Grenville Province, and thus extrapolation of this model to the orogen scale is speculative, oblique convergence and orogen-parallel transpression accompanying orogenesis of "Ottawan" age has been noted in other areas including the Central Gneiss Belt in Ontario (Gower, 1992), Baltica (Stephens et al., 1996; Park, 1992), and South America (Sadowski and Bettencourt, 1996). Therefore, the model presented here may have significant tectonic implications for the final assembly of Rodinia over a broader area.

Supporting evidence for the model comes from paleomagnetic polar wander paths for both North America and Baltica. They show a pronounced 90° bend at about 1020 Ma which is consistent with an abrupt change in plate motion, perhaps in response to a shift from convergence to strike-slip motion (Bylund, 1992; Park and Gower, 1996).

Even if plate convergence was purely orthogonal, considerable strike-slip faulting and horizontal-escape tectonism due to plate-margin geometry is possible. The Himalayan stress field is related to the shape of the Indian subcontinent (rigid indenter of Tapponnier and Molnar, 1976) and resulted in the lateral escape of crustal blocks in southeast Asia along major transcurrent zones. In contrast, the Himalayan contractional structures (thrusts and fold nappes) are of limited areal extent. Recent work has shown that the stress field in the crust is reflected in the subcontinental mantle (Holt, 2000). The fast polarization direction of split shear waves beneath the Adirondacks has been shown to be E-W (Barruol et al., 1997), parallel to the east-west structural fabric of the south-central Adirondack Mountains (Dawers and Seeber, 1991). This east-west trend truncates the prevalent northeast-trend of both the Grenville and Appalachian orogen in eastern North America (Barruol et al., 1997). Because the Hudson Highlands are outboard of the Adirondacks, they were positioned near the margin of Laurentia or originated as part of the overriding South American (Dalziel et al., 1994) continent. The recognition of strike-slip faulting and transpression in the Grenville core may record the escape of tectonic elements (Gates, 1995) and enhances analogs drawn with the Himalayas and models based on indentation tectonics (Hoffman, 1992).

Based upon existing age constraints, this conjugate shear system was active in the core of the Ottawan orogen during and subsequent to peak metamorphic conditions and within the range of ca. 1008 to 876 Ma. Relative to modern geographic coordinates, the Grenville strike-slip shear zones yield bulk-extension and bulk-compression directions of west-northwest and east-northeast respectively. These strain axes are consistent with compression directions deduced from en echelon transpressional folds in the Hudson Highlands and the en-echelon domes on the central Adirondacks (Chiarenzelli et al., 2000). This bulk strain analysis assumes that bulk rotation of the Hudson Highlands relative to the Adirondacks during Paleozoic Appalachian tectonic events (Taconic, Acadian, Alleghanian orogenies) and Mesozoic extension was minimal. The assumption is reasonable because there is no post-Precambrian penetrative deformation in the western Hudson Highlands and the major folds and faults in the surrounding Paleozoic strata are essentially parallel to those in the crystalline rocks indicating similar strain axes and minimal rotation.

The extensional deformation identified in the northwestern Adirondacks can be explained using the conjugate model with the interpreted bulk-strain directions (Figure 11). The Grenville Province north of the Adirondack Lowlands contains numerous Proterozoic normal faults and shear zones with an overall northwest-southeast extension direction (Streepey et al., 2000), and published age data suggest that these normal faults were active as much as 100 Ma after peak metamorphic conditions in the Adirondack Highlands. The conjugate shear model proposed by Gates et al. (2004) is consistent with the orientation, timing, and location of these later extensional faults such as the Carthage-Colton mylonite zone (separating the amphibolite facies Adirondack Lowlands from the Highlands) and extension in the Central Metasedimentary Belt in Ontario (van der Pluijm and Carlson, 1989).

Gates (1995) proposed that eastern Laurentia underwent escape tectonism along major faults as a result of a second Grenville collision somewhere between the present New England and Labrador. This model must be reconsidered in light of the new data. The early Himalayan-type collision that formed the westward-directed fold nappes and granulite-facies metamorphism is present throughout the Grenville orogen. The transcurrent-transpressional deformation post-dates it. This deformation could still have resulted from a second collision, but it could also have been the second phase of a single event like the Himalayas, where the escape tectonic features overprint the earlier contractional features. The extensive sinistral shearing in the southern Adirondacks equals or may even exceed the exposed dextral shearing in the Hudson Highlands. However, strike-slip deformation has yet to be identified in the Blue Ridge Province in the southern Appalachians. Therefore, the marked predominance of one conjugate fault set over the other as in the Himalayas does not appear to be the case in the study area. Instead, the

distribution of the conjugate faulting appears relatively balanced. This situation may have resulted from the location of the area directly in front of the “indenter” or the lack of a “free face” (Tapponnier et al., 1982) that characterizes the Himalayan geometry. An uneven, leading, Amazonian margin with promontories that impinged on the equally irregular Laurentian margin could have produced local syntaxes with relatively balanced conjugate transcurrent faulting.

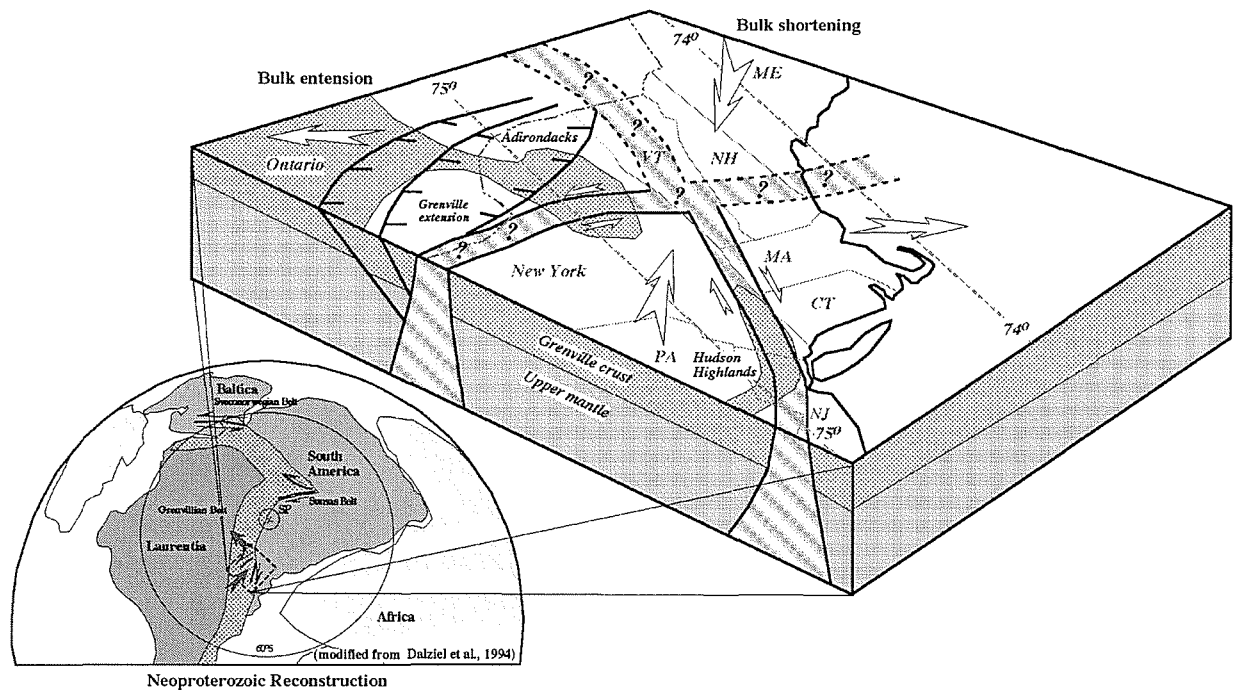


Figure 11. Block diagram depicting the crust-scale conjugate ductile shear zones forming a syntaxis. The inset shows the location of the syntaxis in a reconstruction of Rodinia (modified from Dalziel et al., 1994).

ACKNOWLEDGEMENTS

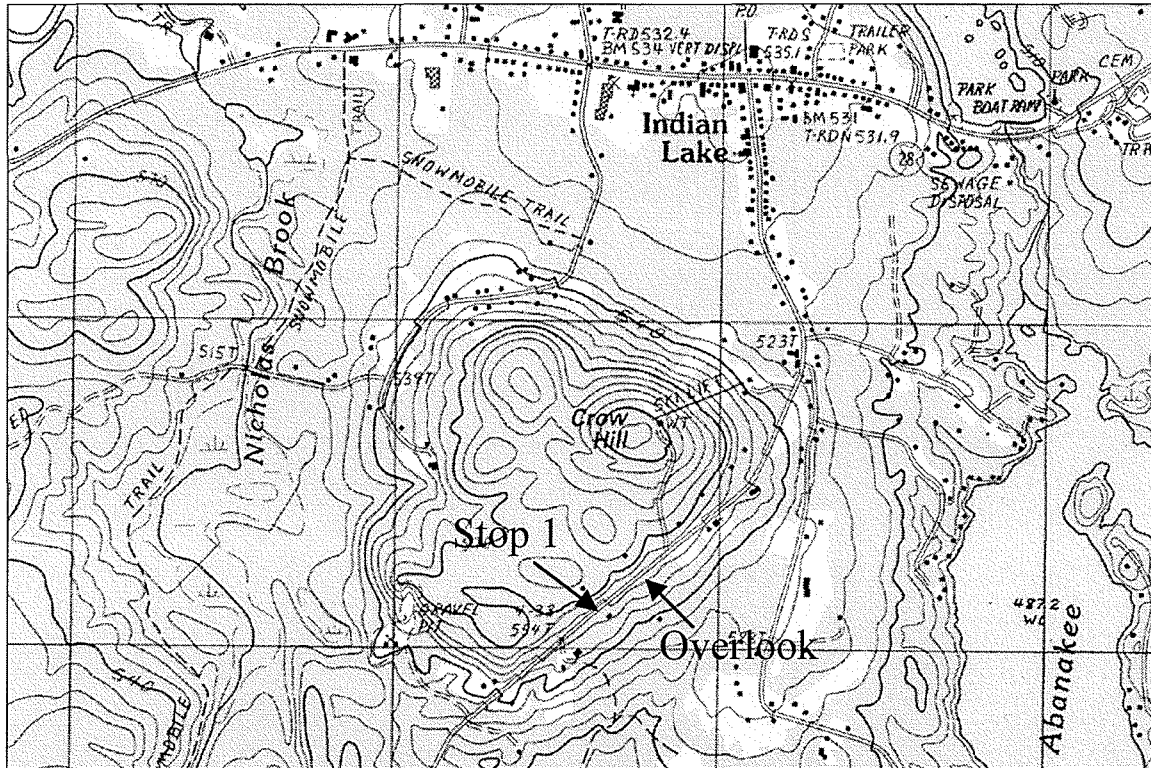
Funding for the work presented here was through Faculty Development and UUP Grants from the State University of New York at Oswego to Valentino. We also acknowledge the Division of Continuing Education (Yvonne Petrella, Tom Ingram and Jean Dufore) at the State University of New York at Oswego for support through the Summer Field Geology Research Program. We thank P. Whitney for introducing us to the geology of the Moose River area, and would also like to thank J. McLelland and R. Facundiny for suggesting these areas for structure research.

FIELD TRIP DESCRIPTION AND ROAD LOG

Road Log:

Mileage:

- 0.0 The trip begins at the assembly point in the parking lot of the Tops supermarket in the town of Indian Lake, NY, at the eastern intersection of Rts. 28 and 30. Proceed south on Rt. 30.
- 1.0 Turn left into the overlook parking lot, and walk south on Rt. 30 approximately 0.2 miles to the first roadcut on the west (right) side of the road.



STOP 1: Calc-silicate gneiss on the north side of the Snowy Mountain Dome (SMD).

Calc-silicate gneiss with penetrative foliation and folds occurs in outcrops on the west side of Route 30. The foliation is defined by planar aggregates of recrystallized plagioclase, quartz and diopside (Figure 13). Locally the calc-silicate gneiss contains quartzofeldspathic layers that define isoclinal folds, and locally there are recrystallized masses of diopside (some >10 cm in diameter).

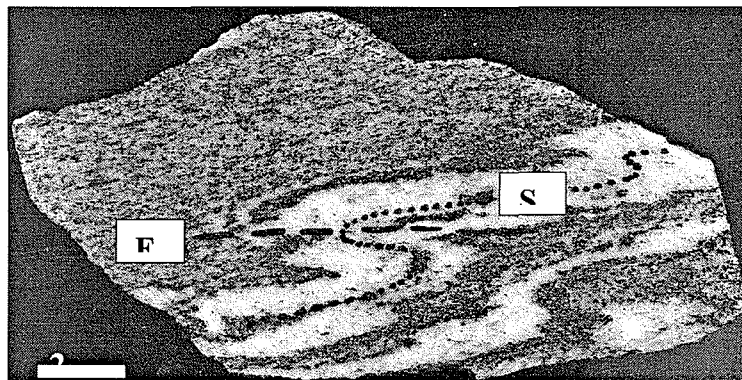
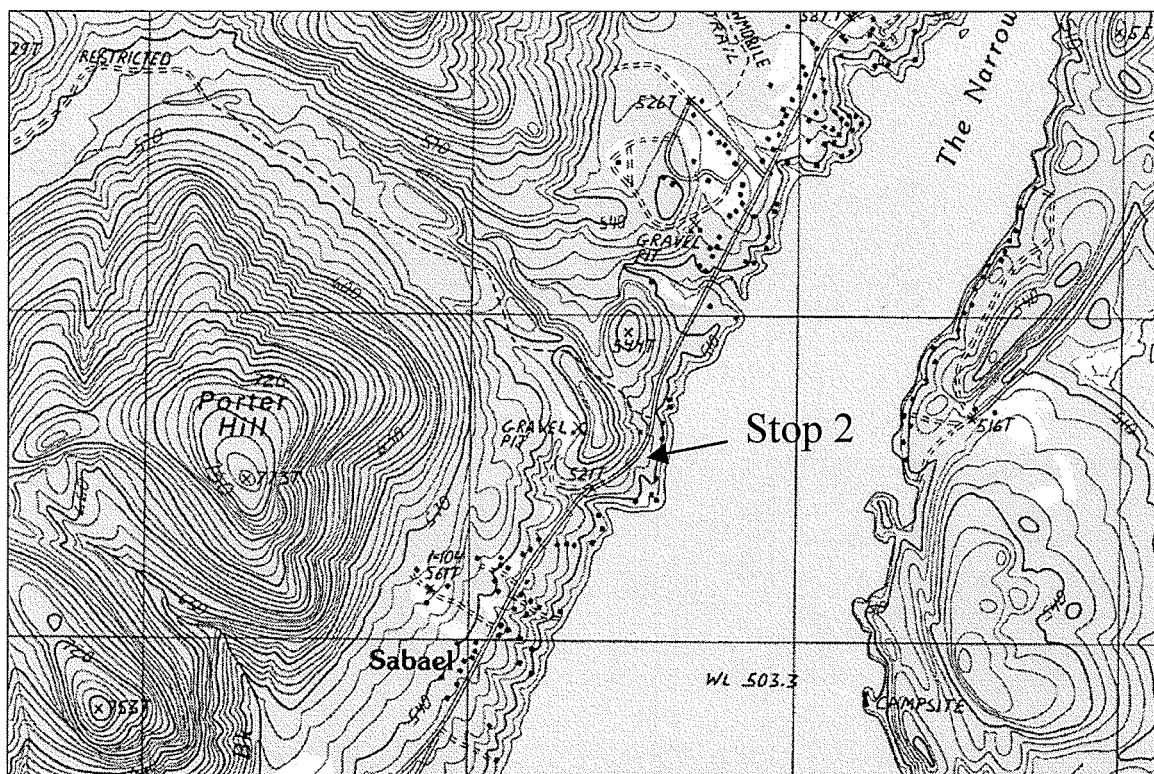


Figure 12. Rock slab of calc-silicate gneiss showing the S1 foliation defining F2 isoclinal folds.

The dominant foliation in the outcrop in most places is structurally continuous with penetrative foliation (S2) in the Snowy Mountain dome, and dips moderately northward at this location. Portions of the exposure reveal an earlier foliation (S1) preserved mostly in the hinges of the isoclinal folds (F2) (Figure 13). The S1 foliation does not occur in the rocks of the Snowy Mountain suite, and the S2 foliation dies out away from the Snowy Mountain dome. In a relative sense, the S1 foliation either predates or is synchronous with the intrusion of the Snowy Mountain suite, and the S2 foliation is superimposed on the suite.

Mileage:

- 1.0 Continue south on Rt. 30 towards Speculator.
- 2.1 Point Breeze Hotel
- 2.6 Roadcuts of charnockitic gneiss.
- 3.5 Park on the right side of Rt. 30 and cross the road to the roadcut on the east (left) side (at the "Southwinds" sign).



STOP 2: Charnockitic gneiss on the north side of the SMD.

The contact between the calc-silicate gneiss of STOP 1 and charnockitic gneiss of the Snowy Mountain suite occurs approximately 1 km northeast of this location, and is concordant with the S2 foliation. Here there is exposure of highly deformed charnockitic gneiss on both sides of the road. The foliation (S2) is defined by planar aggregates of dynamically recrystallized plagioclase and broken grains of hypersthene and augite. The foliation dips moderately northeastward and weak mineral lineations trend shallowly toward the east. Many of the outcrop surfaces reveal augen of plagioclase with core-mantle structure. Dynamically recrystallized tails developed on porphyroclasts of plagioclase merge with the penetrative foliation. The plagioclase augen are interpreted to be relict igneous crystals, possibly original megacrysts. When viewed on outcrop surfaces that are parallel to the lineation and perpendicular to the foliation, the augen appear to be asymmetric defining both σ - and δ -porphyroclasts. Additionally, domino structures and Type I S-C fabrics can be viewed on some optimum surfaces. The

kinematic indicators are consistent with top toward to the west ductile shearing, or low-angle sinistral considering the shallow plunge of the lineations.

Proceeding south across the Snowy Mountain dome, the penetrative foliation in the charnockitic gneiss progressively dips toward the east and then toward the southeast. There are numerous outcrops along Route 30 that can easily be viewed. Where the southeastern spur of Squaw Mountain intersects Route 30, there is exposure of gabbroic gneiss and megacrystic anorthosite. We will not be stopping at this outcrop during this trip due to time constraints. However, this is a good place to view the transitional compositions and deformation fabrics. The megacrystic anorthosite lacks penetrative deformation at this location, but some parts of the outcrop contain dynamically recrystallized anorthosite with well developed S2 foliation. The gabbroic gneiss contains penetrative foliation and well developed lineations at this location.

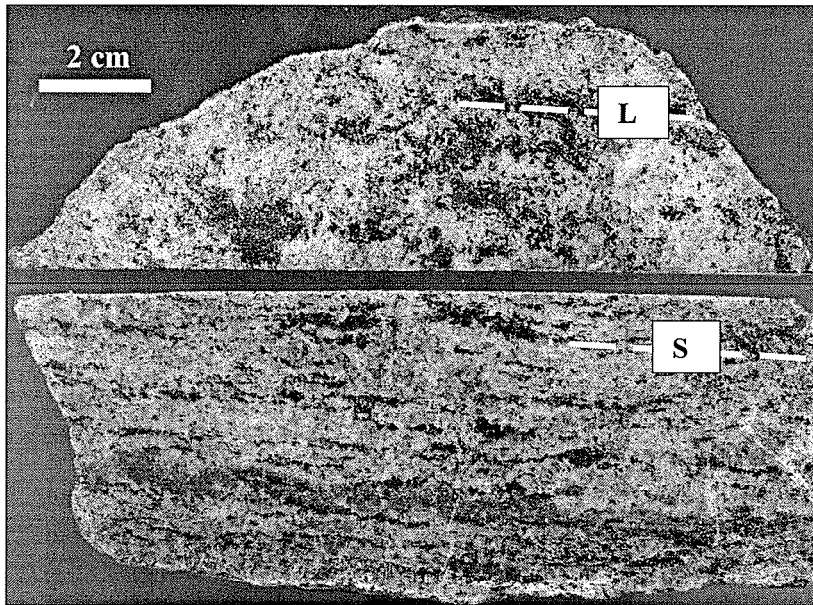


Figure 13. Mutually perpendicular rock slabs of charnockitic gneiss from the northeastern flank of the Snowy Mountain dome. The top slab is cut parallel to the S2 foliation revealing weakly developed mineral lineations. The bottom slab is cut perpendicular to the foliation and parallel to the lineation to reveal the penetrative foliation.

The transition from gabbroic- to charnockitic-gneiss occurs approximately 1000 meters northeast along the Squaw Mountain spur. This transition was documented by DeWaard and Romey (1969). Within the charnockitic gneiss branching high-strain zones can be seen (Figure 14). In places, the high-strain zones merge and have tapered terminations, and close inspection will reveal the penetrative foliation. Compositionally, the rocks in the high-strain zones are identical to the bounding charnockitic gneiss, except for the occurrence of minor quartz veins. The high-strain zones have the same general strike as the location foliation, but typically dip steeper northward in this area. Mineral lineations are better developed in the high-strain zones. Shear sense indicators are consistent with the shear sense indicators observed in the charnockitic gneiss with top toward the west ductile flow, or low-angle sinistral. The high-strain zones contain the same metamorphic minerals as the lower-strain charnockitic gneiss.

Mileage:

- 3.5 Continue south on Rt. 30 towards Speculator.
- 5.9 Roadcuts of gabbroic metanorthosite and megacrystic metanorthosite.

- 7.1 Trailhead to Snowy Mountain. Drive slowly for the next mile or so.
- 8.0 Just after Griffith Brook, turn right into a turnout and park for Stop 3.

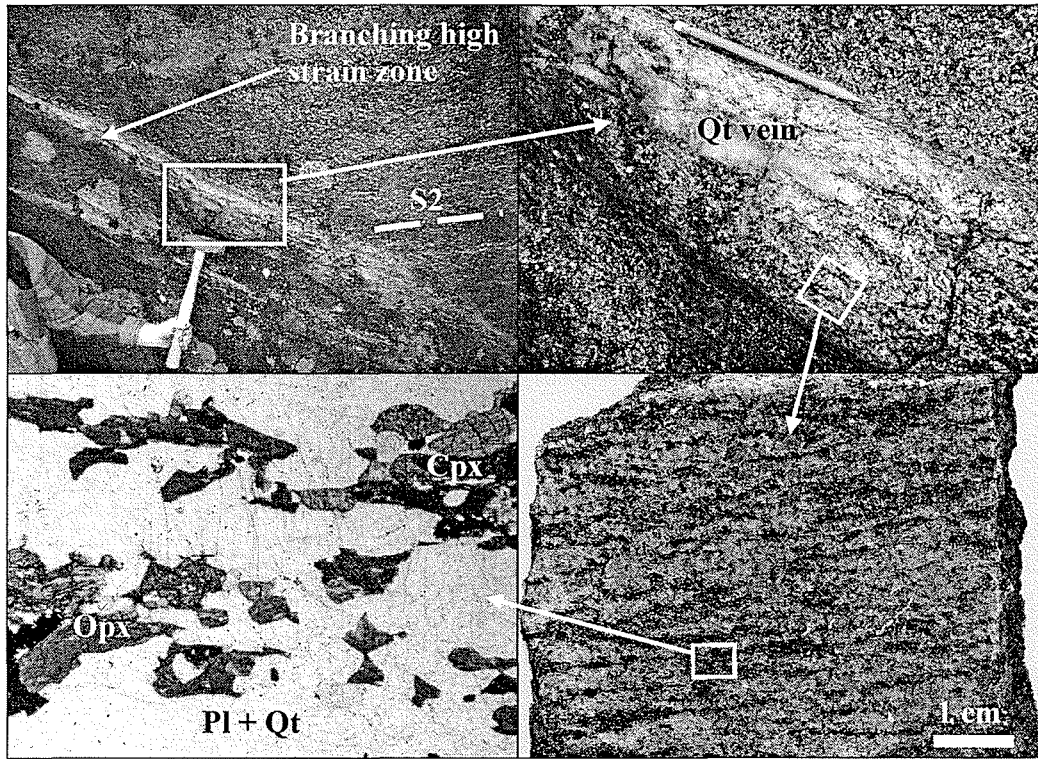
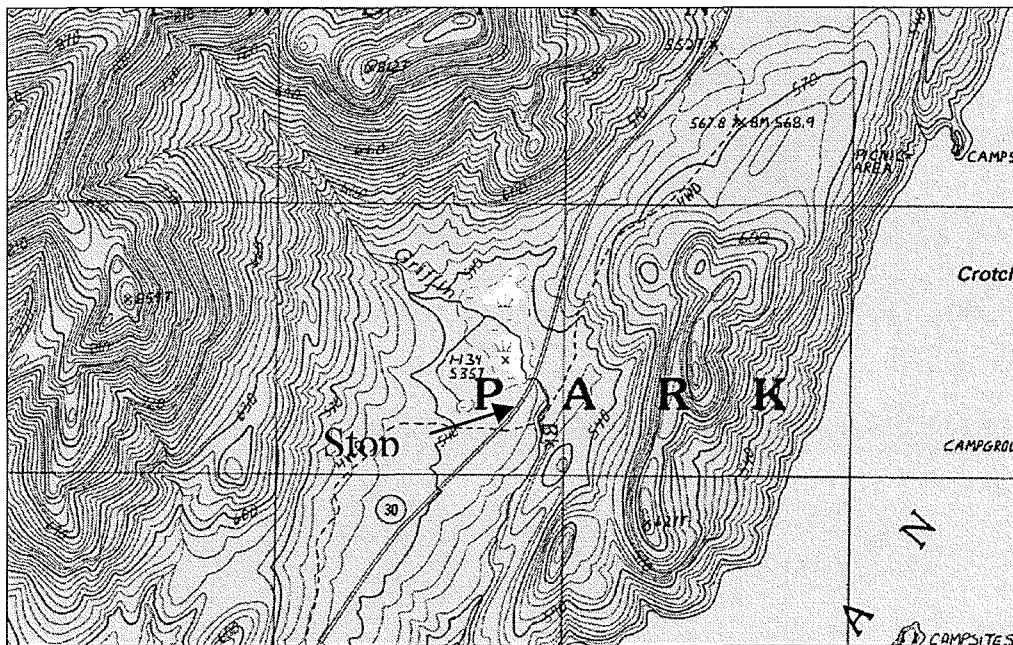


Figure 14. Example of a branching high-strain zone in charnockitic gneiss on the eastern flank of the Snowy Mountain dome in the area of Squaw Mountain. See text for details.



STOP 3: “Underview” of the Snowy Mountain Dome:

From this location, the entire structure of the Snowy Mountain dome can be viewed. Numerous slide faces expose the shallowly dipping foliation that occurs at the top of the dome (Figure 15). The exposures at the top of Snowy Mountain can be accessed by a popular hiking trail that occurs about 2 km north of this location. The top of Snowy Mountain is underlain by gabbroic gneiss with penetrative S2 foliation. The foliation dips shallowly toward the north and subhorizontal mineral lineations trend nearly due east. A near vertical outcrop near the top of the mountain reveals abundant shear sense fabrics. Detailed kinematic analysis using porphyroclasts, S-C fabrics and shear bands resulted in dominant shear of top toward the west. However, some domains upward of a few meters thick showed conflicting shear sense of top toward the east. These exposures are the structurally highest part of the dome.

Mileage:

- 8.0 Continue south on Rt. 30 towards Speculator.
- 9.2 Access road for Timberlock resort on left.
- 10.5 Sign noting “Entering Camping Area” of Lewey Lake and Indian Lake Campgrounds.
- 11.3 Turn right onto access road for campsites. Drive this road until just into the woods, and park in the wide flat area just before the bridge over Falls Brook. Walk across the bridge and past the metal gate, then plunge into the woods on the right of the access road about 10 meters to the outcrops in the brook that form the falls.

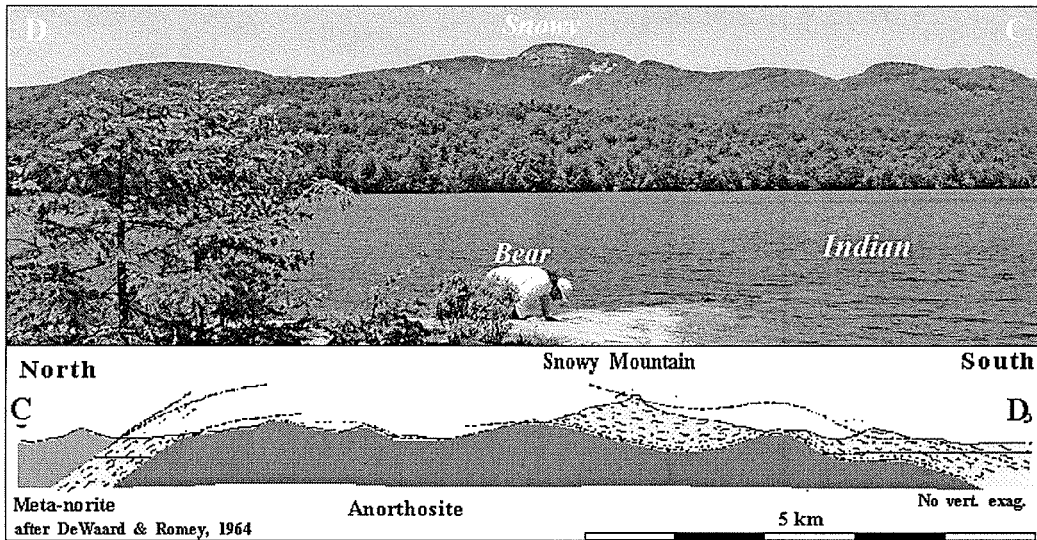
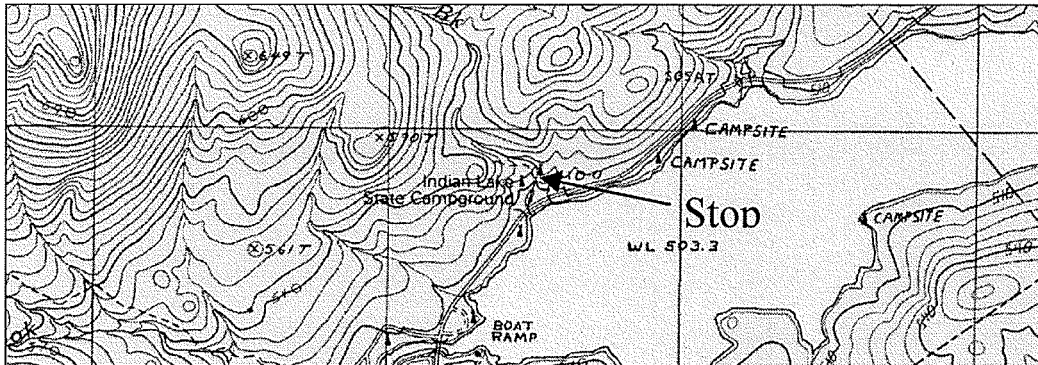


Figure 15. Westward view of Snowy Mountain from the east shore of Indian Lake (top) with the cross section of DeWaard and Romey (1964). The cross section is an eastern view of the area so “C” and “D” are reversed on the photograph.



STOP 4: Charnockitic gneiss on the southeast side of the Snowy Mountain Dome.

Stop 4 is of highly deformed charnockitic gneiss, the same lithology as Stop 2. However, the penetrative foliation dips moderately toward the southeast due to the position on the Snowy Mountain dome. At this location, and as before, the foliation (S2) is defined by planar aggregates of dynamically recrystallized plagioclase and broken grains of hypersthene and augite, and weak mineral lineations trend shallowly toward the east. Augen of plagioclase have dynamically recrystallized tails, often forming asymmetric kinematic indicators. As well, Type I S-C fabrics are well developed in some domains (Figure 16). Unlike Stop 2, the shear sense determined at this location is top toward the east. But, considering the dip is southerly, and mineral lineations trend easterly, the shear sense can be considered low-angle sinistral.

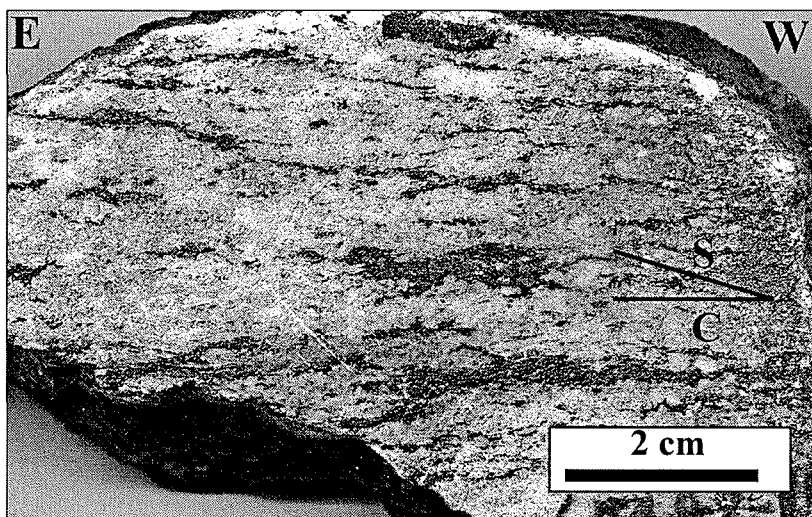


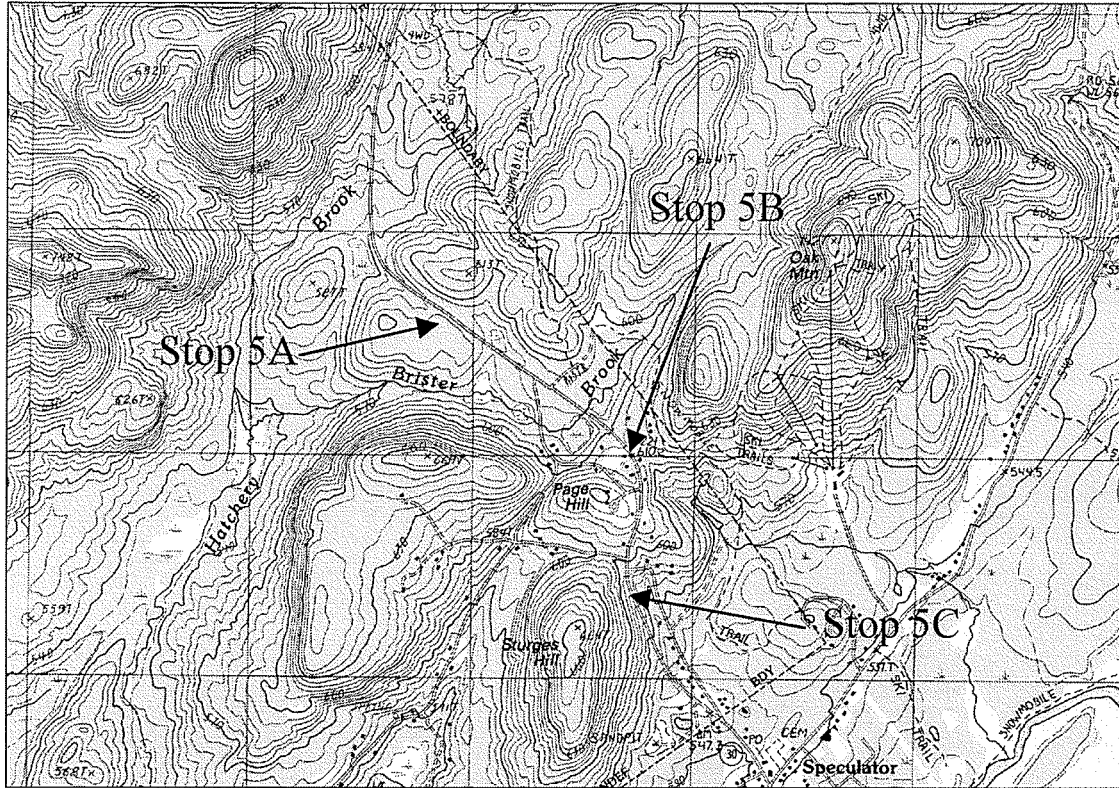
Figure 16. Rock slab of charnockitic gneiss from the falls on Falls Brook with Type I S-C fabric. The shear sense is top toward the east or sinistral. The dark minerals are broken grains of hypersthene and augite, while the lighter portions of the rock consist of recrystallized aggregates of plagioclase and quartz.

Mileage:

- 11.3 Return to Rt. 30, and continue south towards Speculator.
- 11.9 Lewey Lake on the right.
- 15.8 Intersection with dirt road on right (“Mountain Bike Trail”).
- 16.2 Mason Lake on the right.
- 17.6 Jessup River.
- 18.4 Roadcuts of quartzo-felspathic gneiss with granite dikes on both sides of the road.
- 19.0 Roadcut of calcite-garnet rock on the right, with a rock painted as a pig on the left.
- 21.1 Roadcut of steeply-dipping dextrally sheared rocks on the right.
- 21.3 Intersection with dirt road on right (“Mountain Bike Trail”).
- 22.4 Park on west (right) side of road at the large roadcut for Stop 5A.

STOP 5: Rocks typical of the intervening zone between the SMD to the north and the PLSZ to the south.

Rocks of each outcrop for Stop 5 are typical of rocks that occupy the zone between the SMD to the north (STOPS 1 to 4) and the PLSZ to the south (STOPS 6 to 13).



STOP 5A: Garnet amphibolite, calc-silicate rock and quartzo-feldspathic gneiss. Here, these three rock types and their contacts are seen. The northern portion of the outcrop consists of garnet amphibolite, the next section of the outcrop is calc-silicate rock and the southern portion is fine-grained quartzo-feldspathic gneiss. Complex sheath folds with sub-horizontal tight, isoclinal and sheath folds of foliation and compositional layers dominate the rock, particularly in the gneiss (trend to 110°) (Figure 17). Excellent views of the folds are seen on top of the southern part of the outcrop. The contacts between the rock types are also folded in similar fashion. Matrix minerals define lineations that are E-W and sub-horizontal, but are variable in orientation due to folding.

Mileage:

22.4 Continue south on Rt. 30 towards Speculator.

23.0 Park on the right, just after the guard rail, as you ascend the north slope of Burgess Hill (see location map). The outcrop is a roadcut on the east (opposite) side of Rt. 30 just north of the sign for Lake Pleasant.

STOP 5B: Garnet amphibolite and quartzo-feldspathic gneiss.

Here the garnet amphibolite and garnet-bearing quartzo-feldspathic rock are in sheared contact. The amphibolite has a distinct foliation and lineation that is folded into shallowly inclined tight folds (N-dipping axial planes) whose axes are shallowly E-W plunging. The lineation in the amphibolite is shallowly plunging to 112° . The fabric in the quartzo-feldspathic rock is distinct in contrast to the amphibolite, showing a penetrative L>>S tectonite fabric whose lineation plunges shallowly to 112° . The L>>S fabric is defined by both rods of quartz and quartz aggregates, and by tails around garnet. The highly fractured nature of the outcrop offers excellent views of this fabric. The contact between the rock types is distinct due to the color difference, but also because the amphibolite is boudinaged (foliation boudinage) due to apparent contact-parallel shear. The interboudin partitions are in-filled by plagioclase and amphibole (Figure 17).



Figure 17. Pavement view of top surface of rock at Stop 5B showing the foliation boudinage in the amphibolite (bottom) and the penetratively strong fabric in the quartzo-feldspathic rock (top).

Mileage:

- 23.0 Continue south on Rt. 30 towards specularator.
- 23.2 Top of the hill (garnet amphibolite roadcuts on both sides of the road).
- 23.4 Park on the right side of the road just south of the intersection, and walk to the top of the large roadcut for southerly views of Lake Pleasant and Speculator Mountain, and the PLSZ.

STOP 5C: Overlook of Speculator Mountain, and the PLSZ.

The rock here is sub-horizontally stratified, with the rock at the top of the hill to the north (garnet amphibolite) the lowest stratum, and the base of the outcrop is interlayered amphibolite and granitic gneiss, followed by granitic gneiss with mica ‘mats’ at the top (at the viewing area). Foliation is sub-horizontal here, but, again, the mineral lineation is shallowly E- and W-plunging.

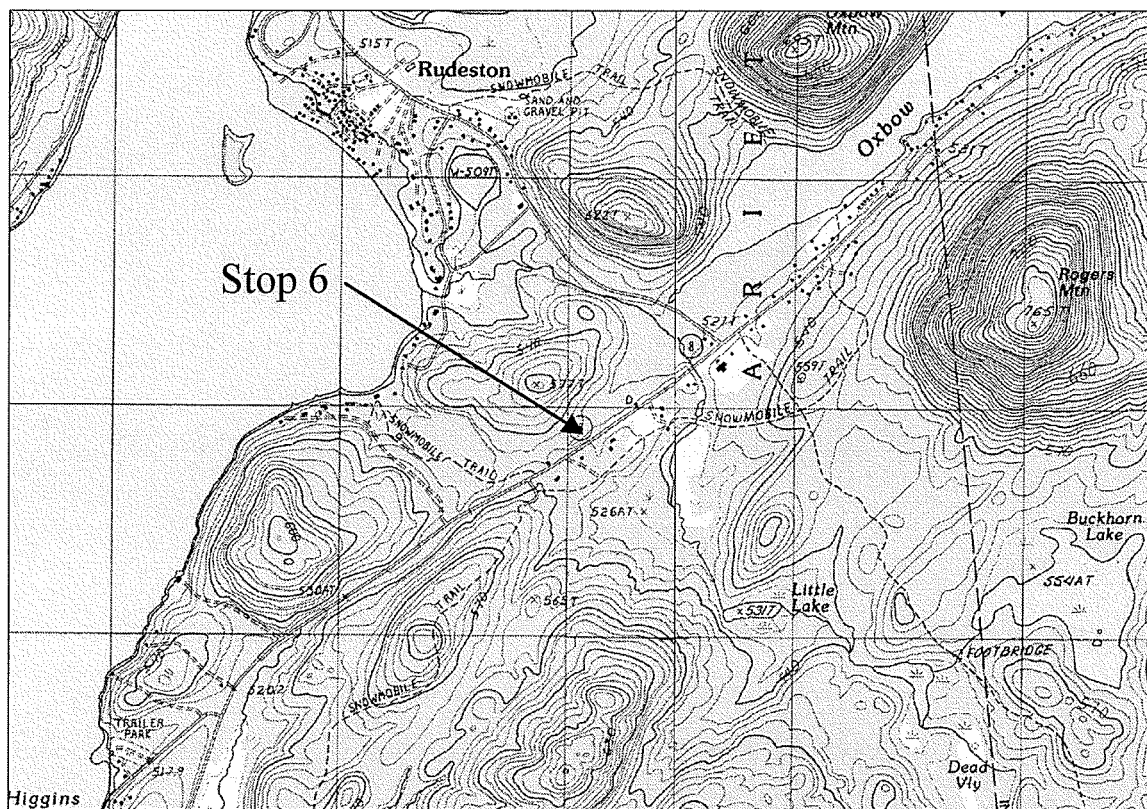
The view to Speculator Mountain illustrates the structure of the late history of the PLSZ. The bench on the east side of the mountain is the top of the hanging wall block of a moderately W-dipping normal fault, and the peak of Speculator Mountain is the hanging wall block. This normal fault is defined by fabric with a distinct top-down fabric trajectory (see Figure 10), and defines the zone to be about 100 m thick. This is one of many normal shear zones that cut the E-W fabric that defines the PLSZ, but this one is perhaps the thickest. Most identified are a few centimeters thick (as in Figure 10).

Mileage:

- 23.4 Continue south into Speculator.
- 24.1 Turn right (west) onto Rt. 8.
- 26.1 Roadcut on right is gneiss in the PLSZ.
- 27.1 Lake Pleasant
- 27.5 Lake Pleasant town center.
- 33.0 Intersection with Old Piseco Road in Piseco, NY.
- 34.0 Park on right side of the road at the low roadcut for Stop 6.

STOP 6: L-S and L>S fabrics in the PLSZ.

The Piseco Lake shear zone is developed in rocks of granitic composition. Dynamically recrystallized feldspars and quartz form spectacular ribbon- and rod-shaped mineral lineations (McLelland, 1984), in addition to mafic phases such as biotite, chlorite and accessory magnetite. In many places, the alignment of ribbons forms the foliation in this outcrop (Figure 18). Individual quartz-ribbons have aspect ratios upward of 60:1. The foliation dips gently southward and the lineations trend about 110° (Figure 18). This location occurs on the southern flank of the map-scale antiform defined by the foliation in the Piseco Lake shear zone. At the western end of the outcrop there are rods of amphibolite (10-30 cm diameter) within the granitic gneiss.



In the granitic gneiss, both biotite and chlorite blades form microscopic lineations and foliation parallel to the macroscopic structure. Rare grains of hypersthene have been found, but they always have well developed overgrowth textures that include biotite and chlorite. The biotite and chlorite are the most abundant index minerals in the granitic gneiss, and suggest the deformation was last active under low-grade metamorphic conditions, although probably began at much higher conditions to account for the relict grains of hypersthene.

Mileage:

- 34.0 Continue west on Rt. 8.
- 36.4 Turn south onto Rt. 10.
- 36.9 Roadcuts for Stop 12 (see below).
- 37.4 Piseco Outlet.
- 37.6 Turn right onto Powley Road (becomes dirt road).
- 45.3 Turn around at a wide and grassy DEC camping area to return north on Powley Road.
- 46.6 Park as far off the road as possible. The outcrop for Stop 7 is pavement exposures located within the bed and the gutter on the east side of the road.

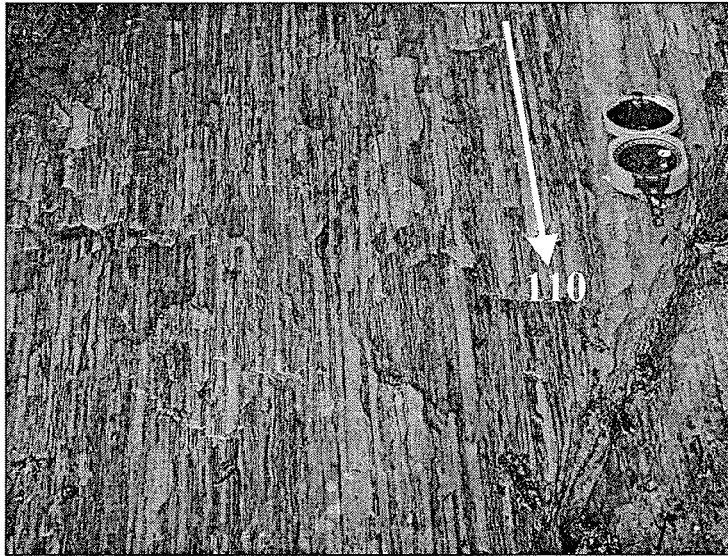


Figure 18. Pavement exposure of granitic gneiss with penetrative mineral elongation lineations defined by quartz ribbons and aggregates of dynamically recrystallized feldspar. The view is looking toward the west.

STOPS 7 TO 12 are a sequence of outcrops chosen to illustrate the variation and progression of textures and structures associated with the southern PLSZ (Gates et al., 2004). The sequence is in order from outside the PLSZ into central part. The rocks associated with STOPS 7 to 11 are located on or next to Powley Road, a dirt road that runs obliquely across the structure of the PLSZ (Figure 19). In the event that the town paves Powley Road, much or all of this rock will be covered.

All rocks at these Stops are very similar in mineral content, and vary only in detail with regard to mineral percentage and fabric type and intensity. The rock is dominantly quartzo-feldspathic gneiss with intense sub-horizontal to shallowly WSW- and E-plunging mineral elongation lineation and steeply S-dipping foliation. Both fabric elements are defined by ribbons of quartz, and ribbons of aggregate feldspar + quartz (generally 1-5 cm long depending upon grain size). Intensity of the fabric varies across strike at the 50 cm scale, with local layers of significantly coarser-grained fabrics (grains up to 1 cm in diameter).

STOP 7: Shear fabrics of the southern PLSZ.

This stop consists of a sub-continuous series of pavement exposures located in the road bed, and in the gutter on the east (northeast-bound) side of the road. Due to the nature of this location, the extent of the exposed rock at this stop changes daily, so some or all of the rock described here may be viewable depending upon the time of the season in which the stop is visited (best later in the season).

Here, quartzo-feldspathic gneiss has intense shallowly WSW-plunging lineation and steeply S-dipping foliation, both defined by ribbons (generally 1-5 cm long depending upon grain size). Locally, the gneiss has layers (up to 50 cm wide) of coarser-grained fabrics (grains up to 1 cm in diameter). Within the gneiss is lens- to block-shaped, and blunt-ended amphibolite bodies, also with a distinct mineral fabric that is sub-parallel to that of the gneiss. In general, the long dimension of lens-shaped amphibolite bodies are sub-parallel to the host gneiss fabric. The lengths of these bodies are not quantified due to the fact that the outcrop is composed of meter-scale windows through road gravel, but short dimensions are usually exposed showing bodies 10 to 30 cm wide. Fabric in the amphibolite is generally terminated at the boundary of the body, whereas the fabric in the quartzo-feldspathic gneiss

draped the amphibolite bodies, showing fabric tails at the blunt ends of the bodies, sub-parallel to the mineral lineation (as porphyroclasts draped by matrix minerals; Figure 19).

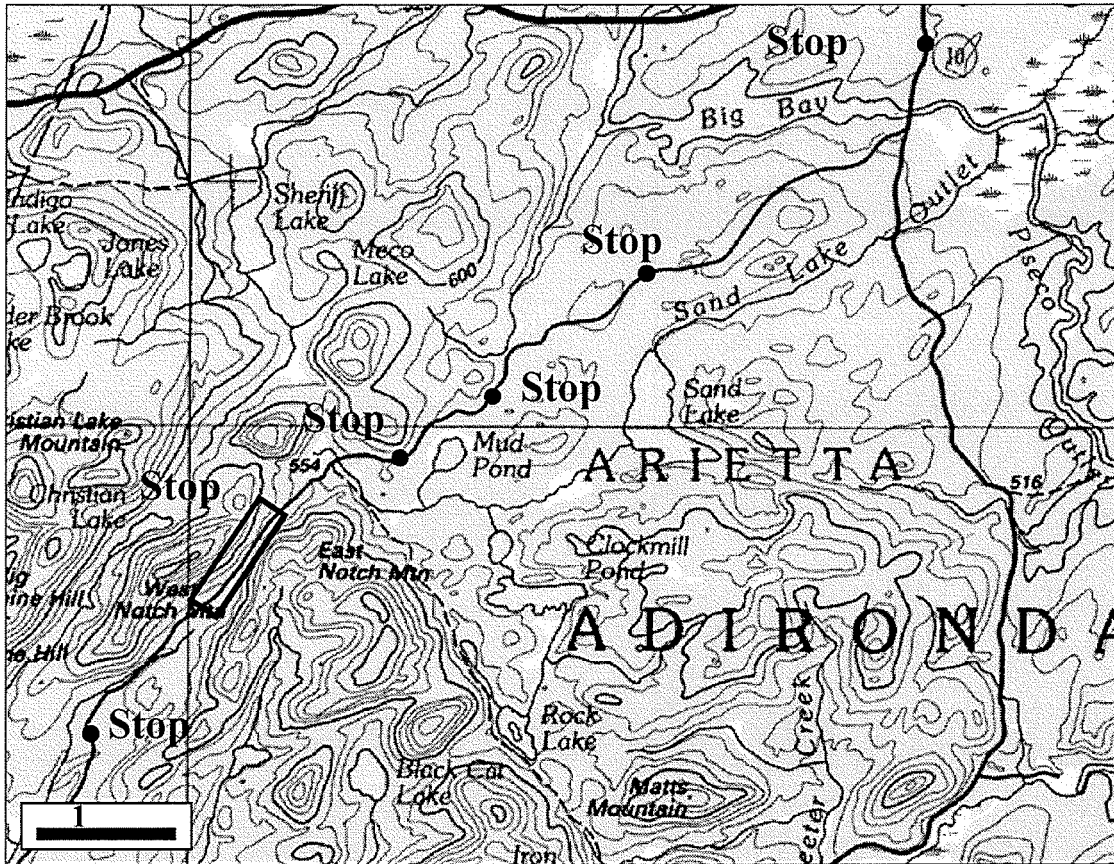


Figure 19. Location map of STOPS 7 through 12. STOPS 7 to 11 are on Powley Road, which cuts across the east-west trend of the PLSZ.

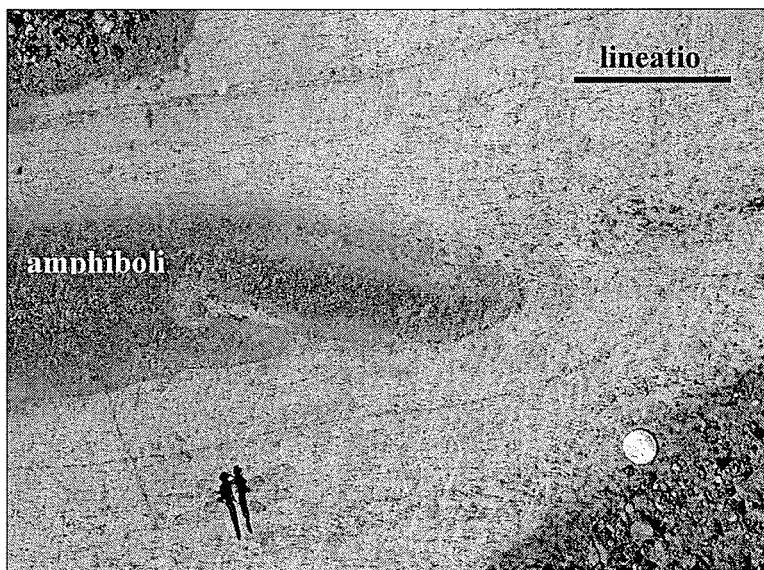


Figure 19. Pavement view of exposure at Stop 7 from within the road bed. Top is north. Note the apparent deflection of the fabric and difference in texture of the quartzo-feldspathic gneiss where it forms a 'tail' at the 'nose' of the 'shark'-shaped amphibolite lens.

Mileage:

- 46.6 Continue northeast on Powley Road, back towards Rt. 10.
- 46.8 Pavement outcrop on right gutter.
- 48.1 Park along the side of the road in “the notch” between East and West Notch Mountains (see location map). The notch is Stop 8, featuring 0.2 miles of continuous exposure on both sides of Powley Road. The exposure on the northwest side (left) is the subject of the stop.

STOP 8: Variations of L-S, L>S and L>>S fabrics of the PLSZ.

Due to the continuous nature of the exposure in an across-strike direction, the fabrics within the quartzo-feldspathic gneiss may be examined for their variations at about the meter scale. In general, the rock fabrics vary between L-S to L>>S tectonite. Foliation intensity is variable, but mostly weak here. Foliation dip varies greatly across strike (moderately to steeply south-dipping), whereas the intensity and orientation of the lineation is consistently sub-horizontally E- and ESE-plunging. Of particular note in this outcrop, in addition to the matrix fabrics, is the pervasive feldspar porphyroclasts. Fabrics drape the porphyroclasts to form tails that are elongate sub-parallel to the matrix mineral lineation (sub-horizontal). Perhaps the cleanest views of the fabrics along the lineation may be seen at the very end (northeast end) of the exposure. We suggest that it is best to leave this spot for last in order to best appreciate the nature of the fabric in these rocks.

Mileage:

- 48.1 Continue northeast on Powley Road towards Rt. 10.
- 48.8 Swampy area and sign for “snowmobile trail”.
- 49.2 Park along the side of the road avoiding the blind curve. The outcrops for Stop 9 are along the side and gutter of the northwest side of the road just before and at the left-hand curve in the road.

STOP 9: Fabric variations in garnet-bearing quartzo-feldspathic gneiss in the PLSZ.

Here the quartzo-feldspathic gneiss fabrics vary from L>S to L>>S tectonite, whose lineation is shallowly E- to ESE-plunging, and the relatively weak foliation is moderately to steeply S-dipping. Feldspar porphyroclasts are present as at Stop 8. The southwest end of the exposure shows a high density of garnet porphyroclasts within foliation. Locally, garnet is concentrated into 2-3 cm-wide bladed bands, or is apparently flattened. Also locally, garnet occurs in patches or ‘clots’ 3-5 cm wide and up to 20 cm long.

Mileage:

- 49.2 Continue northeast on Powley Road towards Rt. 10.
- 49.8 Outcrop on the left at the top of the hill.
- 50.0 Park on the side of the road for a set of small low pavement exposures on the left (northwest) side of the road as the top of the hill is approached.

STOP 10: Mylonitic augen gneiss of the PLSZ.

Best views of the fabrics in the quartzo-feldspathic gneiss are seen in the approximately 1.5 meter-long, beautifully polished pavement at the top of the hill. Here the rock has meter-scale mineralogical layers where the northern part is relatively more leucocratic, dominated by feldspar (up to 1 cm wide) and quartz ribbons (up to 3 mm wide). The fabric is intensely strong L-S tectonite throughout the exposure, with a steeply S-dipping foliation, and a sub-horizontal shallowly E-plunging lineation. The fabric may be considered ‘textbook’ mylonite, with spectacularly grain-size reduced texture in the less leucocratic layer. The mylonitic fabric transects the sharp contact between mineralogical layers at a low angle where it transitions into a more ribbon texture in the leucocratic layer. Of particular note here, besides the intense matrix fabrics, is the penetrative augen (generally 1 to 4 cm long) composed exclusively of aggregates of millimeter-grain-size quartz + feldspar, not single crystals. In every case,

augen are draped by the matrix fabric, elongate sub-parallel to the lineation. There are a few much larger of these augen in this rock composed of rounded single feldspar crystals (up to 4 cm long) that are surrounded by aggregate quartz and feldspar (Figure 20).

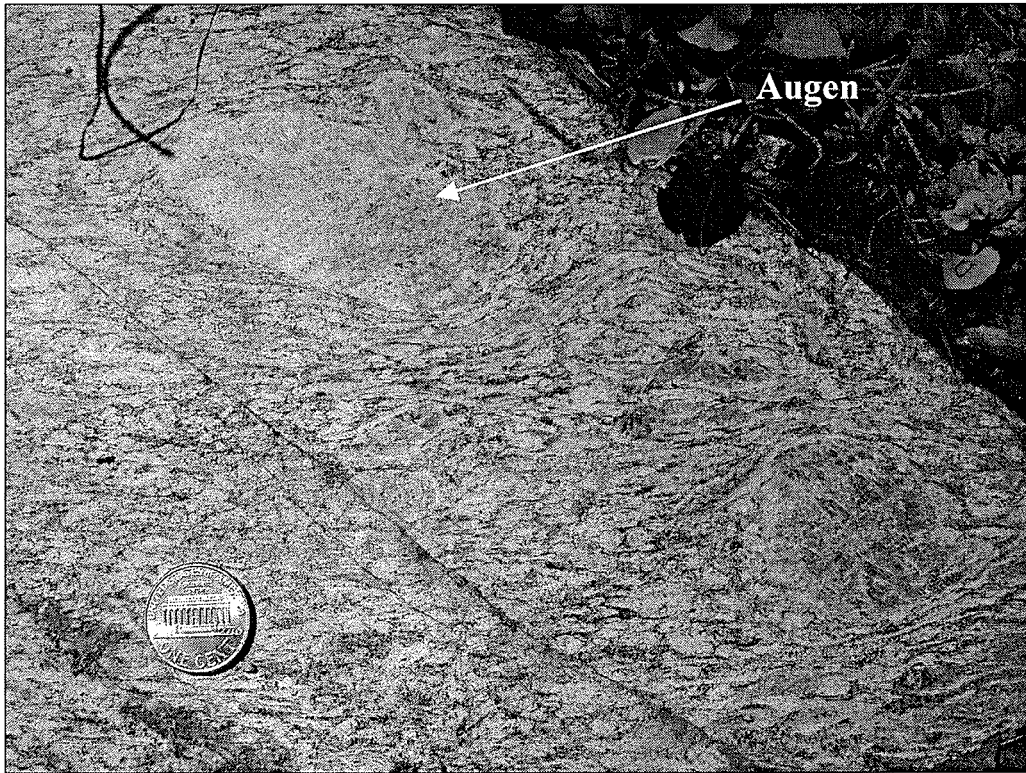


Figure 20. View of pavement at Stop 10 showing pervasive augen and two larger augen, all draped by matrix fabrics.

Mileage:

50.0 Continue northeast on Powley Road towards Rt. 10.

51.3 Park on the side of the road to view the two small pavement exposures in the bed of the road for Stop 11.

STOP 11: Ultramylonite of the PLSZ.

These outcrops are very small (about 1 m or so long each) and isolated, so whether or not these rocks are viewable depends upon many factors including whether or not the road has been re-graded recently. As with STOP 7, the exposure of these rocks is better later in the season.

The quartzo-feldspathic gneiss here shows spectacular mylonitic fabrics, as at Stop 10, where foliation and lineation are penetratively parallel across the small exposures (E-W fabrics with steep south dips and sub-horizontal E-plunges). Centimeter-scale textural layers are the highlight of this exposure where 1 to 5 cm wide bands of quartz + feldspar aggregate. Relatively thin layers of these aggregates are seen 'pinched and swelled' lenses. Individual augen of the aggregate are in the less leucocratic layers. We envision these textural variations to illustrate a progression of mylonitization where larger bands progressively become augen. Further, we suggest that the augen are seen kinematically combined, and as they interfered, they may form new aggregate bands. In a manner of speaking, one could say that the fabrics in this rock are snapshots of the progression, and that this rock is mylonite that has been multiply reworked as deformation continued.

Mileage:

51.3 Continue northeast on Powley Road towards Rt. 10.

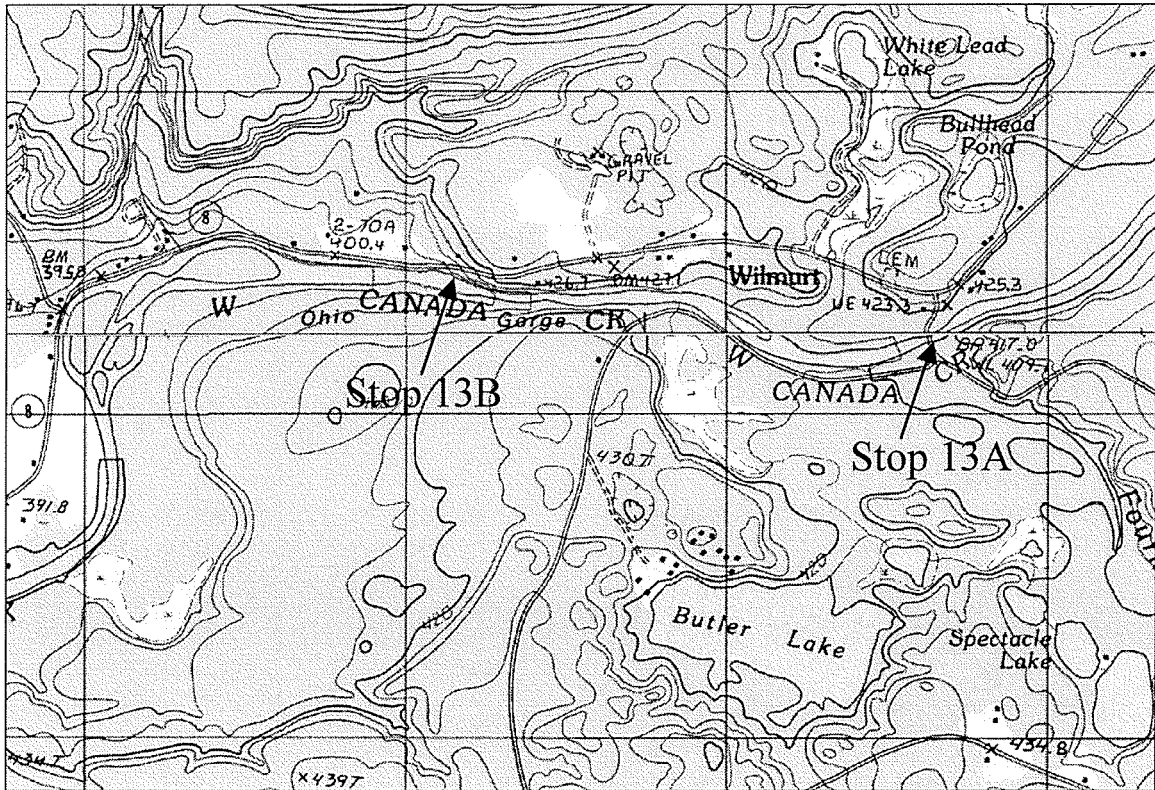
- 51.5 Mylonite pavement outcrop (similar to the rock at Stop 11).
- 53.0 Turn left onto Rt. 10 north towards Rt. 8.
- 53.7 Park on the right side of the road for the roadcuts just over the top of the hill.

STOP 12: L-S tectonite of the PLSZ.

The quartzo-feldspathic gneiss here is spectacular L-S tectonite, whose foliation is moderately SSW-dipping, and whose lineation is shallowly W-plunging. As at Stop 10, augens are aggregates of fine-grained feldspar + quartz, and some here have asymmetric delta tails that show sinistral offset (see Figure 9B). Pavement outcrop at the top of the western roadcut show excellent three-dimensional views of the fabric.

Mileage:

- 53.7 Continue north on Rt. 10.
- 54.2 Turn left onto Rt. 8 west.
- 73.7 Turn left onto Gray Wilmurt Road just after a sharp right-hand curve in Rt. 8. Cross a bridge over the West Canada Creek and park at the intersection with Jones Road. Walk back toward the bridge over West Canada Creek and down the hill to the outcrop just east (upstream) of the bridge (see location map). The outcrop forms a small water fall on the creek.



STOP 13: The PLSZ at the Ohio Gorge of West Canada Creek.

The Piseco Lake shear zone traces westward through the West Canada Creek basin. Some of the best continuous exposures occur in the Ohio Gorge near Wilmurt. The last stops for this field trip are in highly deformed granitic gneiss in the gorge. During periods of high water, the exposures at the eastern and western end of the gorge may be covered or not easily accessed. Permission is needed from the landowner at Stop 13A.

STOP 13A: East of the gorge.

The West Canada Creek forms a small waterfall at the upstream part of this outcrop. Pavement exposures reveal the L-S and L>S deformation fabric in granitic gneiss (Figure 21). Foliation is gently dipping and the lineations are subhorizontal. In the region immediately down-stream of the falls, the foliation is defined by planar aggregates of recrystallized K-feldspar and quartz that alternate with dark layers containing abundant chlorite and minor biotite. The dominant fabrics are cross cut by at least three small high-strain zones. Two are steeply dipping and strike about east-west, and the third strikes south and dips moderately westward. One of the steeply dipping high-strain zones occurs in the vertical face at the southern side of the outcrop. Another occurs at the western limit of the outcrop close to the water. The north-south striking zone occurs in the low ledge near the falls. This small shear zone contains deformed pegmatite, and cross cuts the PLSZ foliation and lineation (Figure 10). Shear sense is top down to the west or normal. The other high strain zones both contain evidence for oblique sinistral shear.



Figure 21. Outcrop of granitic gneiss with L>>S fabric. The view is looking west. Note the textural differences in this view. The area above the coin is a subvertical surface with the ends of the mineral lineations exposed. The rest of the outcrop is broken parallel to the lineations.

Mileage:

- 73.9 From the parking area, turn around and back track to Route 8.
- 74.1 Turn left onto Route 8.
- 75.2 Park on the right shoulder just after a steep downhill drive. Walk upstream along West Canada Creek to the first bedrock exposures for the westernmost outcrops in the Ohio Gorge, and Stop 13B.

STOP 13B: Western limit of the outcrop belt in the Ohio Gorge.

At this location the north dipping foliation of the Piseco antiform can be viewed in addition to the typical variation in L-S and L>S fabrics at the outcrop scale. Again, the foliation is defined by planar aggregates of dynamically recrystallized feldspars and quartz. Quartz also occurs in greatly attenuated ribbons, as seen at other locations during this field trip. Of particular interest at this location, are abundant kinematic indicators that are easily observed. Outcrop surfaces that are perpendicular to the foliation and parallel to the lineation reveal asymmetric augen of K-feldspar and plagioclase forming

both σ - and δ -type shear sense indicators with most showing top toward the west displacement (Figure 9A). Since the mineral lineations are subhorizontal, the shear sense is considered to be low-angle sinistral at this location. The abundant large (cm-size) porphyroclasts of feldspar provide some information about the protolith for the PLSZ rocks in this region. The relict grains are most likely the remains of megacrysts from an original granite.

END OF TRIP.

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Trip B-2

METAMORPHIC PETROGRAPHY BETWEEN TUPPER LAKE AND BLUE MOUNTAIN LAKE

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INTRODUCTION

This trip examines the petrography and petrology of roadside outcrops along Route 30 between Tupper Lake and Blue Mountain Lake. As with most Adirondack rocks, these have been intensely metamorphosed. Lost during the metamorphism are the features which distinguish sedimentary rocks from extrusive and intrusive igneous rocks. Their intrusive igneous textures and/or content of fossils, clay minerals, layers of volcanic lava and ash, have long since been transformed. We will visit outcrops of marble and quartzite that clearly represent metamorphosed limestone and sandstone, and amphibolites that most likely were basaltic dikes. Most rocks, however, are gneisses with varying proportions of feldspars, quartz, amphibole, pyroxene and garnet. Without geochemical analysis, it is sometimes difficult to determine if their protolith was an igneous or sedimentary rock. We draw your attention to features at the outcrop that support our interpretations; color microphotographs will be provided at most stops. We anticipate lively discussion of interpretations about the outcrops.

Our understanding of the geologic history of the Adirondacks is an ever-evolving project that involves the work of hundreds of researchers. We offer a brief summary, and refer you to more detailed studies by Isachsen et al. (1991), Chiarenzelli and McLelland (1991), McLelland et al. (1996), Hamilton et al. (2004), and the summary by Kirchgasser in this volume (Trip B-3).

The oldest rocks in the Adirondacks are 1.2 to 1.3 billion year old metasedimentary rocks that include marbles and gneisses seen on this trip. Included are gneisses that carry a geochemical signature of island-arc complexes, suggesting that northern New York consisted of a marine environment fed with materials from a nearby island arc. These rocks were metamorphosed during the Elsevirian Orogeny about 1210 to 1160 million years ago (Hamilton et al., 2004). Intruded into this sequence were the anorthosites, mangerites, charnockites and granites comprising the AMCG suite of McLelland et al. (1996). The ages of many of these plutonic rocks cluster around 1155 million years; the rocks at stop 1 are younger. A second orogenic event, the Ottawan, occurred between 1090 and 1030 million years ago (Hamilton et al., 2004). It was associated with the supercontinent of Rodinia and the formation of the Grenville Mountain range, whose heights were similar in magnitude to the present-day Himalayas. By the time Rodinia broke up, between 600 and 550 million years ago, the Grenville Mountains had been eroded to a gently rolling landscape, not unlike the present-day Adirondack lowlands, except barren of vegetation. Detailed apatite fission-track thermochronology by Mary Roden-Tice (Roden-Tice et al., 2000) at SUNY Plattsburg indicates that uplift and unroofing of the central Adirondacks began during the late Jurassic.

THE FIELD TRIP

Convene at the Tupper Lake public boat launch on Route 30, about 2.6 miles south of the junction of Routes 3 and 30 in the center of Tupper Lake Village. Set your odometer to 0.0 miles.

Meeting Spot. *Public boat launch*

The boat launch, with restrooms, was renovated in 2002 with \$610,000 provided by the Department of Environmental Conservation and the Environmental Protection Fund. Access to the lake is considered essential to the region's enjoyment and economy, and the launch is a very busy place in summer.

Proceed south on Route 30 for 2.1 miles from the boat launch.

2.1 mi. **STOP 1. Metamorphosed, fractured and mineralized meta-syenite.**

A long roadcut of reddish-colored rock on the right (west) side of Route 30. This outcrop was the focus of a senior research project by SUNY Potsdam student Scott McDonald, whose data are presented here.

Meta-syenite

This dark reddish-brown stained rock contains abundant red to tan K-feldspar, albite, and quartz (Fig. 1-1). The dark minerals are hornblende, but locally have been altered to chlorite. The k-feldspar shows marvelous perthitic textures. The minerals display pronounced parallel alignment. We believe the protolith was an igneous syenite and classify the rock as a meta-syenite or hornblende-alkali feldspar gneiss.



Fig. 1-1. Meta-syenite gneiss at stop 1. Lighter colors are primarily potassium feldspar, with lesser amounts of albite and quartz; dark streaks were hornblende now altered to chlorite.

Microprobe data for albite are listed in Appendix 1, for potassium feldspar in Appendix 2, and for calcite and chlorite in Appendix 3. Data was obtained on the microprobe at SUNY Binghamton, with the help of probe guru Bill Blackburn. The data show that the plagioclase was almost completely altered to albite during metamorphism, and that the potassium feldspar contains very little sodium.

The rock probably was coarse grained to begin with. What once were randomly oriented, tabular crystals of alkali feldspar were later transformed by shearing into small, parallel-aligned grains. Some chunky feldspar crystals were deformed into lens-shaped grains or augen, (German for "eye"). On the east side of the road, the gneiss is brown and finer grained, but it grades into reddish meta-syenite and probably is the same rock. Zircon crystals, $ZrSiO_4$, were separated from similar rock at a nearby outcrop. They have a uranium-lead age of 1098+/-4 million years, which is the age of crystallization of the syenite magma (McLelland et al., 1988, p. 921, their rock sample #10). The meta-syenite is typical of younger granitic rocks of the Adirondack Highlands which have not been studied in detail.

Joint planes and rockfalls

This outcrop has many prominent joint planes. Note the geometric shapes of the large blocks at the south end on the west side. Produced by breakage along sets of intersecting joints, they resemble children's play blocks perched precariously on edge (Fig. 1-2). A small rockfall occurred by breakage along joints on the east side of the road (Fig. 1-3). In July, 2000, crushed green plants beneath the rubble indicated that the fall had occurred a few days prior to our visit.

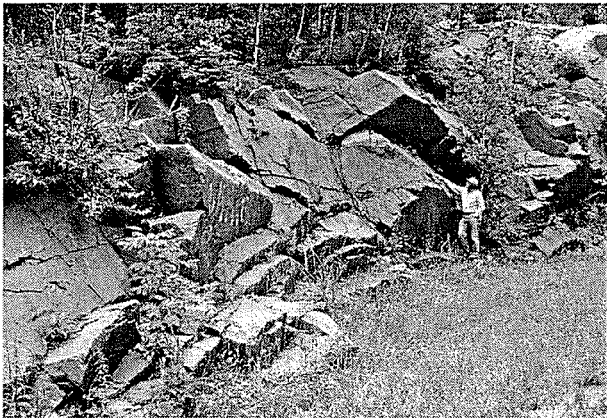


Figure 1-2. Blocks of meta-syenite displaying joint surfaces.

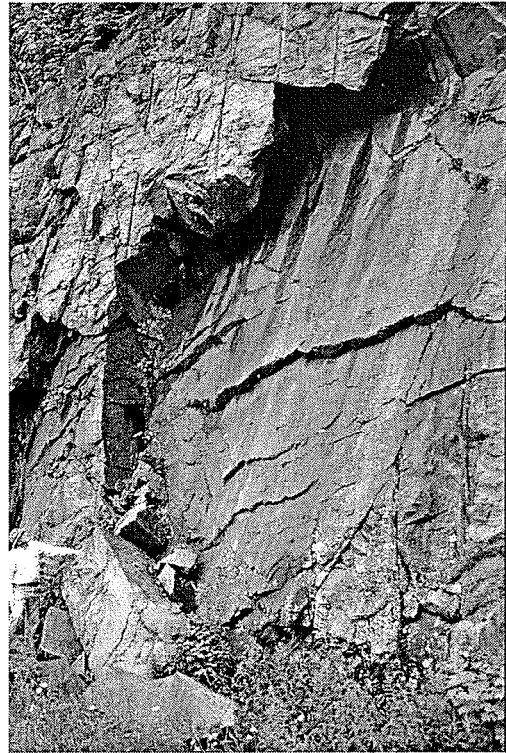


Figure 1-3. Site of rock fall along joint surface in July 2000.

Mineral deposition in breccia zones

Pace off about one hundred feet from the north end of the outcrop, west side, and locate the zones of crushed, broken and angular rock fragments (Fig. 1-4). The breccia formed long after cooling of syenite magma and long after the period of Adirondack metamorphism, perhaps during uplift of the Adirondack dome. The breccia zones are shown by the presence of irregular patches and stringers of low magnesium, Mn-bearing calcite, CaCO_3 (see microprobe data in Appendix 3).



Figure 1-4. Brecciated meta-syenite with calcite zone. vein filling.



Figure 1-5. Pyrite crystals deposited in a breccia. Pyrite occurs as small shiny crystals that cover surfaces of brecciated meta-syenite.

The calcite was deposited as cement in open spaces in the breccia. However, the calcite hides a sprinkling of tiny, brassy-yellow crystals of pyrite (FeS_2). The crystals occur as a coating on brecciated meta-syenite rock fragments (Fig. 1-5). Magnified under a hand lens, the pyrite consists of millimeter-sized crystals of two types: (1) cubes with six square-shaped sides, and (2) pentagonal dodecahedrons, a geometric form consisting of twelve faces, each with the five sides of a pentagon.

The calcite could have originated in one of two ways. It could have precipitated from fluids that dissolved minerals from overlying rocks, or, less likely, it could be igneous calcite (carbonatite) with CO_2 derived by mantle degassing. To test these hypotheses, a sample of the calcite was sent to Steve Howe, stable isotope magician at the mass spectrometer lab at SUNY Albany. His analysis shows a delta ^{18}O value of -14.927 per mil (compared to PDB) or $+15.474$ per mil (compared to SMOW), and a delta ^{13}C value of -4.303 per mil (compared to PDB). These stable isotope numbers indicate a meteoric origin of the water and a bedrock source for the carbonate (Steve Howe, personal communication).

The carbon and oxygen isotope data therefore indicate that the calcite came from the dissolution of overlying layers of marble, the dominant carbonate rock in the Adirondacks. Calcite was dissolved in water to produce ions of calcium (Ca^{+2}), bicarbonate (HCO_3^{-1}), carbonate (CO_3^{-2}) and molecules of carbonic acid (H_2CO_3). The ions and molecules were transported downward by groundwater, perhaps traveling a considerable distance before crystallizing as calcite in the breccia. The marble source of these components, probably hundreds to perhaps thousands of feet above your head, was long ago removed by erosion.

The sulphur-bearing mineral, pyrite, is virtually insoluble in oxygenated groundwater. Reducing conditions are required for transport and deposition of iron sulfide. Such groundwater is generally deep-seated, oxygen-depleted and full of dissolved material. The point being made is that the kind of groundwater required to transport calcite is incompatible with water that

transported the iron and sulphur. Separate solutions from different sources must have formed the minerals, the pyrite was first and the calcite later on.

Continue south on Route 30.
(3.6 miles between Stops 1 and 2)

5.7 mi. **STOP 2. Calc-silicate metasediments**

Park in the large, paved pullover on the right (west) side of Route 30. We are located on South Bay at the south end of Tupper Lake. Examine the roadcut opposite the middle of the parking area (Fig. 2-1). This outcrop was discussed by Jim McLelland in the 1992 NYSGA Guidebook.

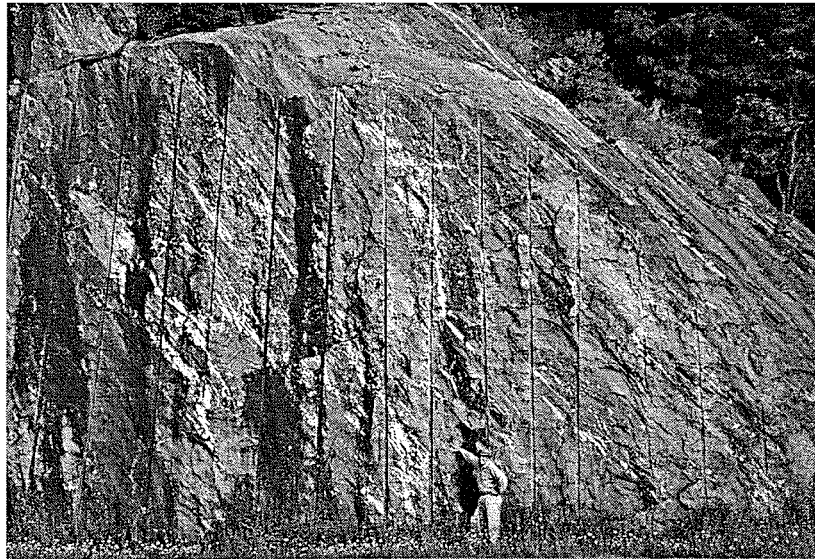


Figure 2-1. Calc-silicate outcrop at Stop 2. Jim Carl for scale.

We have left metamorphosed igneous rocks and entered a domain of metamorphosed sedimentary rocks. This outcrop is a slice through the steep west side of a bedrock hill, and the steeply inclined rocks include pale green gneisses with abundant diopside, $\text{CaMgSi}_2\text{O}_6$ (Fig. 2-2). These metasediments must be older than the meta-syenite and other igneous rocks that intruded them.



Figure 2-2. Diopside-feldspar gneiss. Dark grains are diopside, light grains are potassium feldspar and quartz.

The mineral assemblage of diopside, quartz, K-feldspar, plagioclase feldspar and sphene formed during the metamorphism of impure limestone. A chemical reaction occurred among minerals that commonly occur in limestone—calcite, CaCO_3 , dolomite, $\text{CaMg}(\text{CO}_3)_2$, and the so-called impurity—a little quartz sand, SiO_2 . Note that the formula of diopside, $\text{CaMgSi}_2\text{O}_6$, contains elements derived from each of them.

A difficulty with the presence of diopside at this outcrop is the scarcity of carbonate minerals, calcite and dolomite, that were needed to make it. Note the presence of light colored seams and veins that help to define the gneissic banding. At first glance, they might be mistaken for calcite, but the minerals do not fizzle in acid and cannot be scratched with a knife. The light-colored mineral is potassium feldspar, not calcite. We suspect that calcite and dolomite of the impure limestone protolith were completely used up in metamorphic reactions to produce diopside.

Before leaving, examine the outcrop from a distance and note the color change where green, diopside-bearing gneiss gives way to gray hornblende-biotite-feldspar gneiss as you look from right (south) to left (north). The gray gneiss was interpreted by McLelland (1992, p. 40-41) as an igneous intrusive rock, even though its contact with the diopside-bearing gneiss appears gradational over a distance of a few feet. McLelland's interpretation is that this is a highly sheared contact between two very different rock types, one igneous and one sedimentary. Another interpretation is that both are sedimentary and that the gray gneiss represents a facies change in the original sedimentary protolith, an impure limestone, to perhaps to a shale or mudstone that was metamorphosed to a hornblende-biotite gneiss. A few tens of feet north of the contact between diopside gneiss and the gray hornblende gneiss is another much smaller zone of diopside gneiss, interpreted as either a sheared fragment of the diopside gneiss or another facies change. You may form your own opinion.

Continue south on Route 30.

6.1 miles Junction with Route 421 on right

8.7 miles Intersection with the north entrance road to the William C. Whitney Wilderness Area on Little Tupper Lake.

The William C. Whitney Wilderness Area

Called the “most significant Forest Preserve acquisition in twenty five years,” the estate of Mary Lou Whitney was purchased by the State of New York in December, 1997. The purchase consisted of 14,700 acres surrounding Little Tupper Lake, once the largest privately owned lake in the northeast. The eight mile-long lake is relatively shallow (less than twenty five feet deep), drains into the Bog River and is home to a native strain of fish called the Little Tupper brook trout. Canoeists were pleased with a land purchase that connected major canoe routes throughout a vast region of wetlands, lakes, bogs and cut-over timberland. In March, 2000, the area was classified as wilderness.

The road leads to an eighty acre site on the lake's north shore, once used as the headquarters for Whitney Industries. Now classified for “administrative use,” the site includes a ranger station in a grove of tall pine trees, a parking area and a canoe launch. The lake has become one of the most widely used, flat water canoe routes in the East, and several tens of primitive camping sites have been constructed around its perimeter.

9.4 mi. STOP 3. Marble and other metasediments

Drive beyond the outcrop and park beyond the guard rail at the south end. Walk north and examine three outcrops on the west side. These outcrops were studied by SUNY Potsdam student Aaron Fiaschetti for his senior research.

Here's a good example of diopside-bearing marble, an easily recognized metamorphic rock that once was a limestone (Fig. 3-1). The marble lies between gneissic layers of debatable origin. Separated by intervals of soil, the three parts of the outcrop include (1) garnetiferous biotite gneiss with quartzite layers at the south end, (2) marble outcrops in the middle, and (3) garnet-bearing gneiss at the north end.

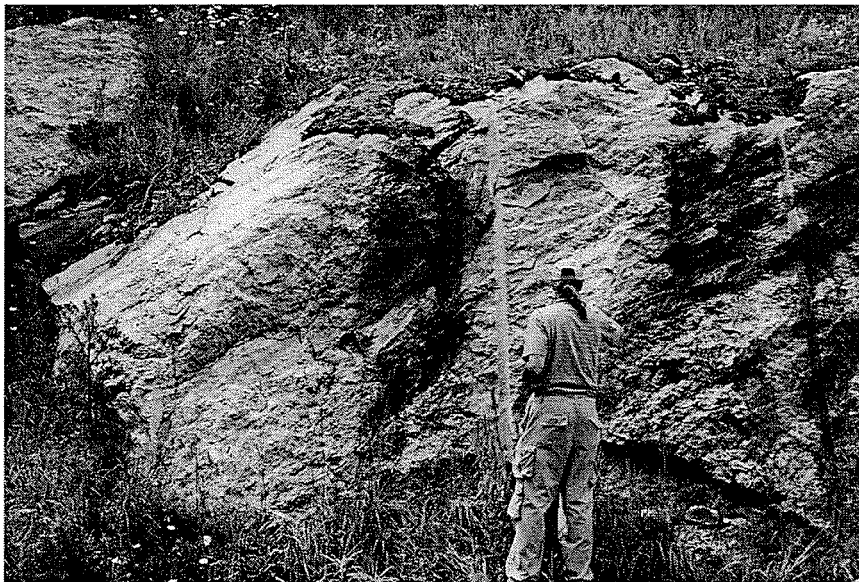


Figure 3-1. Impure marble outcrop at stop 3. Rob Badger for scale.



Figure 3-2. Banded hornblende-biotite gneiss at south outcrop, Stop 3. Thin dark seams are biotite.

South outcrop

The dark gneiss contains alkali feldspar, quartz, hornblende, seams of biotite and locally garnet (Fig. 3-2). The mica seams are close together and locally give the gneiss a schistose appearance. Some of the biotite appears to have been altered to bronze colored phlogopite. Non-geologists have misidentified such grains as flakes of gold. Thin layers of quartzite that broke away from weathered mica seams give the rock a slab-like appearance. The hornblende gneiss contains pods of quartz with small grains of garnet (Fig. 3-3) whose lavender color indicates a small spessartine (i.e. manganese, Mn) component.



Figure 3-3. Pod of quartz with reddish-lavender garnet, quartz and feldspar, within hornblende gneiss.

Middle outcrop

The white marble and calc-silicate rock are easily recognized in the center outcrop (and across the road) (Fig. 3-1). They consist of coarse calcite grains that were recrystallized from limestone during metamorphism. Most likely, the marble is much lighter in color than the original limestone. Finely dispersed coloring agents such as organic matter, clay minerals and iron oxides, were either expelled from the limestone or incorporated into the crystal structure of another mineral during metamorphism.

Glassy grains of green diopside are present, but there are fewer of them than at Stop 2. Also present are muscovite, brown sphene, shiny black flakes of graphite (pure carbon), tiny grains of pyrite, smoky to clear grains of quartz, and light colored seams of chunky alkali feldspar that, at first glance, can be mistaken for calcite. Look for veins of milky quartz. The graphite is probably the recrystallized remains of primitive algae that once lived in the warm marine environment in which the original limestone was deposited. A breccia zone at the south end of the outcrop may have formed at the same time as the breccia zone at stop 1.

North outcrop

This hornblende-biotite-garnet gneiss has more hornblende and less biotite than gneiss at the south outcrop. There are layers and lenses of pink alkali feldspar, as well as quartz veins that parallel the gneissic layering. Some layers were deformed into ragged and elongate stringers,

whereas others were pulled apart into sausage-like boudins. Garnets in the boudins are iron-rich and reddish in color.

Layers of quartzite in the south outcrop and the proximity of the intervening marble lead us to interpret the gneisses at both ends of this outcrop as shales or mudstones prior to deep burial and metamorphism. There's a certain chemical "richness" to shale, thanks to the presence of sheet-structured clay minerals such as illite, chlorite, kaolinite and montmorillonite. They became unstable and decomposed during high temperature metamorphism, and their elements were re-combined to form a variety of high-grade metamorphic minerals. Imagine the conversion of compact and drab mud into an attractive crystalline aggregate of garnet, hornblende, biotite mica and feldspars (Fig. 3-3). Hence, the well known saying, "There's nothing wrong with a sedimentary rock that 10 kilobars can't cure."

Continue south on Route 30.

(1.1 miles between Stops 3 and 4)

10.5 mi. STOP 4. Multiple igneous intrusive rocks?

Park beyond the guard rail and examine the rocks on the opposite (east) side of the road.

Description

This outcrop contains a variety of metamorphic rock types, from pink, garnetiferous gneiss to gray garnet-poor gneiss to pegmatite with coarse, black hornblende crystals. Clearly, multiple protoliths are called for.

The massive, pink and gray gneisses that predominate at the south end of the outcrop (Fig. 4-1) contain abundant quartz and potassium feldspar with lesser amounts of plagioclase feldspar, biotite and a few small garnets scattered here and there. In thin section, the potassium feldspar contains a wide range of excellent examples of perthitic textures, which clearly suggest an igneous origin. The rock has a fairly uniform grain size. It lacks the pronounced banding and segregation of minerals that we observed at Stop 3. It also lacks dark colored minerals, but chemical reactions that produced the garnet may have used them up. Most likely this rock was originally a granite.

Present in the light colored granitic gneiss is a distinctive 10-15 inch wide layer of amphibolite (Fig. 4-1), composed predominantly of black hornblende and plagioclase feldspar. This rock probably was a basaltic dike that intruded the granite prior to metamorphism.

The mafic content of the gneiss increases towards the north end of the outcrop, and the rock becomes an orthopyroxene-bearing granitic gneiss, or "charnockite" (see discussion of charnockites at Stop 9). Much of the opx has been altered to chlorite and other alteration minerals, but the persistence of relict cleavage indicates that the mafic grains were originally pyroxenes. Other portions of the rock contain significant amounts of hornblende. Again, an igneous protolith is called for, but the high mafic content suggests this intrusive rock unit differs from the mafic-poor granite gneiss at the south end of the outcrop.

A coarse grained pegmatite occurs near the north end of the outcrop (Fig. 4-2). It contains coarse grains of potassium and plagioclase feldspar, hornblende and two varieties of pyroxene—one a pale green with second order interference colors of clinopyroxene, the other a pale pink with first order interference colors of orthopyroxene. The opx shows more alteration than cpx, which is typical in Adirondacks rocks with co-existing pyroxenes. Apatite is also a significant component. The coarse minerals are randomly oriented as though crystallized from a silicate melt in the presence of a watery fluid. The pegmatite

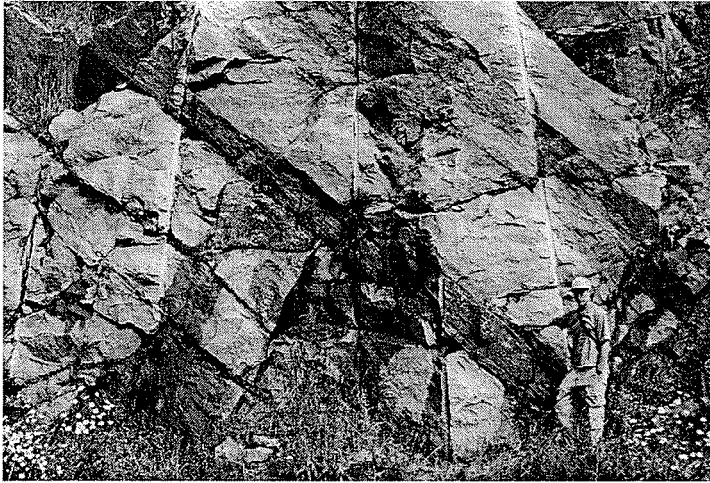


Figure 4-1. Amphibolite dike cutting garnetiferous pink and light gray granitic gneiss.

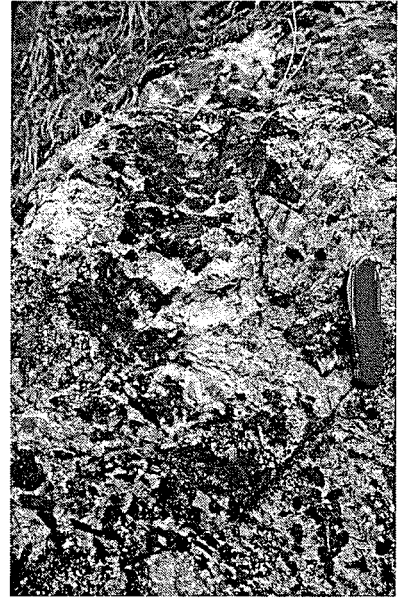


Figure 4-2. Coarse hornblende and feldspar in pegmatite dike, north end of outcrop at Stop 4.

appears to be a late igneous intrusion that post-dates metamorphism. Or, given the compositional similarity to the surrounding rock, it could be recrystallized gneiss in the presence of hot, watery fluids of late stage metamorphism.

Continue south on Route 30.
(1.0 miles between Stops 4 and 5)

11.5 mi. **STOP 5. The granite quarry outcrop.**

Park at the south end of this long roadcut, beyond the guard rail, and examine the outcrop on the right (west) side (Fig. 5-1).

Quarries

No, they don't quarry the granite for building stone here. In a sense, however, all road cuts are quarries because rock was removed to make room for the roadbed. The Department of Transportation blasted through the massive rock, and much breakage occurred along the natural fractures (joints). Breakage along prominent near-horizontal sheeting joints has provided some flat and narrow surfaces that resemble crude stair steps in the face of the outcrop, similar to the working face of an active stone quarry.

Metamorphosed granite

The finely foliated meta-granite or alkali feldspar-quartz-hornblende gneiss, has small grains of dark hornblende aligned as parallel stringers (Fig. 5-2). Some of the hornblende has altered to chlorite, but most is intact. A little plagioclase feldspar is present, along with apatite and a few grains of zircon. Cutting diagonally across the outcrop is a dark amphibolite layer (Fig. 5-1) that once was a tabular dike of basalt that intruded the granite. A small fault extends from the granite into the dike about midway up. See if you can find it. The top part of the dike was displaced a few inches to the right of the bottom part. Also note whether the dike lies parallel to, or cuts across the gneissic layering in meta-granite.

Small faults in meta-granite are often coated with fault gouge. Slickenlines in the gouge

indicate the direction of fault movement (Fig. 5-3). The fractures are coated with green hydrous alteration minerals, probably chlorite and serpentine.

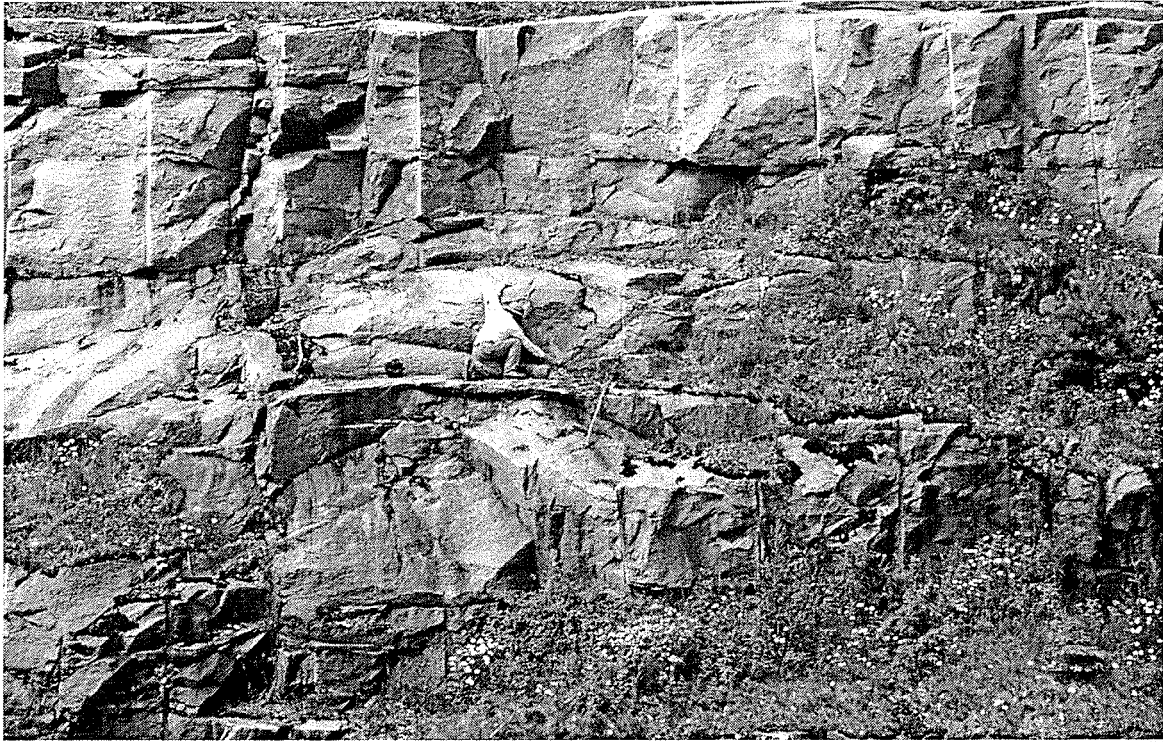


Figure 5-1. Granitic gneiss at Stop 5 showing horizontal sheeting joints. Jim Carl is pointing to a thin mafic dike that cuts diagonally across the outcrop.

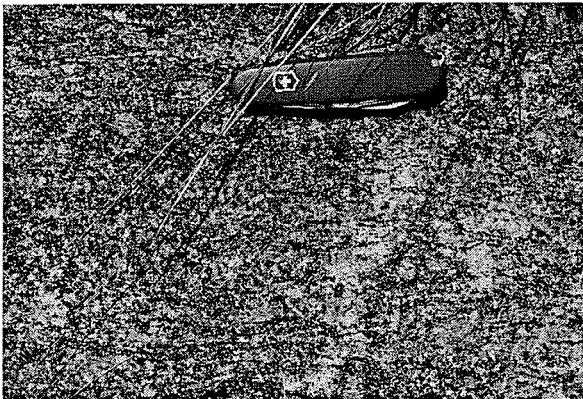


Figure 5-2. Alkali feldspar-quartz-hornblende gneiss at Stop 5. Note parallel alignment of hornblende grains.



Figure 5-3. Slickenlines parallel to pen indicate direction of movement along small fault.

Continue south on Route 30.
(3.1 miles between Stops 5 and 6)

12.4 mi. Intersection on the right (west) side with the south road (Sabattis Road) to the William C. Whitney Wilderness Area.

14.6 mi. STOP 6. The marble cake outcrop (that isn't marble). Evidence for igneous intrusive origin.

Examine the outcrop on the left (east) side of Route 30. The rock is cream and black mottled gneiss that reminds us of a marble cake. The light portions are composed primarily of plagioclase (An_{36} , optically determined) and alkali feldspar, with very little quartz, while the dark zones are predominantly composed of clumps of hornblende and diopside, with minor garnet, magnetite and scattered apatite. At the south end of the outcrop and on the west side of the road is a different type of rock. Thus, our “marble cake” rock may be of small volume and confined to this outcrop, but we think it is the most unusual rock on this field trip.

To make a marble cake, one takes a yellow cake batter and divides it into two parts. Chocolate is added and thoroughly blended in one part. Spoonfuls of the chocolate batter are then dropped into the remaining yellow batter, and a spatula is used to swirl the blobs about. This outcrop is the result. Or so it seems. The dark, steeply inclined layers contain abundant hornblende and pyroxene (Fig. 6-1). The “free form” pattern of layers, ribbons, loops and swirls, however, was not produced by stirring. The pattern results from the intersection of the viewing surface with the plane of gneissic banding, whether parallel to it, perpendicular, or somewhere in between. Marble cakes and rocks that resemble them have beautifully convolute patterns, but the anticipation of eating is absent here.

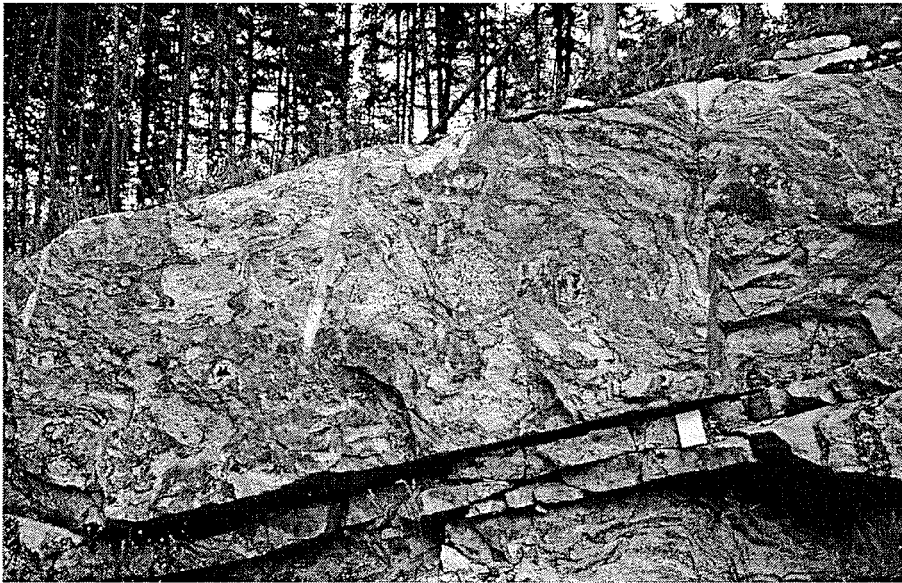


Figure 6-1. Mottled feldspar-hornblende-quartz gneiss at stop 6. (See front cover for color photo)

An early effect of metamorphism was to segregate a coarse-grained igneous rock into light and dark layers. The rock then became “mobile” and began to flow. Some of the dark layers behaved rather stiffly. They were ruptured and shredded while the light-colored, feldspar-rich layers flowed plastically around them (Fig. 6-2).

Evidence that the swirled gneiss was an igneous rock includes a large fragment of diopside-bearing marble in the gneiss (Fig. 6-3). The fragment is a xenolith whose presence is a powerful argument that the gneiss was once magma and that the fragment was caught up in it. Another xenolith is composed of green diopside and red garnet (Fig. 6-4). Note that the gneissic layering is deflected around it. The swirled gneiss also contains large feldspar crystals up to eight inches across (Fig. 6-5). Minerals of that size generally have crystallized from low viscosity silicate melts, often in the presence of watery fluid. The question is how such large crystals survived the metamorphism, especially the shearing that produced the gneissic banding.

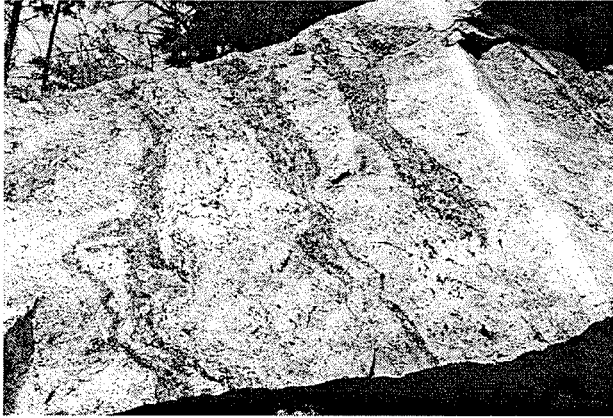


Figure 6-2. Dark bands of hornblende gneiss segregated from lighter feldspar rich zones.



Figure 6-3. Calc-silicate xenolith (to right of knife) in contact with its meta-intrusive host.

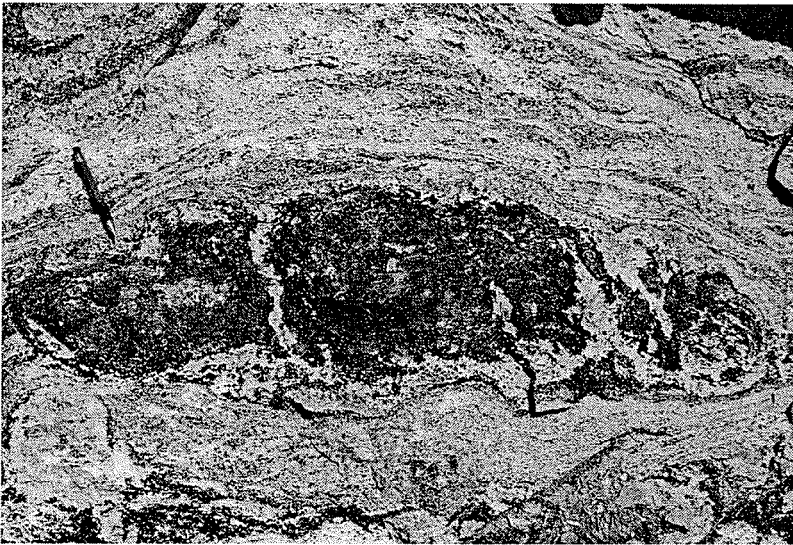


Figure 6-4. Xenolith of garnet-diopside gneiss within its intrusive host.

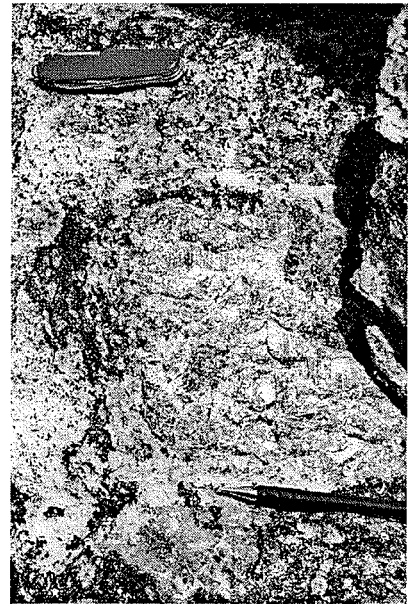


Figure 6-5. Feldspar phenocryst between pencil and dark border below knife.

Our explanation is not very profound. A wide range in grain size is expected if the shearing had been a hit and miss operation. Some parts of the rock were reduced in grain size, whereas other parts were left undisturbed. Primary igneous textures are preserved elsewhere in the Adirondacks, including anorthosite outcrops near Saranac Lake which contain single plagioclase feldspar grains more than 12 inches long.

We note that angular fragments make up a breccia zone parallel to the gneissic banding (Fig. 6-6). This post-metamorphic breccia zone may be synchronous with the one seen at Stop 1.

A change in rock type occurs at the south end of the outcrop. The banded rock gives way to a pinkish and green, faintly foliated gneiss whose minerals include pink alkali feldspar, quartz, biotite, a little hornblende, and locally significant amounts of red brown garnet (Fig. 6-7).



Figure 6-6. Fragments of broken rock (breccia) within a foliated matrix.

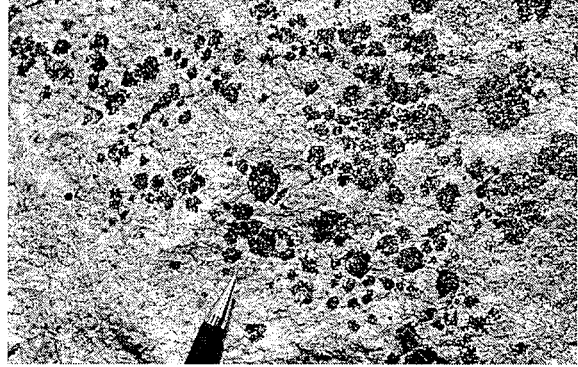


Figure 6-7. Garnet grains in pink feldspar gneiss at south end of outcrop at Stop 6.

Continue south on Route 30.
(1.6 miles between Stops 6 and 7)

16.2 mi. **STOP 7. Layered “gray gneiss,” a common metamorphic rock.**
Examine the left (east) side of the road.

Welcome to the “gray gneisses,” a common and widespread rock type in Precambrian age rocks throughout the eastern United States and Canada. This medium grained example has fewer surprises than the last outcrop. It, too, contains plagioclase and alkali feldspar, hornblende, pyroxene, garnet, quartz and a little biotite mica. The gneissic banding consists of stringers and seams of cream-colored alkali feldspar. Some bands are convoluted and pinch out, and all are vertical or steeply inclined (Fig. 7-1). The gneiss is peppered with garnets, and the large ones are prominently displayed in the light colored seams. The rocks at this outcrop lack the large feldspar crystals and marble xenoliths seen at the previous stop, and may not be intrusive in origin.



Figure 7-1. Vertical gneissic layering in hornblende-garnet-biotite gneiss at Stop 7.

This gray gneiss may have been volcanic ash, an extrusive igneous rock. Similar-looking rock underlies a belt more than seventy miles across in the Adirondack Lowlands to the northwest. Published geological studies suggested that the original rock was sedimentary in origin, a shale or an arkose, but the chemical data were a good match for dacite volcanic rocks

(Carl, 1988). We have not analyzed the rock at this outcrop but it, too, could represent a thick pile of volcanic ash.

Note the presence of a fifteen inch-thick pegmatite vein that cuts across the gneiss (Fig. 7-2). It consists of smoky quartz and coarse, chunky grains of alkali feldspar, cream to gray in color. The vein also contains dark and tabular hornblende crystals about three quarters of an inch wide and up to four inches long (Fig. 7-3). The crystals are randomly oriented as expected from growth within a low viscosity, water-bearing silicate magma. Such magma would promote the growth of large crystals, as well as the crystallization of the hydrous minerals hornblende and biotite observed along the vein margins.



Figure 7-2 Coarse pegmatite dike at Stop 7. Hornblende-garnet-biotite gneiss on right.

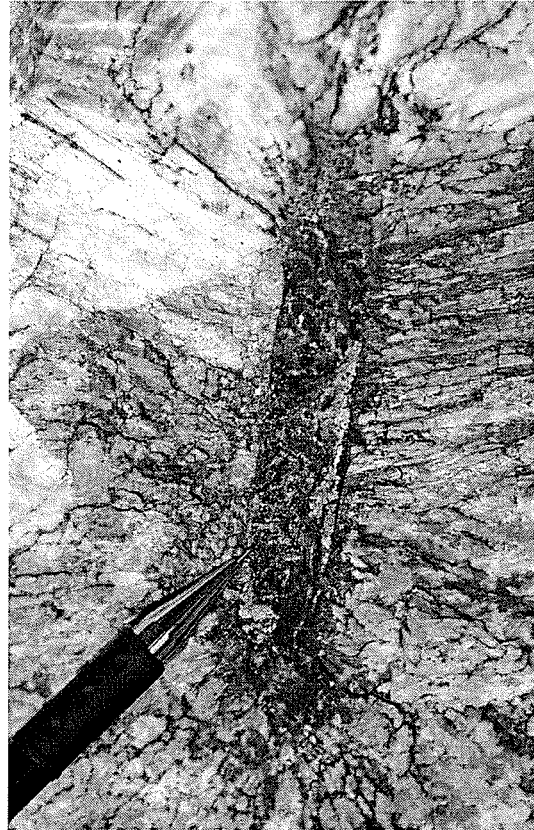


Figure 7-3. Hornblende grain in pegmatite of previous figure.

Continue south on Route 30.
(8.4 miles between Stops 7 and 8)

16.9 mi. Lake Eaton campground on the right (east) side.

18.8 mi. Bridge, beach and floatplane dock at Long Lake

19.5 mi. The junction of Routes 28N and 30. Turn right (west) on Route 28N and 30.

Turnoff to Buttermilk Falls

22.5 mi. Turn right (south) onto North Point Road. The turnoff occurs on a sharp left curve. Drive 2.1 miles west to the parking area for Buttermilk falls.

24.6 mi. STOP 8. Buttermilk Falls on the Raquette River.

Park near a small sign on the right (north) side of North Point Road. Walk the short distance to the waterfall. We are located upstream less than a mile from Long Lake.

This relatively steep stretch of the Raquette River lies east of Forked Lake and southwest of Long Lake. The river drops 116 feet in five miles, and Buttermilk Falls is the third of three canoe carries from Forked Lake. Rapids here extend for about one hundred yards before ending in a waterfall, and the total drop in elevation is about forty feet.

The bedrock at the falls is a highly weathered, dark brown, metamorphosed granite. One can see pods and veins of milky quartz that crop out near the shore. The bedrock is covered with pine needles and shallow soil. Trees are shallow-rooted and unstable in high winds.

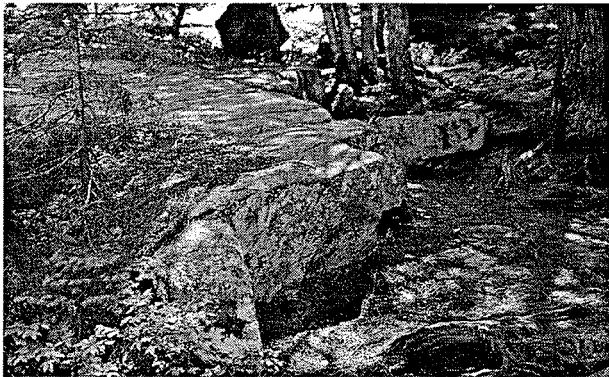


Figure 8-1. Prominent jointing at outcrops near Buttermilk Falls. Joint planes intersect at nearly right angles, and blocks have broken away to leave vertical walls.



Figure 8-2. Potsdam student taking advantage of stairsteps produced by jointing at Buttermilk Falls. The river has removed blocks between joints and deposited them downstream.

Unless many rock hammers improve the quality of fresh outcrop exposures, this is a structure stop, and the petrography of the rock is best examined at Stop 9. Two prominent directions of jointing are present here (Fig. 8-1), with one extending across the river. The joint planes had little influence in creating the stream channel, in contrast to joints that lie parallel to stream courses. But “cross joints” like these are partly responsible for the presence of rapids. Blocks were removed from the downstream side of a joint, resulting in stair steps that decline in the downstream direction. The river spills over them. People who sit in spaces where the blocks once sat will either enjoy a shower or a bouncing ride downstream (Fig. 8-2).

The same joint spacing, often outlined by pine needles caught in the grooves, can be observed in the bedrock surrounding the falls. The origin of jointing is unclear. Is it due to isostatic rebound following glacial retreat? Or is it much older, related to uplift of the Adirondacks and erosion of the overlying bedrock? Or is it older still, caused by tectonic forces shortly after metamorphism?

The falls and spray sparkle in the sunlight, and our geology field trips get bogged down when the college students disperse among the rocks. They sit at the falls and perch with the demeanor of poised herons, legs crossed, patiently waiting for a stray fish. They relax, get wet and cannot hear their professor’s voice over the roar of the falls. If the timing is right, this is a good place for lunch.

Turn around and drive 2.1 miles back to Route 30.

(6.3 miles between Stops 8 and 9)

26.7 mi. Intersection of North Point Road with Route 30. Turn right (south) on Route 30 towards Blue Mountain Lake.

(4.2 miles from this intersection to Stop 9)

30.9 mi. **STOP 9. Dark brown meta-granite with pegmatite.**

Park on the shoulder of Route 30, before the curve and near the center of a long outcrop on the right side.

The dark brown colored meta-granite (Fig. 9-1) is similar to the bedrock at Buttermilk Falls. This type of rock was quarried and used as a building stone in handsome but very dark-walled churches in Saranac Lake, Lake Placid, Tupper Lake and elsewhere. The major minerals are alkali feldspar, hornblende and orthopyroxene with lesser amounts of quartz, plagioclase feldspar, clinopyroxene, garnet, magnetite and apatite. Gneissic banding is faint, steeply inclined and hard to see when the outcrop is wet.

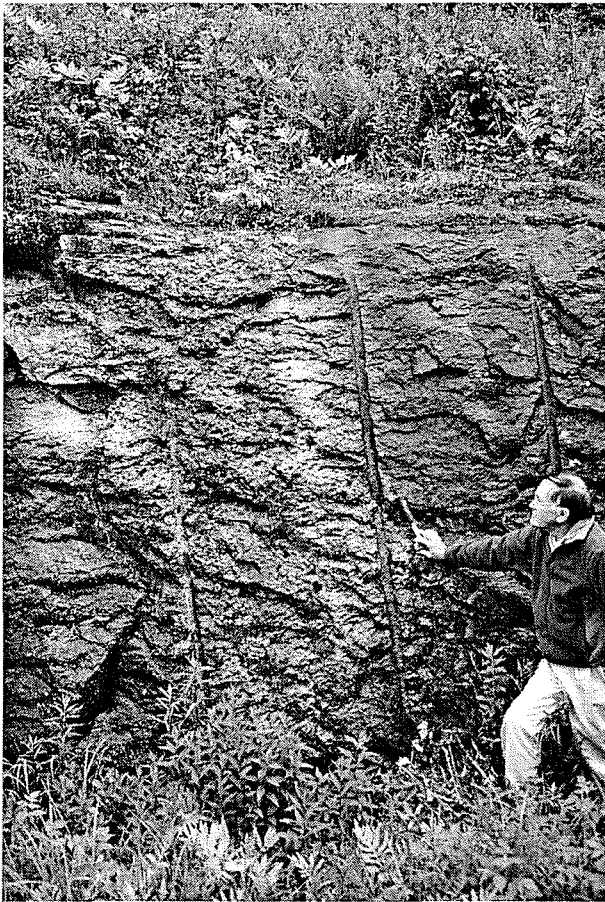


Figure 9-1. Pegmatite dike pointed out by Jim Carl at Stop 9.



Figure 9-2. Pods of crystallized melt that probably moved very little from their point of origin.

The presence of pyroxene is unusual for granite, and geologists have a special name for orthopyroxene-bearing granite: charnockite. The name honors Job Charnock, the founder of Calcutta, India, who died in 1693. Charnock was not a geologist and may not have appreciated this particular rock, but his memory is preserved among geologists because the first described example of charnockite was his tombstone.

Charnockites are igneous rocks that were subjected to high grade metamorphism. The presence of hypersthene pyroxene, $(Mg,Fe)SiO_3$, raises a question. Did the mineral crystallize in the magma and, therefore, is of igneous origin? Or did it form much later during metamorphism when water-bearing silicate minerals, such as biotite and hornblende, dehydrated and converted into hypersthene? If so, hypersthene would be a metamorphic mineral. Adirondack charnockites are widespread igneous rocks that make up the “C” part of the AMCG suite of intrusive rocks.

Look closely along the outcrop, before the right bend in the road, for a pegmatite vein consisting of quartz and alkali feldspar (Fig. 9-1). Also of interest are mottled patches of light colored, slightly coarser grained rock that lack hypersthene (Fig. 9-2). The patches are best seen on dry surfaces around the bend towards the south end of the outcrop. The pegmatite and mottled patches are generally interpreted as having formed by partial melting of the charnockite.

During metamorphism, the temperatures were hot enough to melt some of the biotite, hornblende, quartz and feldspar. Most likely, the break-down of biotite and hornblende supplied enough water to lower the melting temperatures of the other minerals. Where appreciable quantities formed, the melt migrated into fractures to form pegmatite veins, like the one seen here, that may have migrated several tens or even hundreds of feet. The patches, on the other hand, appear to be small quantities of melt that did not migrate very far. The patches are sometimes called “sweats,” a reminder of efforts by the human body to cool itself. The sweats at this outcrop solidified near where they formed.

If you have time, continue 2.4 miles on Route 30 to the Adirondack Museum at Blue Mountain Lake.

Adirondack Museum at Blue Mountain Lake

The Museum honors the people of the Adirondacks. There are exhibits about the lives of Native Americans, early settlers, wealthy tourists who joined them in summertime, the unique architecture of Adirondack camps, and the intricate transportation networks that brought people into the woods. One learns about farmers, hunters, miners, loggers, guides, artists, writers, furniture makers and, most of all, tourists like you, drawn here for more than 150 years by the natural beauty of the mountains, lakes and forests.

The museum itself is a mountainside courtyard of large and small buildings, some serving to house a collection of artifacts, and others to illustrate a distinctive style of Adirondack architecture. All are clustered on a mountain side, the site of a former hotel and resort. The center of the grounds is a courtyard with an artificial pond and the steam engine from the Marion River Railroad. People climb on the engine, sit on Adirondack chairs, and leisurely stroll about, enjoying a spectacular view of mountains that overlook Blue Mountain Lake. The lake and its inflowing streams are the source of the Raquette River that we encountered at Tupper Lake, Long Lake and Buttermilk Falls.

As geologists, we call attention to the building and exhibits entitled “Mining in the Adirondacks” with an emphasis on iron mining. Note the diorama of the 1847 McIntyre iron works, as well as the wall-size photograph of the main arch of the 1854 charcoal-fueled blast furnace. Also on display are Adirondack industrial products that include graphite, garnet, talc and zinc. Be sure to visit the log cabin of the Buck Lake Club and examine the mineral specimens mounted in the stone fireplace that include agate, garnet, rose quartz, flint, obsidian, feldspar, tourmaline and magnetite.

END OF TRIP

APPENDICES

Sample #	tlb141	tlb142	tlb143	tlb145	tlb146	tlb147	tlb148	tlb149	tlb150	tlb1410
SiO ₂	65.6	65.12	64.53	67.33	66.38	67.07	66.73	67.78	68.03	68.03
Al ₂ O ₃	20.00	21.10	20.66	20.02	20.03	20.11	20.00	20.02	20.08	20.08
TiO ₂	0.00	0.02	0.00	0.01	0.01	0.01	0.03	0.00	0.00	0.00
FeO	0.24	0.17	0.09	0.16	0.16	0.03	0.12	0.03	0.00	0.00
MgO	0.00	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.01
MnO	0.03	0.03	0.02	0.00	0.02	0.00	0.00	0.00	0.02	0.02
CaO	0.20	1.57	1.23	0.08	0.05	0.05	0.03	0.10	0.06	0.05
Na ₂ O	12.96	12.19	12.15	12.80	13.12	13.15	13.01	13.01	12.98	12.98
K ₂ O	0.09	0.14	0.09	0.10	0.04	0.08	0.07	0.11	0.06	0.06

Appendix 1. Microprobe analyses of albite grains in the meta-syenite at Stop 1.

Sample #	tlb131	tlb132	tlb133	tlb134	tlb135	tlb136	tlb251	tlb252	tlb253
SiO ₂	61.21	64.09	60.96	61.11	61.28	61.81	62.23	62.06	61.72
Al ₂ O ₃	18.85	18.32	18.12	19.08	18.95	18.81	18.61	18.60	18.57
TiO ₂	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.04	0.01
FeO	0.02	0.09	0.05	0.01	0.00	0.05	0.05	0.10	0.15
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.01	0.00	0.06	0.01	0.00	0.00
CaO	0.20	0.00	0.55	0.10	0.13	0.10	0.01	0.02	0.03
Na ₂ O	0.81	0.12	0.11	1.54	1.50	1.75	0.49	0.54	1.02
K ₂ O	19.05	19.87	20.54	17.56	17.70	17.74	19.16	19.38	18.56

Appendix 2. Microprobe analyses of potassium feldspar grains in the meta-syenite at Stop 1.

Sample #	tlb137	tlb138	tlb1310	tlb1311	tlb241	tlb242	tlb243	tlb424	tlb425	tlb426
	cc	cc	cc	cc	chl	chl	chl	chl	chl	chl
SiO ₂	0.00	0.00	0.00	0.00	24.66	24.93	24.78	28.54	28.25	29.11
Al ₂ O ₃	0.01	0.00	0.01	0.00	21.13	20.96	21.18	14.98	14.98	15.02
TiO ₂	0.00	0.00	0.01	0.00	0.04	0.01	0.02	0.05	0.02	0.03
FeO	0.20	0.34	0.13	0.20	28.11	28.14	28.25	26.44	27.51	26.25
MgO	0.07	0.06	0.06	0.07	11.73	12.24	11.77	15.70	14.28	15.73
MnO	1.09	1.11	1.07	1.11	0.28	0.28	0.33	0.09	0.06	0.14
CaO	58.65	58.47	60.09	59.50	0.00	0.01	0.01	0.09	0.08	0.14
Na ₂ O	0.00	0.00	0.03	0.00	0.01	0.00	0.02	0.00	0.02	0.01
K ₂ O	0.02	0.08	0.00	0.01	0.01	0.01	0.02	0.03	0.00	0.02

Appendix 3. Microprobe analyses of calcite and chlorite grains in the meta-syenite at Stop 1.

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TRIP B-3

EXCURSION TO CLIMB MT. ARAB IN THE ADIRONDACK MOUNTAINS NEAR TUPPER LAKE

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INTRODUCTION

The easily reached summit of Arab Mountain (Mt. Arab of trail guides), near Tupper Lake in southern St. Lawrence County, with its Fire Tower and open overlooks, offers spectacular panoramic views of the Adirondack Mountains. For geologists, naturalists and tourists of all ages and experiences, it is an accessible observatory for contemplating the geologic, biologic and cultural history of this vast wilderness exposure of the ancient crust of the North American continent.

My connection to Mt. Arab began in the 1980s on the first of several hikes to the summit in the fall season with Elizabeth (Betsy) Northrop's third grade classes from Heuvelton Central School. Although the highways and waterways in these mountains can offer breathtaking vistas, to truly experience the expanse and quiet grandeur of the Adirondacks, one must climb to a summit. At two miles roundtrip on a well-maintained trail and only 760 ft. (232 m) elevation change, Mt. Arab is ranked among the easiest of the fire tower trails in New York State (Freeman, 2001); at a leisurely pace the summit at 2545 ft (776m) elevation can be reached in thirty to forty-five minutes. Mt. Arab is included in many trail guides, among them one with many useful tips on hiking with children in the Adirondacks (Rivezzi and Trithart, 1997). Through the efforts of the Friends of Mt. Arab, the Fire Tower and Observer's Cabin have been restored and there are trail guides available at the trailhead. In recent years naturalist guides are on duty during summer weekdays.

ROUTE FROM POTSDAM TO MT. ARAB

The route from Potsdam up to Mt. Arab follows the valley of the Raquette River along Rte 56 South to its intersection with Rte. 3 at Sevey (or Sevey's) Corners. This leg of the trip follows Trip C of VanDiver (1976) and the notes given here of special features along the way borrow heavily from that geological guide as well as other general accounts of the geological history of the Adirondacks, including Isachsen and Fisher (1970), VanDiver (1980), Fisher et al. (1980), Rogers et al. (1990), Isachsen et al. (1991) and the Department of Environmental Conservation (DEC) Map and Guide (1999). A recently published Geological Society of America monograph (Tollo et al., 2004) summarizes recent studies on the geological evolution of the Adirondacks, much of it based on new U-Pb zircon dates on the various suites of rock and comparison of the tectonic features and mineral suites with those of modern-day mountain terranes. The metamorphic conditions under which the rocks of Adirondack formed have been compared to the continental-collision style tectonics of the Himalaya Mountains.

GEOLOGIC HISTORY OF THE ADIRONDACKS

The basement rocks exposed in the Adirondack Mountains of New York are part of the Grenville Province of the Canadian Shield, a vast continuous belt of ancient metamorphic rocks along

the eastern margin of the North America Continent (Fig. 1). They are connected to the shield via the Frontenac Arch, a northwestward trending corridor, also exposed through the sedimentary cover, that crosses into Canada at the Thousand Islands. The sedimentary and igneous rocks of the Grenville Province were intensely folded, faulted and metamorphosed during the Grenville Orogeny, a complex sequence of tectonic events, during the Proterozoic Era, between about 1.3 and 1.0 billion years ago.

The Adirondack Highlands to be seen on this trip are a roughly circular-shaped landform of rugged, uplifted mountainous terrane underlain primarily by intensely deformed (granulite facies) metaigneous rocks and minor metasedimentary rock, part of the Central Granulite Terrane. By comparison, the Adirondack Lowlands of northwestern St. Lawrence and northern Jefferson Counties, is a subdued landform, underlain primarily by less intensely deformed (upper amphibolite facies) and more easily eroded variety of metamorphosed sedimentary and volcanic (metasedimentary, metavolcanic and metaigneous) rocks, part of the the Frontenac Terrane.

The boundary between the Adirondack Highlands and Adirondack Lowlands is a .67-6.7 mile (1-10 km) wide northeast-trending zone of highly strained metamorphic rocks (mylonites) comprising the Carthage-Colton Mylonite Zone (CCMZ), a shear-zone and fault boundary which extends northward beneath the sedimentary cover in New York to the Labelle Shear Zone of southern Quebec. The origin of the Grenville terranes and the CCMZ boundary are discussed in detail elsewhere in this volume and only a brief summary is given below.

The geological evolution of the Grenville orogenic belt comprises three major events as summarized by McLelland and Chiarenzelli (1990), McLelland et al. (1988, 1996) and Tollo et al. (2004): a. an island-arc related Elzevirian Orogeny that began about 1350 Ma. (million years ago) and ended about 1185 Ma. when outboard terranes had been accreted, the associated compression having overthickened the crust and underlying lithosphere; b. an interval from about 1175 to 1125 Ma. when the Elzevirian orogen or mountain belt foundered and magmas of the anorthosite-mangerite-charnockite-granite suite (AMCG magmatism) originating from the upper mantle and lower crust intruded (at around 10 km depth) first in the northwest and later and more profusely to the southeast in the area of the Adirondack Highlands. There are no rocks in New York dated in the interval (1125 to 1100 Ma.) but at around 1110 to 1090 Ma. hornblende granites (Hawkeye Suite) intruded in the northern Adirondack Highlands; c. the final major Grenville orogenic phase, the Ottawa Orogeny, began around 1080 Ma. and continued to around 980 Ma. This global-scale, continental collisional-event strongly deformed and metamorphosed the older rocks, most intensely the more deeply buried (17 to 20 mile; 25 to 30 km. depth) Highland rocks. The Ottawa compression approximately doubled the thickness of the crust and lithosphere, and produced a mountain range comparable in height to the modern Himalaya chain.

It was during the late or the foundering phase of the Ottawa orogen or mountain belt that the Highlands and Lowlands terranes became juxtaposed along the CCMZ. The boundary is interpreted as a post-collisional event, an oblique-to-strike slip displacement followed by dip-slip movement along an extensional fault (dipping northwest) in which part or all of the Lowlands terrane (the hanging wall) was downthrown relative to the Highlands terrane (footwall). The hypothesis is that the Lowlands rocks once capped the Highlands rocks and when the Lowlands rocks slid or collapsed downward to the northwest along the CCMZ, it exhumed or unroofed the roots of the predominantly intrusive igneous rocks (AMCG suite) of the Highlands terrane. These AMCG metamorphic rocks seen today, after post-Grenville uplift and erosion, include the mangerite pluton forming Arab Mountain, and the more resistant and extensive belt of anorthosite plutons of Whiteface Mountain and the Marcy Massif of the High Peaks region.

The Lowlands terrane-over-Highlands terrane hypothesis explains some of the similarities and differences between Lowlands and Highlands rocks. The similar patterns of isoclinal folding, although differing in orientation (Fig. 1), are the result of both regions experiencing Ottawan-phase metamorphism. There are similar metasedimentary facies (ex. marbles) in both areas and alaskitic or leucogranites of metaigneous origin are found in both areas. While the Ottawan phase metamorphic

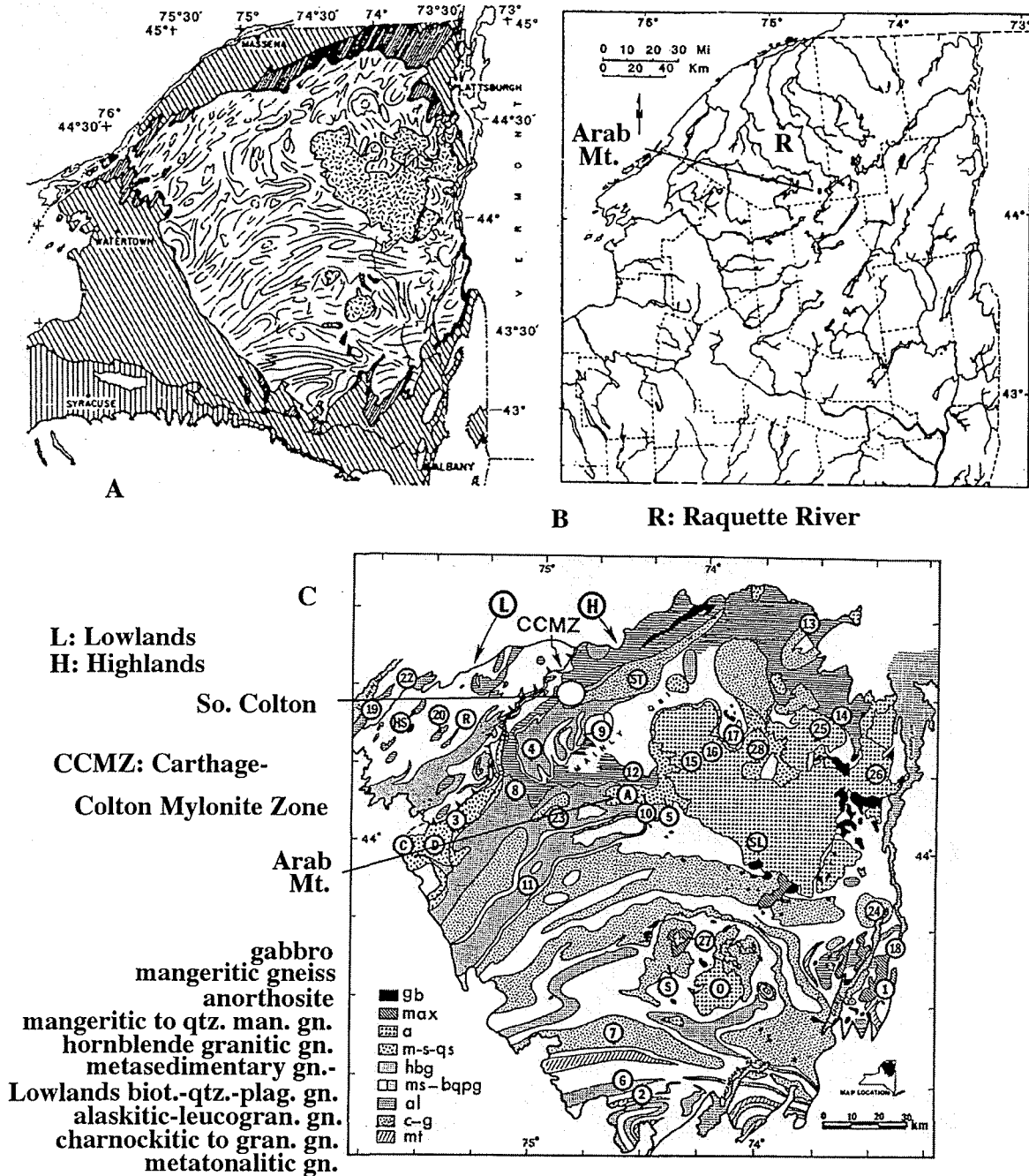


Fig. 1. Maps showing A. fold patterns and B. radial drainage of major rivers in the Adirondacks (from Isachsen et al., 1991) and C. major bedrock units and numbered locations of Zircon dated rocks (from McLelland et al., 1988).

overprint is the predominant structural and fabric signature in both terranes, the Highlands rocks, being more deeply buried in the core of the orogen, experienced the higher grade of metamorphism (granulite facies) during the Ottawa continental collision. By comparison, stromatolite fossils in some Lowland marbles survived Ottawa metamorphism. With the release of pressure following the collapse of the Ottawa orogen, late Ottawa granitic intrusions invaded locally in the Highlands (Lyon Mountain granite) and along the CCMZ. The extensive jointing and faulting and intrusion of basalt dikes in both terranes are believed to be associated with post-Grenville but Pre-Paleozoic tectonics. Following a few hundreds of millions of years of erosion, the Ottawa mountain belt was reduced to sea-level and sediments of the early Paleozoic seas covered the basement rocks across the entire region. The relatively thin, discontinuous sedimentary cover suggests that the Highlands and Lowlands areas were tectonically and topographically positive through the late Paleozoic.

The present-day relief and ruggedness of the Adirondack Highlands is the result of phases of uplift and differential erosion that began in the Mesozoic Era and continues today at around 1 mm/year. In general the individual mountains, like Arab Mountain, or ranges in the Adirondacks are underlain by more resistant metaigneous rocks than the metasedimentary rocks in the surrounding valleys. Adding to the relief and variety of the landscape are the linear valleys aligned along late or post-Ottawan faults and joints. Finally repeated erosion during Pleistocene continental and mountain glaciation (beginning around 1.6 million years ago with the glacial maximum around 20,000 years ago) sculpted the mountains. The final recession (after 12,000 years ago) left behind a landscape with a multitude of streams, lakes and ponds and surfaces covered with glacial debris. Many of the valleys are clogged with glacial fill and, with the accumulation of sediments and growth of plants, the ponds are at various stages of becoming in-filled and forested bogs.

STOP 1. POTSDAM SANDSTONE AT HANNAWA FALLS DAM (FIG. 2)

The section here is close to the great unconformity, the boundary between the Grenville basement metamorphic gneisses of the Proterozoic Era (1.3-1.0 billion years old) and the covering sedimentary rocks of the Paleozoic Era, here in the form of the Potsdam Sandstone of Lower Cambrian (?) age. This is the type area of the famous red Potsdam Sandstone whose age is problematic as there are no fossils (not even trace fossils) here or farther downstream in the exposures in the river and mostly abandoned stone quarries; if Lower Cambrian in age, the "time gap" at the unconformity is in the order of half a billion years. In his correlation chart, Fisher (1977) placed the lower or red Potsdam in the Lower Cambrian and assigned the underlying intermittent occurrences of arkosic conglomerates (Allens Falls/Nicholville) at the unconformity to the Late Proterozoic.

The gneisses hereabouts are typical Lowland Adirondack metamorphosed sedimentary (metasedimentary) rocks, gneisses with light-colored bands of quartz and pink orthoclase feldspar with minor dark bands of hornblende, mica and pyroxene minerals. Good exposures of these rocks may be seen in the rapids just below the dams in the Raquette River at Potsdam.

The Potsdam Sandstone exposed here, and in the rapids and side quarries downstream, display large-scale cross-bedding which indicate deposition in either a deltaic or sand dune environment (Fig. 2). Near the base of the dam on the Mill Steet side, is a cylindrical structure of Potsdam Sandstone. These structures, known elsewhere in the lower Potsdam in the region, are believed to have formed from unconsolidated sands sinking into cavities lower down in the Potsdam or in the underlying Grenville basement (marbles?) (Dietrich, 1953).

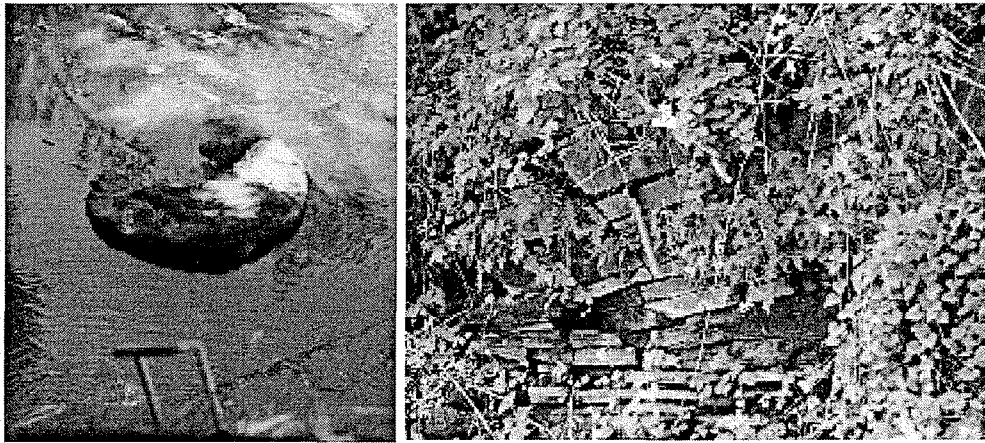


Fig. 2. Cross-bedded Potsdam Sandstone and circular structure of Potsdam Sandstone in Raquette River below Hannawa Falls Dam and exposure in embankment near base of dam on Mill Street side.

The Potsdam here is a medium-bedded, fine to medium grained, silica-cemented orthoquartzite, with hematite-stained quartz grains giving the rock its distinctive red color. Its flat-bedding surfaces, durability, and sets of vertical joints made the rock a valuable dimension stone and flagstone for use throughout the region in the 19th and early 20th centuries. Its limited use today is primarily as a red gravel for landscaping. In place samples of the Potsdam Sandstone can be readily obtained from exposures in the embankment on the Mill Street side of the river near the base of the dam.

The hydroelectric dam at Hannawa Falls is the 9th of 19 hydro-dams in the 167 mile length of the Raquette River between its headwaters in the Adirondacks at Blue Mountain Lake and its entry into the St. Lawrence River. The Raquette River drops some 82 feet from the dam to the powerhouse, a half-mile downstream on the east side of the river. The water at the dam is channelled to the powerhouse in a forty-foot wide, open canal, the only hydroelectric canal in the country. The Hannawa Falls powerstation, maintained by Reliant Power Corporation, generates about 50,000 mwh on average through the year.

STOP 2: SUNDAY ROCK, SOUTH COLTON (FIG. 3)

This huge glacial erratic boulder of Grenville gneiss was dropped by the ice-sheet that covered the North Country during Pleistocene Epoch sometime between 14,000 and 10,000 years ago. It is a legendary trail marker at the cultural boundary between the "civilized" life in the St. Lawrence Valley to the north and the rough and ready workday and recreational life in the great South Woods of the Adirondack Mountains to the south, the area where in the old days there was no Sunday. Through the efforts of the Sunday Rock Association, the boulder was moved from the center to the opposite side of the road in 1925 when Rte. 56 was first built and again to its present park location on the south side of the road in 1965 when the highway was widened. The inscription on the tablet next to the monument reads in part:

“THE TOWN OF COLTON STRADDLES THE NORTHERN BOUNDARY OF THE ADIRONDACK FOREST PRESERVE. ONE END OF THE TOWN TOUCHES ON THE NEAT HOMES OF ST. LAWRENCE COUNTY; THE OTHER REACHES INTO THE WOODS. IN THE MIDDLE IS SUNDAY ROCK.

PREVIOUS TO SETTLEMENT IN THIS AREA, THE INDIAN TRAIL INTO THE MOUNTAINS RAN BY HERE. IN THAT LONG TIME AGO THIS 64,000 POUND GLACIAL BOULDER WAS USED AS A LANDMARK BY THE INDIANS AND WHEN THE WHITE SETTLERS CAME, THEY USED IT FOR THE SAME PURPOSE. THE ROCK WAS A NATURAL LANDMARK AND TRAVELERS WERE GUIDED BY THE BIG ROCK IN THE MIDDLE OF THE ROAD, AND THE ROCK SEPARATED THE WOODS FROM THE WORLD.

THERE WAS NO LAW FOR DEER NOR TROUT, AND ALL OF THE WOODS WAS ONE GRAND HUNTING GROUND. IN THOSE DAYS, IT WAS SAID THAT BEYOND THE ROCK THERE WAS NO SUNDAY. CAMP LIFE WENT ON FROM DAY TO DAY WITH NO CHANGE. IT WAS ONE GLORIOUS HOLIDAY WHEN TUESDAY MIGHT JUST AS WELL AS BEEN SATURDAY, AND THURSDAY AND WEDNESDAY COULD CHANGE PLACES AND FRIDAY MIGHT BEGIN THE WEEK FOR ALL ANYBODY KNEW OR CARED. THE RIVERS, THE BROOKS, THE PONDS, THE MOUNTAINS, THE TREES, THE FLEET DEER, THE RUSHING TROUT, THE WILD CAT, THE BLACK BEAR RULED SUPREME. IT WAS THEIR LAND AND THERE WAS NO SUNDAY. THE ROAD PAST THE ROCK ALSO SERVED AS THE WAY FOR SCORES OF LOGGERS AND FOR THEM, THERE THE ROUGH AND TUMBLE FELLOWSHIP OF THE WINTER CAMP BEGAN. THUS THE BIG ROCK BEGAN TO BE CALLED SUNDAY ROCK. BY WHOM NOBODY KNOWS BUT THE REASON IS EVIDENT.

AFTER A WHILE, THE ROCK CAME TO STAND FOR SOMETHING ELSE. WHEN PEOPLE FROM THE VALLEY PASSED IT ON THEIR WAY TO THE MOUNTAINS, THEY FELT A SENSE OF ARRIVAL, OF HAVING CROSSED A DIVIDING LINE. ON THE OTHER SIDE OF

THE ROCK WERE THE WOODS AND MOUNTAINS, LIFE WAS FREER AND EASIER. SALUTING THE ROCK BECAME A KIND OF JOYFUL RITUAL TO BE OBSERVED. ELDERS MIGHT UNCORK A BOTTLE AT IT AND CHILDREN COULD CUT UP WITHOUT FEAR OF A SCOLDING. HUNTERS AND FIRSHERMEN HAD THE FEELING OF EAGER ANTICIPATION AS THE CARES OF EVEYDAY LIFE WERE LEFT BEHIND...

FOR MANY WHO PASS BY HERE, THE ADIRONDACKS STILL EXERT THEIR MYSTICAL APPEAL. VACATIONISTS WHO RETURN TO THESE HILLS YEAR AFTER YEAR, PROBABLY HAVE THEIR OWN SUNDAY ROCK: A RIVER CROSSING, A TURN IN THE ROAD THAT REVEALS A FIRST GLIMPSE OF THE MOUNTAINS, SOME SIGN THAT YOU HAVE CROSSED INTO A PLACE WHERE THE CALENDAR CAN BE FORGOTTEN, WHERE THERE IS BEAUTY TO LOVE AND THE EVERLASTING HILLS TO SAVOR.

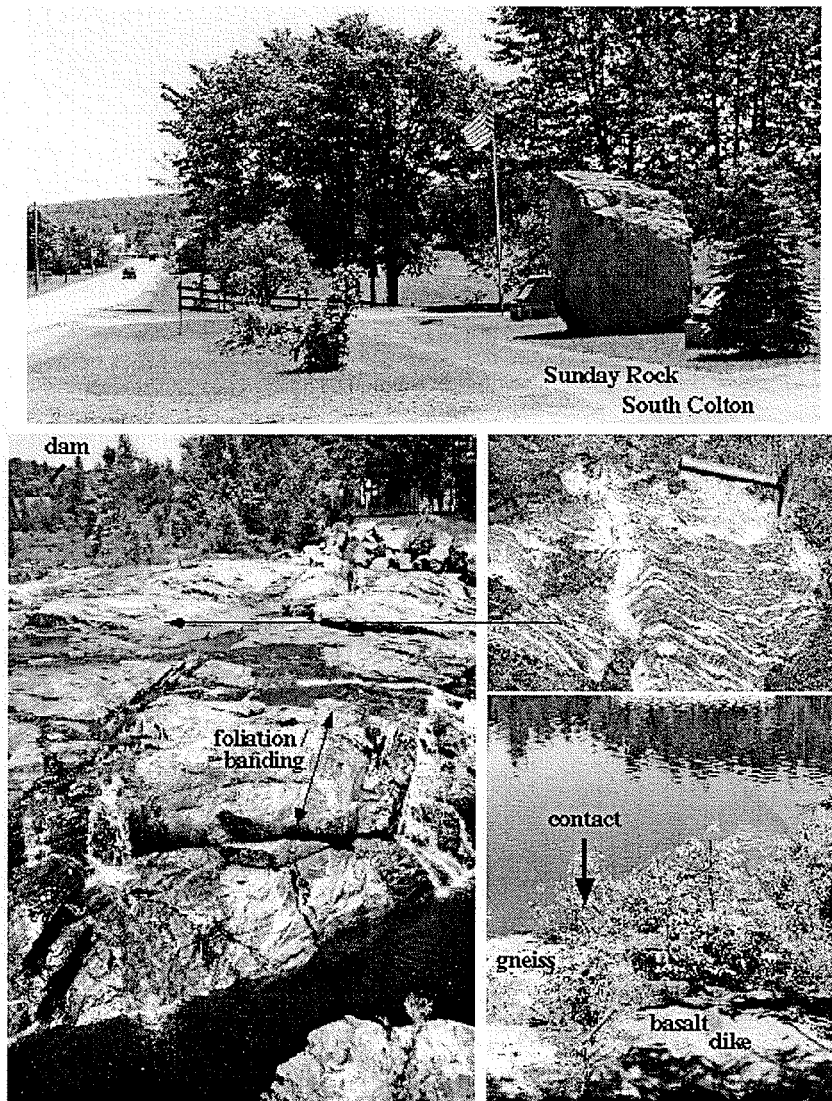


Fig. 3. Sunday Rock, NY Route 56S, at South Colton (Stop 2) and Grenville gneisses in waterfall of Raquette River below South Colton Dam (Stop 3) showing foliation banding, stream rivelets flowing parallel to joints and differentially eroded banded gneisses, small-scale ductile folding and, upstream, contact between basalt dike and banded gneiss.

THE MEANING OF THE ROCK HAS NOT BEEN FORGOTTEN...IT HAS BEEN THE CONTINUED AFFECTION OF MANY GENERATIONS WHICH HAS PRESERVED THE OLD LANDMARK AND LEGEND SURROUNDING IT. SUNDAY ROCK STILL SEPARATES THE WOODS FROM THE WORLD, AND THE MESSAGE FROM THOSE WHO PRESERVED IT IS STILL CLEAR. THE WOODS ARE BETTER.’

Allan Pospisil (1968) Colton Story of a Town. The New York Times. [extracted in part from an article by Potsdam Town Historian C. H. Leete in Potsdam Herald Recorder, September 11, 1925 (Sunday Rock-Its history and the story of its preservation-1929, Herald Recorder Press, Potsdam, N.Y., 55p.)]

STOP 3. GRENVILLE GNEISS BELOW SOUTH COLTON DAM.

Warning: Take care not to be trapped on the outcrop by water released from the dam upstream.

These well-exposed rocks display many of the structural and textural features typical of the Grenville basement rock of the northern part of the Adirondack Highlands. The variety of gneisses and minerals, and the predominantly banded fabric, suggest an original sedimentary sequence that was metamorphosed deep within the roots of a mountain belt under the extreme conditions (granulite facies) associated with continental collision and consequent tectonic burial. Included are pyroxene and hornblende granitic gneisses with subordinate leucogranitic gneisses, amphibolites (dark colored hornblende-rich gneisses) and migmatites (mixed igneous and metamorphic rock) in which coarse pods of pegmatitic crystals of pink K-feldspar indicate partial melting during metamorphism.

Notable are the complex ductile folds and broken layers isolated as fragments or ‘tectonic’ xenoliths. The fold patterns and the predominant NE-SW strike of the foliation or banding are typical of the basement rocks of the region.

At low discharge, the rivelets of water flowing across the surface of the outcrop and the orientation (facing) of the waterfall is a fine example of local structural control of drainage, a microcosm of patterns seen in the Adirondacks as a whole. The broadly radial stream courses (outward from the center of the Adirondack Dome) are locally controlled by differential erosion of the banding, foliation and folding in the various metamorphic facies and the intersections of faults, joints or fractures. Other notable erosion features include potholes at various stages of development.

A hundred yards or so upstream on the west bank of the river, a tabular basalt (diabase) dike (2.3 m across) is well exposed along the shore. The dike is nearly parallel to the steeply inclined foliation or banding of the gneisses. Its dark color and uniform mineralogical texture and higher resistance to weathering contrasts with the lighter colored and banded gneisses. The dike is clearly younger than the host rock and was intruded after the gneisses were metamorphosed but before the tectonic development of the joints. The dike is probably late Proterozoic in age (around 570 Ma.), based on its similarity to pre-Potsdam dikes elsewhere in the region. At high water the dike can be reached by the dirt tract that parallels the edge of the river upstream from the waterfall.

The rock forming the hill to the south of the outcrop, which can be reached along the Allen Hill Road, is a quartz-rich granite-gneiss with prominent pink orthoclase and minor dark mineral (leucogranitic gneiss) that retains its igneous (pluton) texture, and although the contact is not exposed, it probably cross-cuts the banded gneisses at the waterfall and is thus younger than the gneisses and older than the basalt dike.

STOP 4. MT. ARAB (FIGS. 4-6)



Introduction

The trail to Arab Mountain is approximately 1 mile (1.6 km.) long and rises 760 ft. (232 m.) to a summit elevation of 2545 ft. (776 m.). The summit is about 2115 ft. (645 meters) above the elevation of downtown Potsdam 430 ft. (131 meters).

Follow the red Department of Conservation (DEC) markers and stay on the designated trail. The restoration and maintenance of Mt. Arab is under the care of Friends of Mt. Arab, Inc. with the cooperation of the Laurentian Chapter of the Adirondack Mountain Club (ADK). Please register for your safety and help the Friends of Mt. Arab determine the frequency of trail use; the Interpretive Information Brochure in the registration box is a guide to sixteen locations of features of biological interest.

Basement rock

The gravel covering the lower part of the trail is crushed anorthosite, the blue-gray feldspar-rich rock that underlies the region of high mountainous terrane to the east, including Whiteface Mountain and the Marcy Massif of the High Peaks region. At about midway, the trail surface is mainly on mangerite, the principal bedrock of Mt. Arab. Mangerite is an intrusive or plutonic igneous rock, like a granite, but with less quartz and containing the mineral pyroxene. A few hundred yards from the summit, the mangerite bedrock is exposed in a large outcrop. The broad, subhorizontal fractures seen here and at the summit are sheeting or exfoliation structures, formed by the release of pressure on the rock by the tectonic unroofing, and uplift and erosion of overburden rock during the Proterozoic and later times, and most recently following the final melting of the mile-thick Pleistocene glacier. These fractures and the glacial scour are what account for the smooth and broadly rounded shape of many Adirondack summits.

The mangerite exposed here and at the summit is a metamorphosed igneous intrusive (plutonic) rock whose color, composition and texture contrast strongly with the variety of banded metasedimentary gneisses seen at South Colton and the intrusive anorthosites of Whiteface Mountain and the Marcy Massif to the northeast, east and southeast (Fig. 1-C). The mangerite, which contains only minor quartz, consists of cream colored intergrowths of feldspars (mainly potassium feldspar) with dark mafic minerals (pyroxene) oriented subparallel to the long axes of the feldspar crystals (anastomosing, perthitic texture), giving the rock a strongly planar foliation. The contrast with banded

hornblende gneisses seen at South Colton is striking. On the outcrop surfaces (west of the Observer's Cabin) sheared quartz veins (Fig. 6) give evidence of plastic (ductile) deformation and the high intensity of metamorphism (granulite facies with temperatures of 675-800 degrees C and pressures of 7-8 kilobars) in the roots of a mountain range, comparable to some 25-30 km. (17-20 miles) depth below the surface.

A Uranium (U)-lead (Pb) radiometric date on the mangerite of 1134 +/- 4 million years at Tupper Lake (McLelland and Chiarenzelli, 1990) gives the time of crystallization of the magma intrusion. The mangerite in the Tupper Lake region shows a spatial relationship with the anorthosite, the great mass of plutonic rock that underlies the Whiteface Mountain region and Marcy Massif of the High Peaks region; the contact between these units is just east of Tupper Lake. The anorthosite is composed predominantly of the blue-green-gray crystals of the plagioclase feldspar andesine and the small fragments of the anorthosite can occasionally be seen "floating" in the mangerite at Mt. Arab. The age of emplacement of the anorthosite plutons is around 1155 Ma., which is close to the time of emplacement of the mangerites.

Fire Tower

The 35 foot high steel Fire Observation Tower at the summit, installed in 1918, replaced wooden structures dating from 1911 and 1912. This "survivor that still stands guard" (Laskey, 2003) is one of only two remaining fire towers in St. Lawrence County; the other is on Cathedral Rock in Wanakena (Freeman, 2001, p. 44). The network of observation towers was established after the disastrous fires in the Adirondacks in 1903 and 1908; at one time there were 57 towers in the Adirondacks. No longer in service, the Mt. Arab Tower and Observer's Cabin were last staffed in the 1980s in the final stages (accelerated during and after WWII) of the systematic dismantling of the fire tower observation system in Adirondack and Catskill Mountains. After decommission, the Mt. Arab Tower deteriorated and was condemned for public use in 1993.

The restoration of the tower and access trail dates from 1997 and the founding of the citizens's group Friends of Mt. Arab (FOMA), an organization that has coordinated endorsements and financial support from state, county and local government agencies as well as several Adirondack Mountain Club (ADK) chapters, school groups, camp owners and local residents. The Observer's Cabin has been restored as a small museum and base for a summer interpreter, thus completing the functional evolution of the tower and cabin from fire observation to education and recreation. Supported by the Adirondack Architectural Heritage (AARCH), the Friends of Mt. Arab can be contacted at P.O. Box 185, Piercefild, NY, 12973.

Adirondack Landscapes (Figs. 5-6)

Among the features that can be seen from the top of the the Fire Tower: north- northeast, Mt. Matumbla (2700 ft.; 823 m.), the highest point in St. Lawrence County ; northeast, in far the distance beyond Tupper Lake and Tupper Lake Village, Whiteface Mountain (4867 ft.; 1483 m.) with its distinctive white landslide scars; southeast Mt. Morris (3163ft.; 964 m.) with its Big Tupper ski-trail clearings, and in the distance, the rounded profile of Blue Mountain (3759 ft.; 1146 m.) near the center the Adirondack Dome and the headwaters of the Raquette River; far to the east-southeast, the High Peaks , which include Algonquin Peak (5114 ft.; 1559 m.), Mount Colden (4714ft.; 1437 m.) and Mount Marcy (5344 ft.; 1629 m.), the highest point in New York State. Nearby to the southwest, Mt. Arab and Eagle Crag Lakes; and south-southeast, the south end of Tupper Lake.

With modern technology, changes in elevation and geographic position of features on the surface of the earth can be monitored remotely by satellite and laser. Attached to the bedrock on the

summit are three small metal disks, the United States Geological Survey bench marks that were used in surface surveys to determine the geographic position and elevation of Arab Mountain.



One of three U. S. Geological Survey bench marks on the summit of Arab Mountain.

Earthquakes

Earthquakes are not uncommon within the Adirondacks but most events are small (less than 3.0 magnitude), relatively shallow (2-10 km; 1.2-6.2 mi. depth), and are not felt in this sparsely populated region. The seismic events are generated from reactivation of faults in the basement rocks which throughout the region are under compressive stress. None appear to be associated with the uplift of the dome which continues at a rate of about 1mm per year. Notable recent events are the 1983 Goodnow Earthquake, a 5.1 magnitude event near Blue Mountain in the center of the dome which was felt from Maine to Michigan and New Jersey to southern Ontario, and the the 2002 Ausable Forks Earthquake in the eastern Adirondacks, 15 miles southwest of Plattsburgh, also a 5.1 magnitude event, which was felt from Maine to Maryland.

To better monitor earthquakes in the Adirondac region, a seismic field station was installed this year on the summit of Arab Mountain.; the antenna can be seen north of the trail leading to the Observer's Cabin. The Arab Mountain Station is the 8th seismic station located in Northern New York that comprise the SUNY Potsdam Seismic Network, since 1972 under the directorship of Professor Frank Revetta of the SUNY Potsdam Geology Department (revettfa@potdsdam.edu).

Glacial erratic

On the edge of the cliff overhang west of the Observer's Cabin is a fine example of a glacial erratic. The boulder, set down during the final recession of the Pleistocene glacier between 14,000 and 10,000 years ago, is a banded gneiss not unlike the Sunday Rock boulder and the country rock seen at South Colton, and a common bedrock facies in the Adirondack Lowlands. The erratic boulder at the summit of Mt. Arab is sitting on top of the glacially smoothed surface of the Proterozoic-age mangerite. The contact between the bedrock and the erratic thus represents a 'gap' or break in the rock record of earth history of more than 1 billion years.

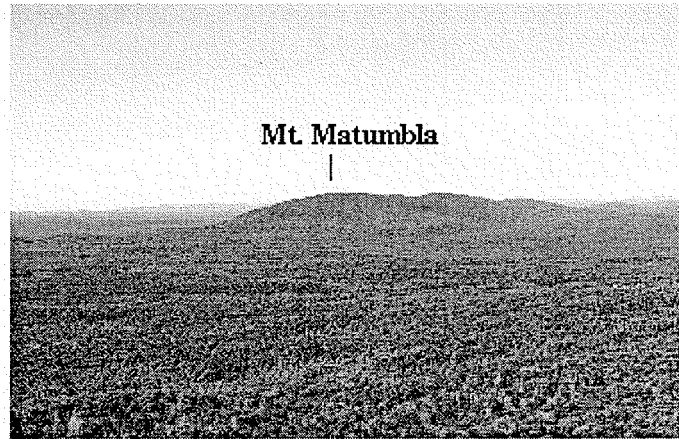
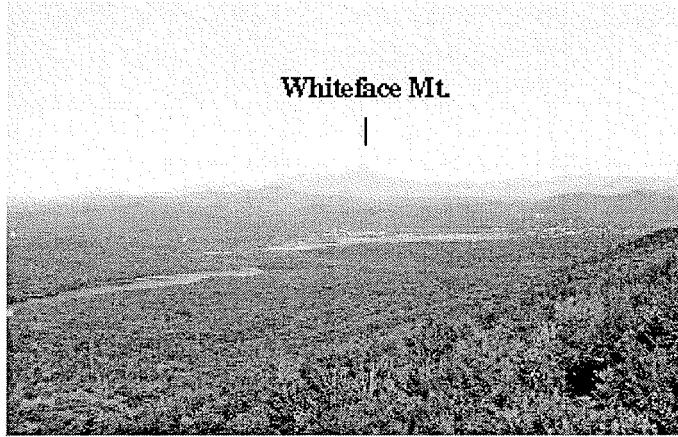


Fig. 4. Views from summit of Mt. Arab. From the Fire Tower: Northeast-Whiteface Mt. (4867 ft.), with prominent landslide scars, beyond north end of Tupper Lake and Tupper Lake Village; North-northeast-Mt. Matumbula (2700 ft.), highest point in St. Lawrence County; Heuvelton Central third-graders sitting on mangerite bedrock, Sept. 1990, overlook crags on southwest side-Mt. Arab Lake (upper-right foreground) and Eagle Crag Lake, beyond; bogs and bog ponds along Bridge Brook, upper left.

PRESERVATION OF ADIRONDACK PARK

The Adirondack Park was established by the State Legislature in 1892, and of the nearly 6 million acres within the “Blue Line” nearly half are privately owned. It remains the largest complex of wild public lands in the eastern United States. The vast still largely undisturbed territory includes 46 mountain peaks over 4,000 feet high, more than 3,000 lakes and ponds, and 6, 000 miles of rivers and streams.

To preserve and manage the Forest Preserve, the Adirondack Park Agency (APA) was established in 1971, under the Department of Environmental Conservation (DEC), with a mandate to “promote appropriate public use ... and to encourage the types of growth and economic development on private lands that will allow the unique character of the park to be maintained” (DEC Adirondack Forest Preserve 1999 map and guide). The APA’s Adirondack Park State Land Master Plan divides the state-owned lands within the park into several classifications, among them Wilderness (about 1 million acres in 17 areas) in which motor vehicles and bicycles are not allowed, and Wild Forest (about 1.3 million acres), the “forever wild” areas with limited access by motor vehicles and bicycles.

Nature’s defenses have long kept the Adirondacks in a largely wilderness state: the terrain is remote and rugged, the winters can be extremely cold, ice and snow make travel hazardous, and insects (such as black flies) effectively control outdoor activity for parts of the rest of the year. Despite these natural barriers, the Adirondack environment is increasingly effected by human activities from outside the park boundaries. Foremost among these is the adverse effect on vegetation and aquatic life by acid rain from industrial and powerplant emissions. The solitude of the Adirondacks is impacted by low altitude overflights of private, commercial and military aircraft. There is the visual intrusion of communication towers on Adirondack summits. A new and serious problem is the introduction of alien species of plants and animals into the Adirondacks with their potential to crowd out and replace elements of the native flora and fauna. The conservation of the Adirondacks as a unique wilderness area for the enjoyment of future generations has thus become truly the responsibility of the national and international (global) community. **“Out of the woods we came, and to the woods we must return, at frequent intervals, if we are to redeem ourselves from the vanities of civilization.”** (Thoreau, quoted by Paul Jamison, 1982, Preface to The Adirondack Reader).

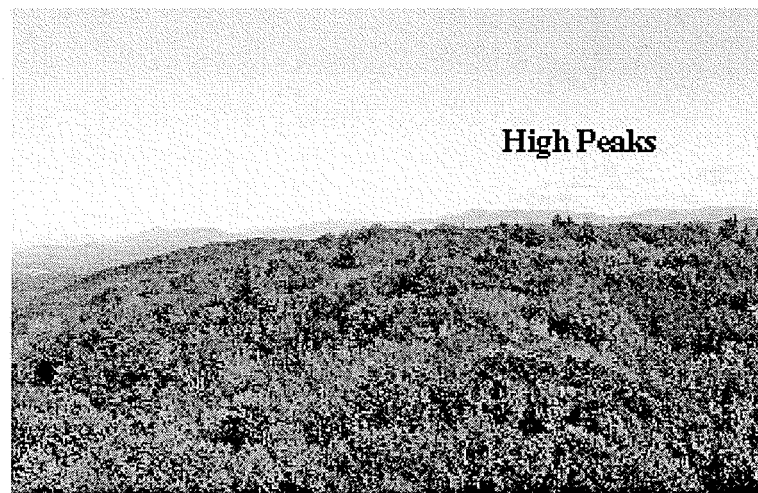
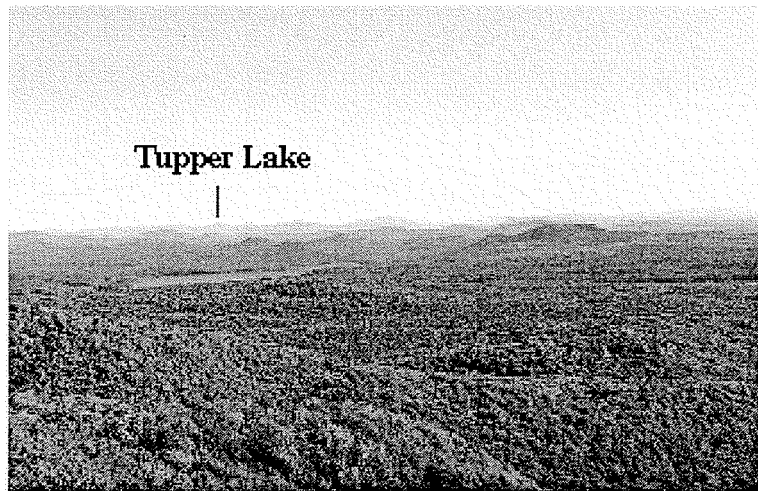
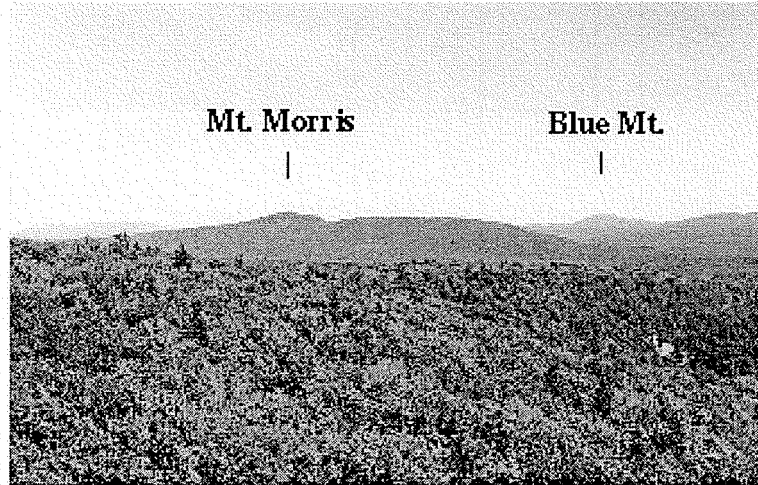


Fig. 5. Views from Mt. Arab Fire Tower: Southeast-Mt. Morris (3163 ft.) with Big Tupper ski-trail clearings, Blue Mountain (3759 ft.) near center of Adirondack Dome; South-southeast-south end of Tupper Lake; East-southeast-High Peaks (Algonquin, 5114 ft., Mt. Colden, 4714 ft., Mt. Marcy, 5344 ft., highest point in New York State).

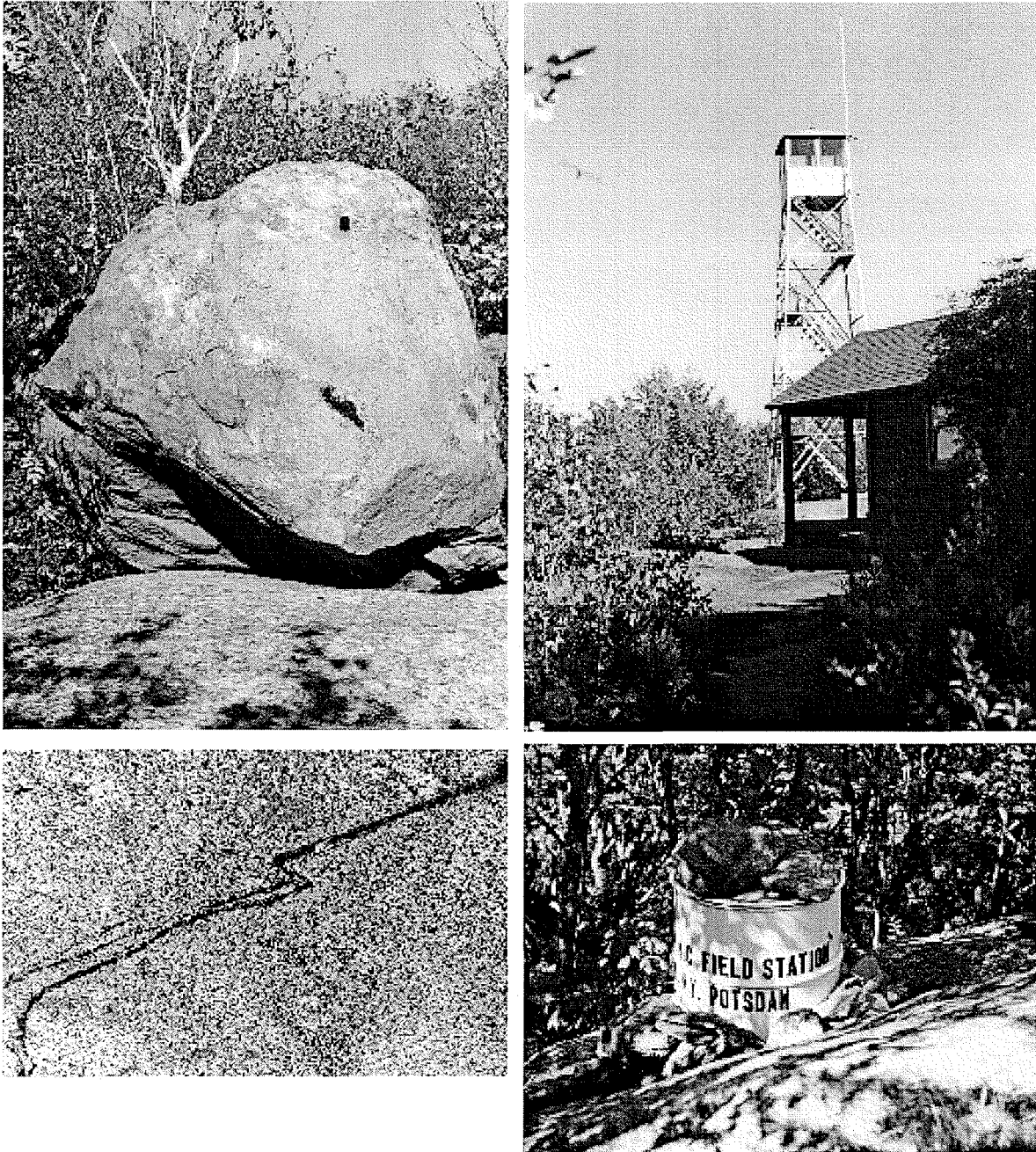


Fig. 6. Pleistocene glacial erratic of banded gneiss (with large hornblende crystals) sitting on mangerite bedrock, west side Mt. Arab summit; Mt. Arab Fire Tower and Observer's Cabin; ductily folded and sheared quartz vein in mangerite, northwest side, Mt. Arab summit; SUNY Potsdam Seismic Station at Mt. Arab summit, installed summer 2004.

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Field Trip Roadlog (miles)

Total	Interval	Route Description (SUNY Potsdam to Mt. Arab).
00.0	0.0	Left turn onto NY Rte. 56 South from Barrington Drive
00.2	0.2	Athletic fields: proglacial lake bottom plain (clays and silts).
00.5	0.3	Glacial-till plain (ground moraine) on left
01.0	0.5	Junct. Rte. 56 and 72: slope of Rte. 72 hill is north-facing front of proglacial-lake delta, the lowest of a series marking stages in the lowering of Lake Iroquois.
01.7	0.7	Golf Course on left.
01.9	0.2	On right: Meander cutoff (oxbow) in Stafford Brook.
02.4	0.5	On left: Large active sand and gravel quarry in kame-moraine-delta complex. Greymont- Potsdam Stone & Concrete.
02.9	0.5	Village of Hannawa Falls. Clean sands at top of proglacial-lake delta (about 550 ft. elevation), marking a static level stage of Lake Iroquois.
03.4	0.5	Church Street. (left turn to Postwood Park, Town of Potsdam).
03.5	0.1	Chip's Place Deli-on right.
03.6	0.1	Rte. 56 Bridge, Hannawa Falls (Hannawa Falls Pond on left, hydroelectric dam and canal on right).
03.7	0.1	Turn right onto Mill Street and park across the road from the Hannawa Falls Firestation Walk about 100 yards along side of road to dirt track* and follow footpath down and back towards the base of the dam. Stop 1. Potsdam Sandstone at Hannawa Falls Dam. (*dirt track is at the south end of the 3.5 mi. Red Sandstone Trail, a nature trail which leads to excellent exposures of the Potsdam Sandstone in quarries and rapids along the Raquette River).
		Return to Rte. 56 S.
04.0	0.3	Hannawa Pond or Flow on left.
04.1	0.1	Far left across pond: Postwood Park Town Beach.
05.7	1.6	Road climbs to flat surface at top of a delta at about 650 ft. elevation marking another static level in proglacial Lake Iroquois. Dunes on right are wind-blown delta sands.
06.0	0.3	County Road 24 (Brown's Bridge Road): left turn leads to bridge over Raquette River and trailhead parking for northern access to Stone Valley Recreational Area (see below). Road begins climb to upper Hannawa Delta at about 680 ft. elev.
06.8	0.8	At crest of hill, view south of St. Lawrence Valley and Adirondack Lowlands.
07.3	0.5	Dune sands on left.
07.4	0.1	Village of Colton sign.
07.9	0.5	Outcrop of Grenville gneiss in front of Colton-Pierrepont Central School.
08.4	0.5	Mill Street Colton. Left turn and follow signs to Stone Valley Recreational Area, a 7 mile-long trail along the Raquette River which gives access to rocks of the Colton-Carthage Mylonite Zone (CCMZ).
08.7	0.3	Bridge over Raquette River: Higley Flow Reservoir.
09.3	0.6	Bog on left.
10.3	1.0	Bog on right.

11.3	1.0	On left: large exposure of pink alaskitic-leucogranitic gneiss.
12.1	0.8	South Colton; dune sands on left.
12.3	0.2	Turn right into parking area. Stop. 2. Sunday Rock , glacial boulder marking cultural boundary between “civilized” life in the St. Lawrence Valley and the rougher life in the Adirondacks, where in the old days there was no Sunday. Return to Rte. 56 S.
12.6	0.3	Turn left onto Wind Mill Road, South Colton and right onto Mill Street and continue on dirt road to parking area. Cross old concrete sluiceway and proceed to top of waterfall. Stop. 3. Grenville gneiss at waterfall below South Colton Dam. Return to Rte. 56 S.
13.3	0.7	Bridge over Raquette River.
13.4	0.1	Cold Brook Drive-right turn to Higley Flow State Park.
13.5	0.1	Allen Hills Road on left: granite-gneiss outcrops at top of hill.
13.7	0.2	Caution: entering “zig-zag” in highway (watergap cut through glacial-delta sediments by Cold Brook).
14.7	1.0	Cold Brook DEC Freshwater Management Area-former St. Lawrence University Snow Bowl ski area.
15.2	0.5	“Blue Line” Sign on right marking boundary of 6 million acre Adirondack Park.
17.6	1.2	“The Plains”-top of proglacial-lake delta at about 1210 ft.
19.4	1.8	Joe Indian Pond Road-on left.
20.5	1.1	Bog pond on right.
21.9	1.4	Catamount Lodge-on left.
23.1	1.2	“Fraternity Rock”-huge, painted glacial erratic on left.
24.7	1.6	Large bog on right.
28.6	3.9	Ham’s Tavern-on right.
29.6	1.0	Bog on right.
30.1	0.5	On right-turnoff to Sevey Corners Bog (take left fork and follow dirt road for 0.1 mile).
31.6	0.5	Turn left (east) onto NY Rte. 3 at Sevey (or Sevey’s) Corners at intersection of Rtes. 56 and 3. Ham’s Mini Mart. Rest stop.
31.8	0.2	Right turn (east) on Rte. 3 from Ham’s Mini Mart.
32.8	1.0	Outcrops of Grenville gneiss on left.
34.5	1.7	Village of Childwold
37.4	2.9	Massawepie Lake-Scout Camp
38.0	0.6	Sand pit on left
39.4	1.4	Mt. Arab Fire Tower visible-straight ahead
41.6	2.2	Turn right onto County Road 62 at sign for Mt. Arab and hamlet of Conifer.
41.8	0.2	Turn right at “Y” intersection onto Conifer Road.
43.3	1.5	Turn left onto Eagle Crage Lake Road at sign for Mt. Arab.
43.9	0.6	Railroad tracks (Remsen-Lake Placid RR).
44.2	0.3	Park on right side of road opposite signs at trailhead. Stop 4. Mt. Arab.

Trip B-4

MINERAL COLLECTING AT J & L STEEL CORPORATION, BENSON MINES, STAR LAKE, NY

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HISTORY OF THE MINES

The ores were first discovered in 1812 when a military road was being built in the region. It became known as the Chaumont Ore Bed. In 1883, the Magnetic Iron Ore Co. was formed. Byron C. Benson, a large land owner in southern St. Lawrence County sold the company the mineral rights on 2,201 acres of the Brodie Tract in the Town of Pitcairn. In 1886, a railroad was started from Carthage to Jayville in the Town of Pitcairn and additional mineral rights on 40,000 acres in the southern part of the county were obtained by the Magnetic Iron Ore Co.

In 1887 and 1888, the company purchased mineral rights for magnetite iron ore on Vrooman Ridge in the Town of Fine and all the mineral rights (9185 acres) in the southeast corner of Chaumont Township (later part of Clifton Township) including the Chaumont Ore Bed. In 1888-89, work was done on the Jayville mines in the Town of Pitcairn. From 1889-93, the Magnetic Iron Ore Co. shipped 150,000 tons of high grade concentrates (magnetic iron ore) to Pennsylvania.

In 1906, Benson Mines Company formed and leased Benson Mines (Chaumont Ore Bed). From 1907-1919, sporadic mining occurred at Benson Mines and in 1922 the Benson Mines Co. gave up its lease and sold its plant to the Magnetic Iron Ore Co., owner of the mineral rights.

Later in 1922, the Benson Iron Co. Inc. was formed, but did not do much mining. In 1941, Jones and Laughlin Ore Co. leased Benson Mines and built a \$7,000,000 mill and upgrade of the mine. In 1946, the Benson Iron Co. Inc. and Magnetite Iron Ore Co. (both belonged to the Benson Family) consolidated to form Benson Iron Ore Corporation and by 1950, it was the largest open pit magnetite iron ore mine in the world.

In 1978 Benson Mines shut down. The St. Lawrence Development Corporation tried to find a buyer or lessee without success. Lumbering is the only thing going on in the mine area now that is bringing in any money, but just barely enough to pay the taxes. Of the 3,200 acres now owned by the company, only 1,200 are cut in a 15 year cycle to allow for replenishment. There is some sale of waste rock, but the income from this is negligible. The mine used to employ 1,000 people and pump 2,000,000 gallons of water a day.

GEOLOGY

The Benson Mines ore body is not of simple origin. Sillimanite gneiss, metagabbro and pegmatitic units are located throughout the pits. Small, localized fault zones rich in secondary mineralization provide the areas of greatest interest to the crystal collector.

MINERALS

The primary ores mined here were magnetite and martite. Samples of each abound. The sillimanite crystals from here are unparalleled in their size. The sunstone, relatively common in the pegmatitic zones, may be fashioned into cabochon and used to make attractive jewelry. Probably the most desired species from this mine is the dark green fluorite cubes, found about 40 years ago in a fracture zone and associated with various other secondary minerals. These are only rarely found. The following minerals can usually be collected, many in crystal form: aragonite, azurite, bornite, biotite, calcite, chalcopyrite, chlorite, garnet, hematite, hornblende, magnetite, malachite, martite, microcline, molybdenite, muscovite, pyrite, quartz, sillimanite, sunstone, tourmaline, and others.

The tools that will be most helpful here are a crack hammer, chisel and pick. Sledges are very helpful on the large boulders of pegmatitic material. Be sure to bring something to store your specimens in for the trip home.

NOTES

Collecting is by clubs or groups only. Permission may be obtained and arrangements made by writing in advance. Please write, call or e-mail me and I will give you the information you need to set up your own field trip.

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ROAD LOG TO J&L STEEL CORPORATION,
BENSON MINES, STAR LAKE, NY

Cumulative Mileage	Miles From Last Point	Route Description
0.0	0.0	Begin trip at SUNY Potsdam's Lot 7 (behind the geology department and Timerman Hall). Exit the lot at the south end onto Lake Placid Drive and turn right onto Barrington Drive.
0.2	0.2	At the fourth stop sign on Barrington Drive is the intersection with Pierrepont Avenue (State Route 56). Turn left (south) here.
6.5	6.3	After driving through Hannawa Falls, you will come to a four corner intersection with County Route 24. Turn right here (west).
15.5	9.0	At the intersection with County Route 27 turn left (south). We will be on this route for most of the rest of the trip, it just takes several turns.
25.7	10.2	Stay with County Route 27 by turning left.
33.5	7.8	Stay with County Route 27 by turning left.
34.3	0.8	At this intersection we meet up with State Route 3. Turn Left here.
40.2	5.9	This is Padgett's IGA, our stop for lunch supplies and cold drinks. After stopping, continue through the village of Star Lake to the mine.
42.3	2.1	Turn left just before the large blue buildings and across the road from the St. Lawrence County Solid Waste Disposal Authority's Waste Transfer Site. This is the mine entrance. We will proceed through the gate, pass the mill buildings and toward the flooded open pit mine. We will let our tour guide lead us around the mine for some history and then head for the mine dumps to do some mineral collecting. The trip after here is toward home. <u><i>There are no plans to return to Potsdam.</i></u>

Trip B-5

INITIAL DEGLACIATION OF THE ADIRONDACK MOUNTAINS AND DEVELOPMENT OF THE FULTON CHAIN LAKES

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INTRODUCTION

The Adirondack Mountains, located in northern New York State, offer a textbook example of radial drainage. The Black River and its tributaries drain the west and southwest region of the Adirondacks (Figure 1). The Moose River is the largest tributary of the Black River and drains most of the southwest Adirondacks. The Fulton Chain is a series of eight lakes that lie along the Middle Branch of the Moose River.

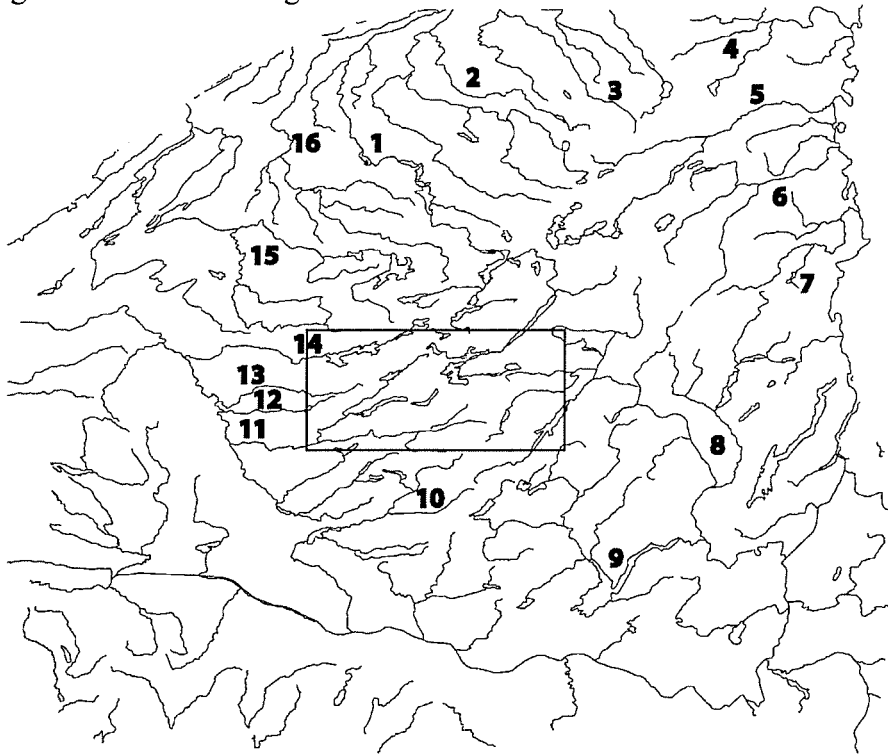


Figure 1. Radial drainage of the Adirondacks accomplished by the: 1) Raquette, 2) St. Regis, 3) Salmon, 4) Great Chezy, 5) Saranac, 6) Ausable, 7) Bouquet 8) Hudson, and 9) Sacandaga Rivers, 10) West Canada Creek, and the 11) Moose, 12) Independence, 13) Beaver, 14) Black, 15) Oswagatchie, and Grasse Rivers. The box outlines the area covered by Figure 2.

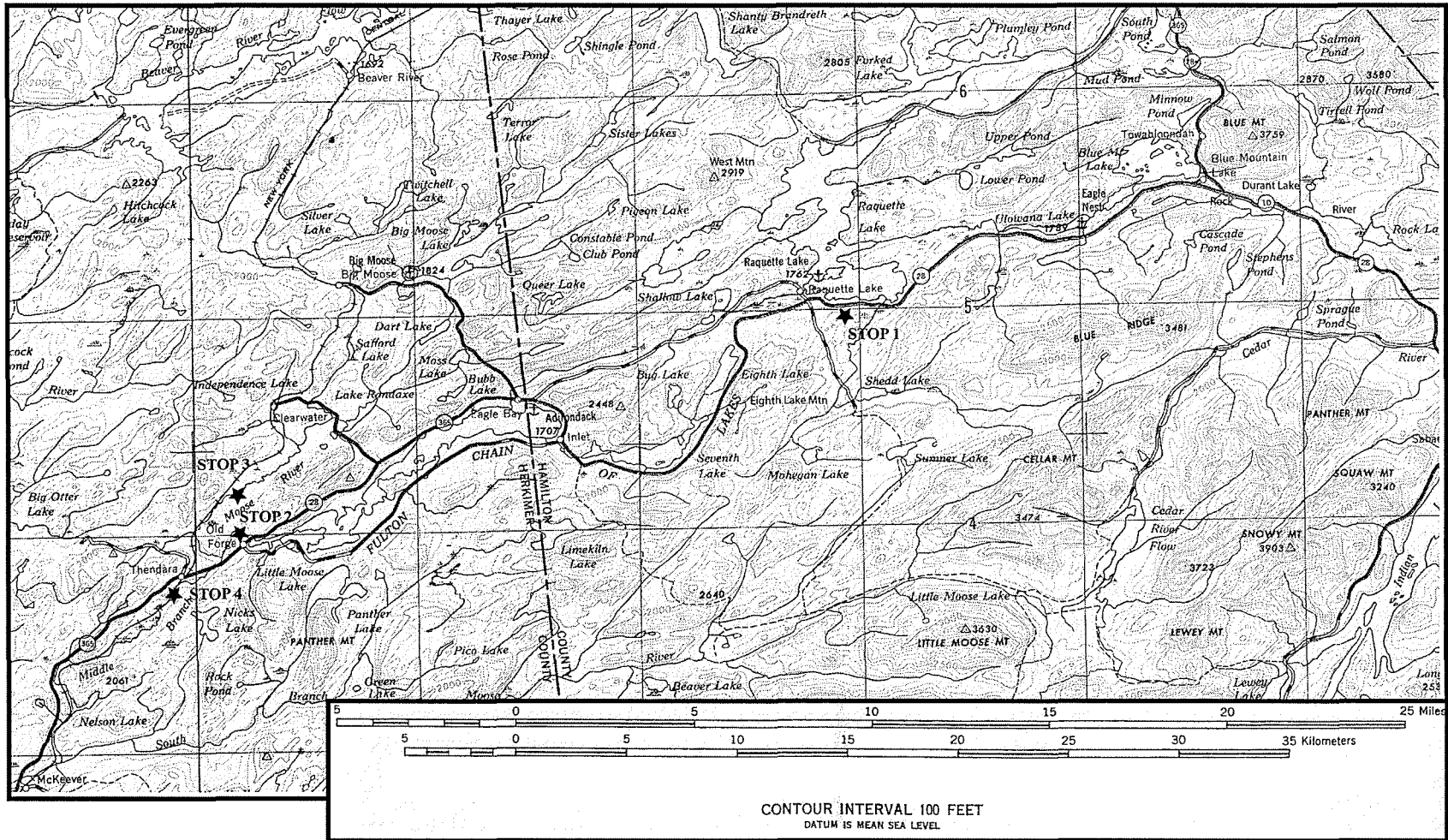


Figure 2. The location of the four fieldtrip STOPS, from Raquette Lake to First Lake, along the Fulton Chain of Lakes.

One purpose of this paper is to describe five proglacial lakes that preceded the present day Fulton Chain, and neighboring Raquette Lake. A second purpose is to relate the formation of those glacier-dammed lakes to the inception of ice withdrawal from the Adirondack Mountains. The third purpose is to correct misrepresentations on the Surficial Geologic Map of New York, Adirondack Sheet (Cadwell and Pair, 1991) for which the senior author of this paper was responsible.

Fieldwork for this study was completed during the 1989 through 1992 field seasons. Fieldwork in the Adirondacks always has been frustrating because of 1) the large area, 2) the great topographic relief, 3) the limited road access, and 4) the paucity of exposures. During 1989 and 1990, under the aegis of the New York State Geological Survey, the existing road networks were covered and all major accessible exposures were examined. Most time was spent packing into wilderness areas during 2-day and 3-day trips – often finding no surficial materials exposed. Under those conditions, an implicit response model was adapted from nearby areas of New York State where almost all level features adjacent to ice-contact deposits are observed to be outwash.

It was not until preparation for oral presentations summarizing the field mapping (Connally and Cadwell, 1991; Fleisher et al., 1991) that Connally began to suspect a consistent error. Fieldwork later in 1991 confirmed the error. In the few places where Connally had observed exposures beneath horizontal topographic features, he had mapped lacustrine deposits. Yet, he inferred outwash beneath similar landforms lacking visible exposures. Each new exposure confirmed lacustrine deposition. When he realized that it was likely that he had systematically misinterpreted those features, the Adirondack Sheet was in final production. It was too late to revise the submitted work.

GEOGRAPHIC SETTING

The Moose River is the master stream draining the southwest Adirondack Mountains (Figure 2). The Beaver and Independence Rivers drain smaller basins immediately west and north of the Moose River basin. To the east, West Canada Creek and smaller streams drain directly south to the Mohawk River. Most of the rest of the Adirondacks is drained by north flowing master streams; the Oswegatchie, Grass, Raquette, St. Regis, and Salmon Rivers, or southeast by the Rock, Cedar, and Indian Rivers in the southeast draining Hudson River system. The northeast corner of the Adirondacks is drained by tributaries to Lake Champlain.

The Moose River

The Moose River funnels waters from the southwest Adirondacks into the Black River. To the north, the Moose River drainage basin shares a divide with the north-draining Raquette River basin. The lowland of the Fulton Chain is continuous, over the low divide of lacustrine sand, with the depression in the headwaters of the Raquette River containing Raquette Lake. East of Raquette Lake, the divide between its tributary, the Marion River, and the east-flowing Rock River, separates the Hudson River that drains east from the Raquette River that drains north.

The Moose River divides into three branches. The South Branch splits off to the east at the hamlet of McKeever, 15 km upstream from the Black River. Events in the South Branch have no bearing on the present study. The North Branch splits off to the north at the village of Old Forge, 13 km upstream from McKeever, draining a large sub-basin that includes Safford Pond and Big Moose Lake. The Middle Branch continues eastward from Old Forge to the low drainage divide with Raquette River drainage, about 3 km southwest of the hamlet of Raquette Lake. The eight lakes of the Fulton Chain are located along the Middle Branch, between Old Forge and the hamlet

of Raquette Lake. All horizontal distances are reported in metric units. However, vertical distances are reported in English units to closely match available topographic maps.

The Fulton Chain

The lakes of the Fulton Chain are named for their position east of Old Forge. First Lake is the closest and Eighth Lake is the farthest. The present elevation of First through Fifth Lakes is 1707 ft. The uniform elevation is due to a dam at Old Forge, first constructed in 1810 at ± 12 ft to operate an iron forge, namely Brown's Tract Forge. In 1880-81, the Old Forge dam was raised another 2 ft, to ± 14 ft, to merge all five lower lakes. The original elevation of Fifth Lake probably was close to the present 1707 ft; Fourth Lake probably was at ± 1705 ft. From the dam height, it appears that the original elevation of First Lake was 14 ft lower at ± 1693 ft. Second and Third Lakes had original elevations between 1693 and 1705 ft.

Sixth and Seventh Lake share a present day elevation of 1786 ft, but a dam was built at Sixth Lake in 1879 to gain additional water storage needed to compensate the Black River system for waters diverted to the Erie Canal. I have measured that dam at ± 13 ft, so the original elevation of Sixth Lake probably was ± 1773 ft, with Seventh Lake at its present 1786 ft. Eighth Lake has a present day elevation of 1791 ft that was never modified. The elevations are summarized in Table 1.

TABLE 1

Fulton Chain Lake	Natural Elevation	Present Elevation
Eighth Lake	1791 ft	1791 ft
Seventh Lake	1786 ft	1786 ft
Sixth Lake	1773 ft	1786 ft
Fifth Lake	1707 ft	1707 ft
Fourth Lake	1705 ft	1707 ft
Third Lake	~1701 ft	1707 ft
Second Lake	~1697 ft	1707 ft
First Lake	1693 ft	1707 ft

The Moose River drainage basin is an area of significant relief. The highest point is Little Moose Mountain at ± 3640 ft, in the South Branch. The lowest point is ± 1200 ft where the river enters the Black River Valley. Most of the divide for the North and Middle Branches varies from 2300 to 2500 ft. The highest point is West Mountain at 2902 ft on the North Branch divide. The divide between the South Branch and the Hudson River basin to the east, has many peaks between 3000 and 3500 ft. The lowland of the North Branch drops from 2001 ft above Big Moose Lake to 1702 ft at its confluence with the Middle Branch at Old Forge, over a distance of 35 km. The South Branch drops from 2144 ft at Little Moose Lake to 1525 ft at its confluence with the Middle Branch at McKeever, over a distance of 47 km. The Middle Branch drops from 1791 ft at Eighth Lake to ± 1200 ft at its confluence with the Black River, over a distance of 62 km.

LACUSTRINE SEDIMENTS

The Sedimentary deposits discussed here originally were interpreted as proglacial outwash by Connally (1990), reported as such by Connally and Cadwell (1991), and published as such by Cadwell and Pair (1991). These sediments have not changed and their degree of exposure has increased very little. It is only our understanding that has changed. Upon re-examination and re-

mapping, we now infer almost all previously inferred outwash deposits in the vicinity of the Fulton Chain to be lacustrine in origin.

We have observed very little sediment finer than sand in the southwest Adirondacks. During the 1991 field season, extensive highway reconstruction between Raquette Lake and the hamlet of Blue Mountain Lake exposed several roadsides for lengths of 100 m or more. Subglacial and supraglacial meltout till, and stratified drift, all are dominated by sand. Pebbles, cobbles, and boulders were present in many exposures, in varying proportions. The sandy matrix material is the presumed source for lacustrine sediment. Therefore, the absence of finer material in the lacustrine sediments is not surprising.

There are only four localities where more than 2 m of sediment was exposed. A vertical face was maintained only after heavy rain. When the sandy sediments dry out, the faces collapse almost immediately. A fresh face remains exposed only where rare silty sediments are interbedded with sand.

At many exposures there are current structures in the sands. Most exposures were adjacent to paleoshorelines where currents from either shoreline or fluvial processes would have been normal. Deltaic deposits were exposed only at Blue Mountain Lake and at Burke's Cabins, shown in Figure 3.

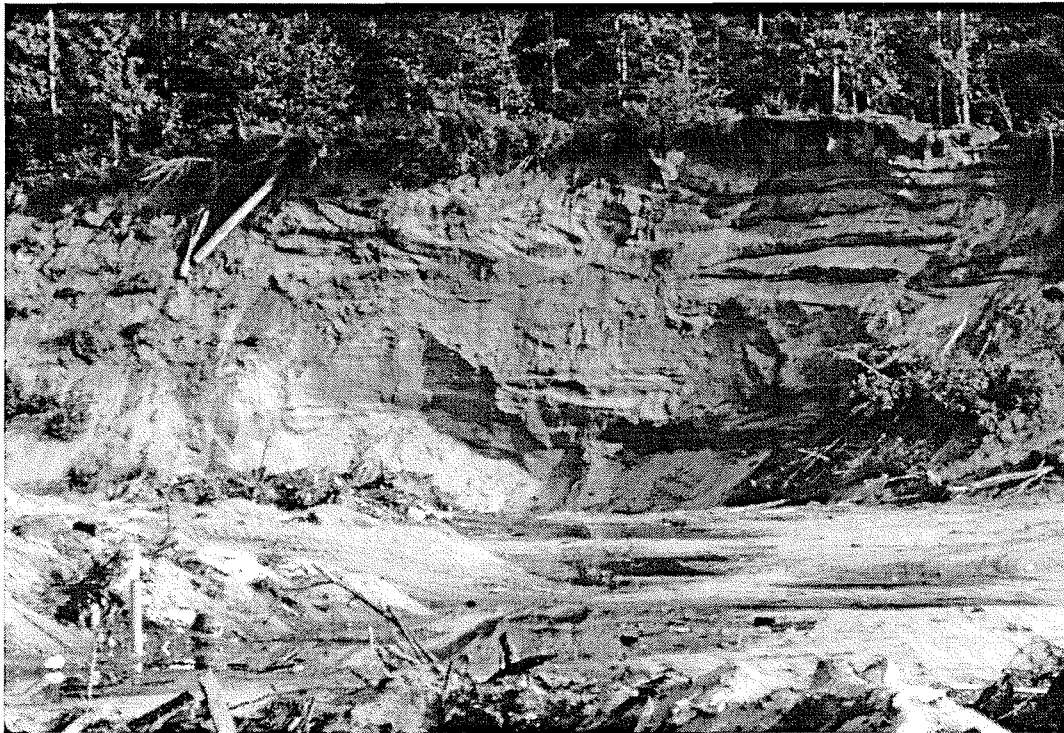


Figure 3. A 1991 view of the ice contact delta sediments south of and behind Burke's Marina. The 1840 ft delta top helps to define the level of Glacial Lake Raquette. Foreset beds are dipping northward toward the viewer.

Most exposures are in roadside ditches where oxidation in the B₂ or B_{2ir} soil horizons produces a distinct reddish color. In the few deep exposures, such as that at Burke's Cabins, the sand is typically light tan (5YR 6/4 to 10YR 4/2). The sediments comprise fine- to very-coarse-sand. The composition is dominated by quartz with dark amphibolitic layers present near Eighth Lake. Neither varves, nor any simple rhythmites, have been observed to date. However, the level

upper surfaces with matching elevations are best interpreted as the result of lacustrine deposition, rather than as proglacial outwash.

Glacial Lake Raquette

The initial high level lake, at ± 1840 ft, straddled the divide between upper Moose River and upper Raquette River drainage. It was centered on the present day Raquette Lake depression and is here named Glacial Lake Raquette (hereafter GLR). GLR spread southwest, up the Sucker Brook valley to beyond Shallow Lake; south into northern Eighth Lake, via Browns Tract Creek; and eastward up the Marion River to the Utowana Lake basin, as illustrated in Figure 4. The ± 1840 ft delta at Blue Mountain suggests a long extension of GLR to the east, down the Rock River valley, where it must have been dammed by Hudson River ice.

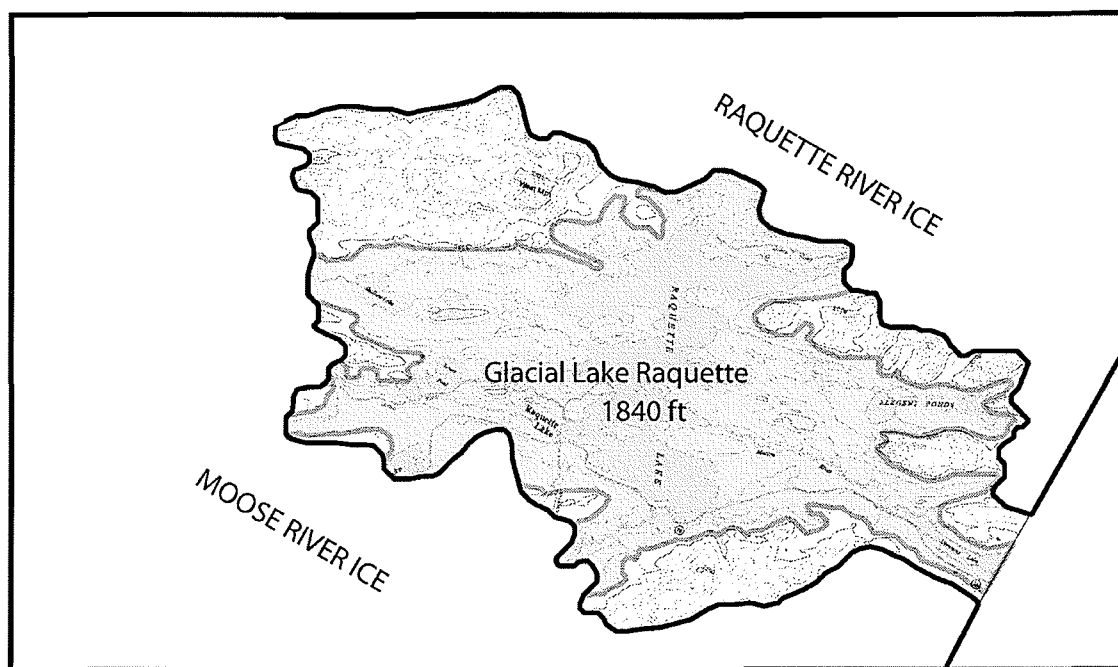


Figure 4. A sketch map of 1840 ft Glacial Lake Raquette, centered above present day Raquette Lake. The outlet is eastward into Hudson River Ice.

Glacier ice in the northern Adirondack drainage basins became the northern border of GLR. South-graded outwash near Grass Pond, above Sargent Ponds, documents the former ice margin. The Forked Lake depression shows no evidence of GLR. Inversion ridges between Outlet Bay of Raquette Lake and western Forked Lake might have resulted from the drainage of GLR northward through or under the ice into Raquette River drainage. The ice margin probably remained banked against the eastern mountains north of the Marion River, anchored to the east at Blue Mountain. At least initially, ice remained along Blue Ridge, south of the Marion River valley.

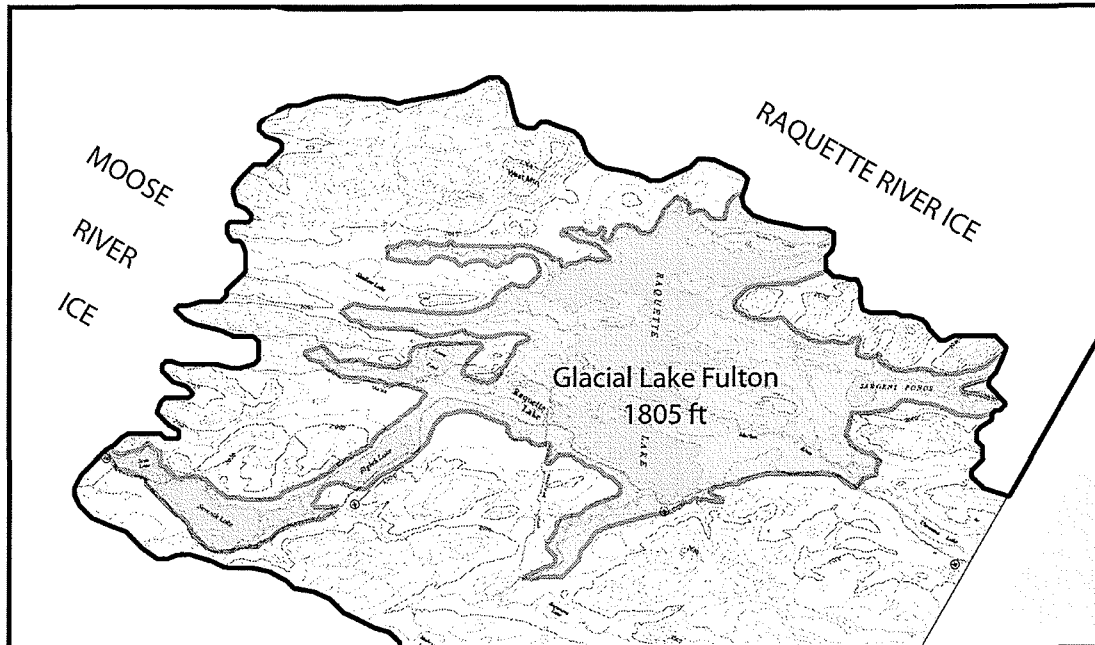


Figure 5. Sketch map of 1805 ft Glacial Lake Fulton, extending into the basins of Seventh and Sixth Lakes. Drainage for Lake Fulton also is to the east, down the Rock River into the Hudson River drainage basin.

There is sedimentary evidence of a small lake at ± 1920 ft between Blue Ridge and Eighth Lake Mountain in the vicinity of Sagamore Lake. That lake might have been contemporary, but probably developed after GLR and its successor had drained. Moose River ice evidently established a margin at the south end of Eighth Lake and in the North Branch between present day Big Moose Lake and GLR. The Hudson-Champlain Lobe ice remained in the upper Hudson River drainage basin at Lake Durant, immediately east of Blue Mountain. Thus, GLR must have been completely surrounded by thick glacier ice.

Although it had a very irregular shoreline, and was barely 0.6 km wide in the Marion River valley, GLR had maximum dimensions of 28 km east-to-west and 12 km north-to-south. The eastward extension is documented by the hanging delta on Blue Mountain northeast of the hamlet of Blue Mountain Lake (Figure 2). Other deposits were observed along Sucker Brook to the west and south of Eighth Lake Mountain from Eighth Lake to the Raquette Lake Reservoir. More are concentrated near Inlet Creek, south of the Marion River, and along Boulder Brook, a second eastern tributary to Raquette Lake. Esker ridges (?) near Eldon Lake, at the east side of Raquette Lake, and ice-contact structures in the Blue Mountain Lake delta, suggest that remnant ice remained in GLR, at least initially.

Where was the outlet for GLR? Ice stood in the Lake Durant depression blocking eastern drainage and in the Forked Lake depression blocking northern drainage. Ice probably remained in Inlet Creek, up to the elevation of Sagamore Pond at 1904 ft. Inversion ridges suggest that this ice did not melt until GLR and its successor had drained. And there are no GLR features south of Eighth Lake. This leaves northward or eastward drainage into the ice; or southwestward drainage via either Eagle Creek or Sucker Brook.

Ice-contact stratified drift appears to have filled Eagle Creek up to ± 1900 ft along Uncas Road. Indeed, the drift may mark the edge of Moose River ice that dammed GLR. Although there may

have been an early level of ± 1960 ft in upper Sucker Brook, that may have drained southwest via the Cascade Lake channel, the thresholds are well above 1840 ft. Thus, it is not now possible to pinpoint a drainage threshold responsible for the level of GLR. The most likely possibility is somewhere eastward within the blocking Hudson River basin ice. It is proposed here that GLR drained eastward into or under leaky Hudson-Champlain Lobe ice where a topographic barrier served as an 1840 ft threshold. The most likely candidate is the channel south of the Stark Hills, 3 km east of Lake Durant. There is a possible threshold at ± 1840 ft on Ledge Mountain south of the Stark Hills that overlooks what may be an abandoned plunge pool. Perhaps GLR waters were on their way to the subglacial Indian River channel.

Glacial Lake Fulton

Glacial Lake Raquette was succeeded by a more extensive lake at ± 1805 ft. The release of 35 ft of water caused lake waters to withdraw almost entirely from Sucker Brook in the northwest. A dense concentration of boulders at Eagles Nest, north of Eagle Lake, probably represents a lag deposit formed during drainage of GLR. The new lake, here named Glacial Lake Fulton (hereafter GLF), spread eastward in the valley of Lake Durant, in the Rock River drainage basin. Inversion ridges west of Stark Hills, near Rock Lake on the Rock River, and between Ledge Mountain and Sawyer Mountain, suggest that this lake drained east like its predecessor into or beneath ice of the withdrawing Hudson-Champlain Lobe. To the south, the lake extended into the Fulton Chain, for which it is named, as far as Sixth Lake. The maximum extent is illustrated in Figure 5.

The dimensions for GLF shrank from 28 to 22 km east-to-west, but increased from 12 to 17.5 km north-to-south, compared to GLR. Stratified sand and silt deposits surround Raquette Lake at ± 1805 ft. Those deposits extend eastward to the head of Utowana Lake and were observed adjacent to eastern Blue Mountain Lake. In the Fulton Chain, 1805 ft terraces were mapped between Eighth and Seventh Lakes and immediately south of Sixth Lake. They extend to the ice-margin deposits in Eagle Creek that probably bounded GLR. Similar deposits at Lake Durant Camp and surrounding O'Neil Flow east of Blue Mountain document extension into the Rock River valley and upper Hudson drainage.

The northern ice border for GLF probably remained unchanged. Outwash south of Forked Lake is graded to ± 1800 and ± 1780 ft. Evidently it was deposited by active northern ice still in place after the demise of GLF. Ice-contact structures in deltas at "Burke's Cabins" and at the former landfill for the village of Inlet document the presence of remnant ice during establishment of this lake. To the east, Hudson-Champlain ice was beginning to withdraw and probably to disintegrate at its western margin. The withdrawal probably initiated the drawdown of 1840 ft GLR to 1805 ft resulting in GLF. To the west, ice still occupied the North Branch of the Moose River in the vicinity of Big Moose Lake. However, in the Middle Branch the ice margin withdrew southwestward through Eighth, Seventh, and Sixth Lakes. A small terrace remnant south of Fifth Lake also may represent this level. GLF waters may have been present in northern Fourth Lake, but we conclude that Fourth Lake deposits near 1805 ft probably represent southwest-flowing drainage that ended GLF. Late in the history of GLF it probably drained into stagnant ice in the Fourth Lake basin.

Glacial Lake Inlet

A ± 1760 ft level is documented in the northern part of Fourth Lake and south of Fifth Lake. It is here named Glacial Lake Inlet (hereafter GLI) for the hamlet of Inlet just north of Fourth Lake. Although GLI was a relatively minor lake at 6 km by 10 km, it was an important step in the overall sequence.

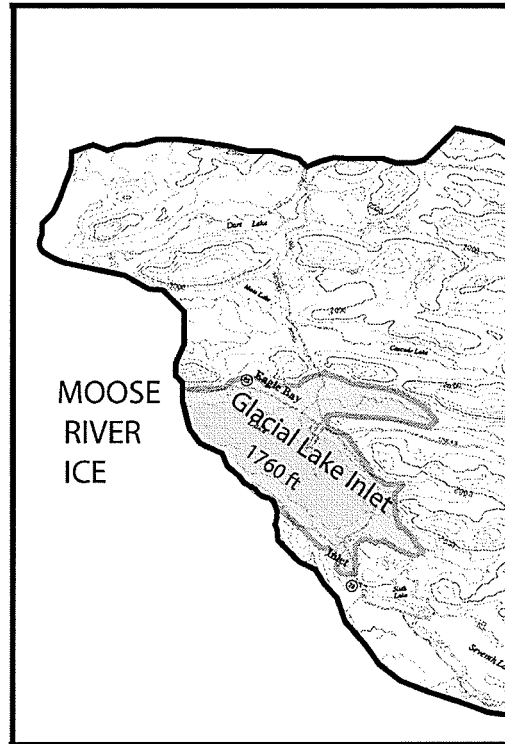


Figure 6. A sketch map of 1760 ft Glacial Lake Inlet which extended over Fifth and Fourth Lakes. Drainage is southwest into the Moose River ice.

East of the Raquette River/Hudson River drainage divide, the Hudson-Champlain ice withdrew farther eastward. GLF waters fell to a new threshold elevation at ± 1790 ft and then drained altogether down the Rock River. No distinct features were observed at that elevation surrounding Raquette Lake. Thus, northern drainage of GLF to the Raquette River probably followed immediately via the Outlet Bay inversion ridge channels. That would have lowered the water level in the Raquette Lake depression to its present level of 1762 ft. South of the Raquette River/Moose River drainage divide, southwestward drainage must have commenced into or onto Moose River ice.

The north portion of the Middle Branch became ice-free enabling Eighth Lake to reach its stable level at 1791 ft, Seventh Lake to reach 1786 ft, and Sixth Lake to reach ± 1773 ft. Miller (1917, p. 70) stated that "From ... Raquette Lake ... preglacial drainage was almost certainly southwestward by way of ... the Fulton Chain ...". Evidently, just the reverse was true. Seventh and Eighth Lakes, without Lake Fulton lacustrine deposits at ± 1805 ft at their northern ends, probably were tributaries to the Raquette River, via the Raquette Lake depression.

In the Moose River basin, ice evidently remained in the South Branch. But a lake developed at ± 1800 ft across the Dart Lake and Moss Lake depressions in the upper North Branch. It is marked by very thick deposits of lacustrine sand. The lake extended to the vicinity of Safford Pond and we here name that lake Glacial Lake Safford. The northern margin of Fourth Lake ice must have been just west of Bubb Lake, then north of Lake Rondaxe to southeast of Safford Pond. It acted as a dam for both Lake Safford in the North Branch and GLI in the Middle Branch

as illustrated in Figure 6. We posit that Lake Safford gradually emptied into the Middle Branch at the hamlet of Thendara, either into the ice or over it, bypassing GLI.

Above Glacial Lake Safford another lake developed at ± 1900 ft from Lake Big Moose northeastward to the drainage divide. That lake, here named Glacial Lake Big Moose, might have developed prior to Lake Safford or contemporaneously. But because overflow deposits from Big Moose Lake appear to be graded to previously deposited Lake Safford sands, we infer that it was subsequent. In any case, the combined waters of Lakes Big Moose and Safford eventually extended Lake Safford down the North Branch to a threshold at Thendara. Drainage into Moose River ice probably caused retreat of the Fourth Lake ice margin to the North Branch/Middle Branch confluence, initiating the succeeding lake.

Because of the lack of sediment downstream in the Moose River, we conclude that superglacial drainage sluiced water and sediment from the central Adirondacks into the Black River Valley. The draining of Glacial Lake Safford and Glacial Lake Inlet initiated large scale sediment bypassing as a process in the Moose River drainage basin. Bypassing was previously proposed by Connally and Cadwell (1991).

Glacial Lake Old Forge

The retreat of Moose River ice to Thendara was accompanied by a lowering water level along the Middle Branch from ± 1760 to ± 1740 ft. Lake Safford and Lake Inlet drained completely. The 1740 ft level is here named Glacial Lake Old Forge (hereafter GLO) for the former Browns Tract Forge and the village of Old Forge. GLO extended 20 km from Fifth Lake to the ice dam at Thendara as illustrated in Figure 7. GLO and its successor were only ± 1 km wide in the Middle Branch of the Moose River and even narrower in the North Branch. Boulder deposits immediately above GLO deposits south of Fourth Lake suggest that the lowering from GLI to GLO was accomplished by strong current action. It might have been catastrophic.

Ice must have remained in the valley of Nicks Creek, to the southeast, because no 1740 ft features were observed there. However, GLO did extend up the North Branch to the vicinity of Rondaxe Lake. GLO terraces are the dominant features surrounding all of the lower lakes of the Fulton Chain. They were particularly well exposed in 1990 at the Old Forge airport. Again, drainage must have escaped southward, sluicing water and sediment through superglacial channels to the Black River Valley.

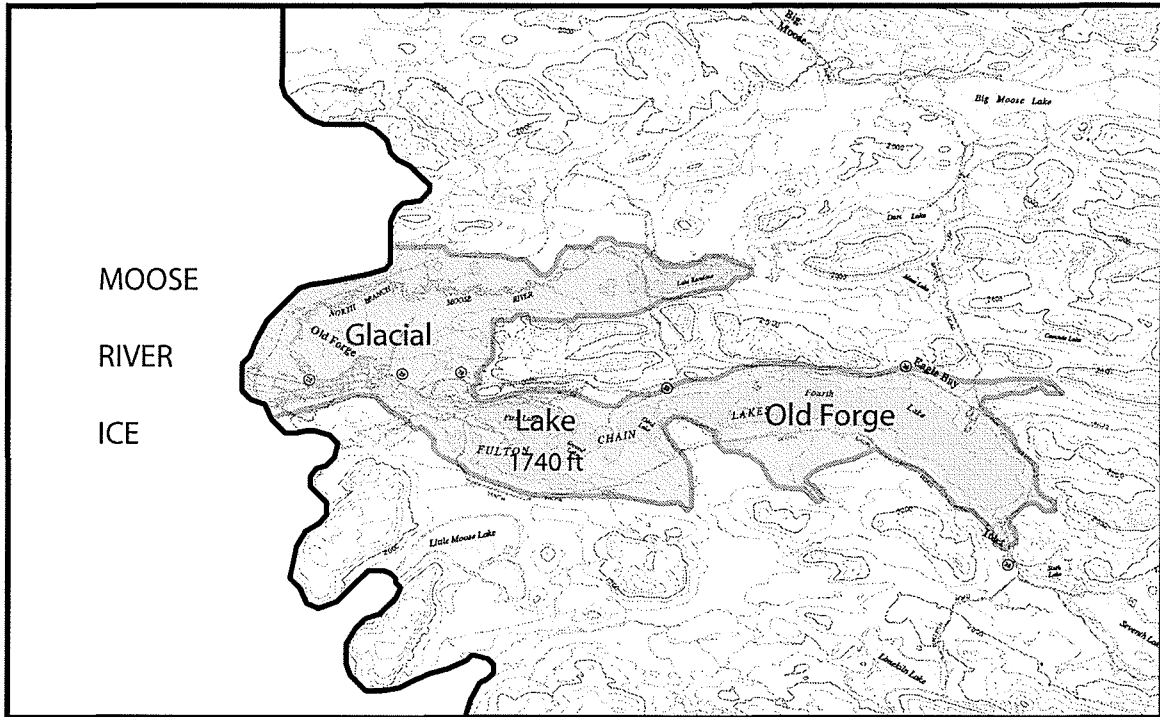


Figure 7. A sketch map of 1740 ft Glacial Lake Old Forge which extended over First through Fourth Lakes. The outlet is to the west over disintegrating Moose River Ice.

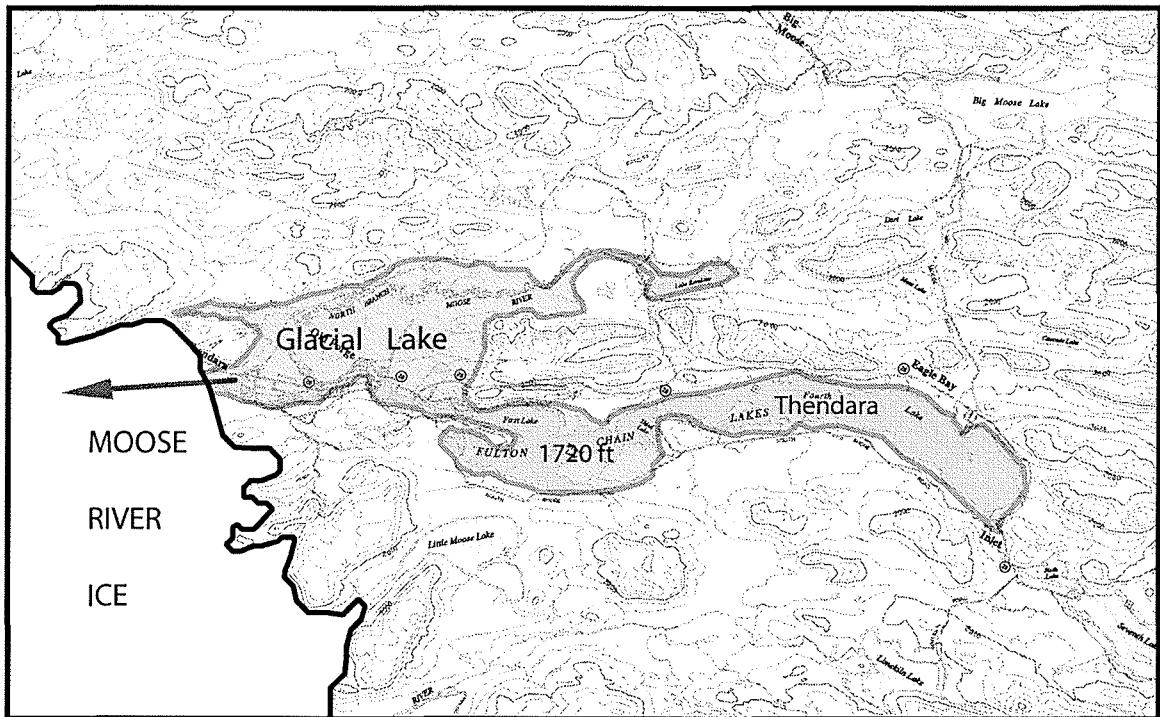


Figure 8. A sketch map of 1720 ft Glacial Lake Thendara that also extended over First through Fourth Lakes. Drainage is southwest into the Moose River ice. The outlet channel deposits are shown in Figure 9.

Glacial Lake Thendara

Evidence for the final pre-Fulton Chain lake is preserved at ± 1720 ft. The Moose River ice margin retreated 1 km southwest and later another 6 km to Flatrock Mountain. The lowest level is here named Glacial Lake Thendara (hereafter GLT) for the hamlet of Thendara. It was ± 27 km long from Fifth Lake to the ice dam as illustrated in Figure 8. GLT left low terraces from 10 to 14 ft high at many points along the lower Fulton Chain. However, GLT deposits are much more prominent along the Moose River southwest of Old Forge and in the valley of Nicks Creek. At the mouth of the North Branch, west of Old Forge, the Thendara Flats were deposited.

Drainage from GLT, like its predecessors, must have been southwest over decaying Moose River ice. Connally was able to identify the probable outlet channel, at least for GLT, in a gravel pit southwest of Thendara. A linear concentration of huge boulders that strongly suggests catastrophic drainage by very swift currents was uncovered in the autumn of 2002. These boulders are illustrated in Figure 9.



Figure 9. Boulders in the Heroux Construction Co. pit, deposited during drainage of Glacial Lake Thendara, as observed in 2002. The wife of the senior author appears at right for scale.

The relationship between the five proglacial lakes of the Fulton Chain, and Raquette Lake, and the natural elevations of the nine lakes are illustrated in Figure 10. The elevations, dimensions, and boundaries for those lakes are summarized in Table 2.

TABLE 2

Major Proglacial Lakes of the Fulton Chain Region

Glacial Lake	Elevation	NS x EW	SW boundary	NE boundary
Lake Raquette	1840 ft	12 x 28 km	Moose River ice	Hudson River ice
Lake Fulton	1805 ft	18 x 22 km	Moose River ice	Hudson River Ice
Lake Inlet	1760 ft	10 x 6 km	Moose River ice	5 th Lake/6 th Lake upland
Lake Old Forge	1740 ft	20 x 1 km	Moose River Ice	5 th Lake/6 th Lake upland
Lake Thendara	1720 ft	27 x 1 km	Moose Rover ice	5 th Lake/6 th Lake upland

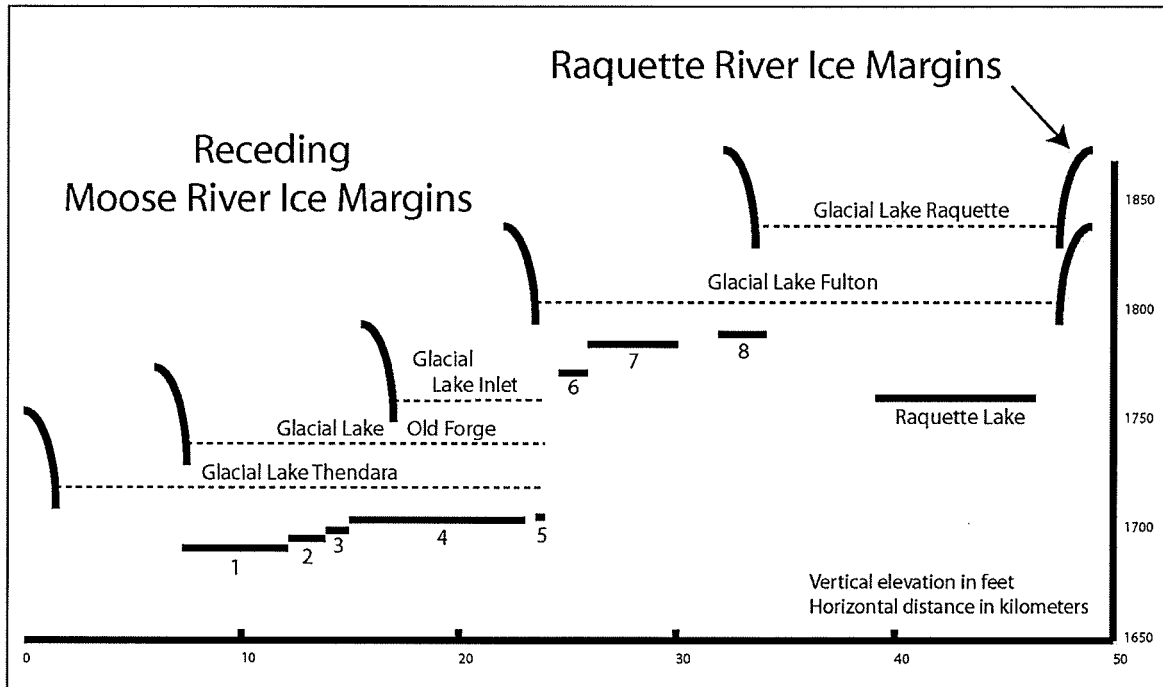


Figure 10. This diagram suggests the association of retreating glacier ice in the Raquette and Moose River valleys, with the elevation and position of both the proglacial and present-day lakes. The eight Fulton Chain lakes are represented by number.

ADIRONDACK DEGLACIATION

The Events outlined above probably initiated deglaciation of the entire Adirondack region. When deglaciation began, the Raquette Lake depression was critically located between northern sublobes, the Hudson-Champlain Lobe to the east, and glacier ice that was south and west of the major drainage divides. If the Raquette Lake area is not the place where deglaciation began, it is one of very few candidates.

At some time during general deglaciation of western and central New York, continental ice had shrunk back to the Adirondack Mountains. The last time that Adirondack ice, and probably Black River ice, contributed to the Mohawk Valley was during the West Canada Advance (Ridge and others, 1991) prior to the Shed Brook Discontinuity (Ridge, 1997). To the north, Adirondack ice was continuous with the continental glacier that covered central Canada and the Maritime Provinces. According to Connally and Cadwell (2004) free drainage that created the Shed Brook discontinuity commenced at 19,500 yBP. Note here that all dates have been translated into calendar years (yBP) using Calib 4.3 (Stuiver et al., 1998). Actual ^{14}C dates (ka) are quoted in parentheses where appropriate.

Following the erosion that created the Shed Brook Discontinuity, presumed active ice furnished sediment to deltas on the northeastern shore of proglacial lakes in the Black River Valley (Connally and Cadwell, 1991). According to Connally and Cadwell (2004), the free drainage had ceased by 17,800 yBP. At the southern edge, presumed active ice furnished sediment to Lake Miller deltas in the Mohawk Valley (Fullerton, 1971). To the southeast, the

Hudson-Champlain Lobe still was active, re-blocking the lower Mohawk Valley and extending south into the mid-Hudson Valley as the Rosendale Readvance.

At the next geological instant, downwasting in the Adirondacks reached a critical threshold where new ice could no longer replenish the ablating ice to the south. The glacier was no longer thick enough to maintain flow over the high, mountainous divides. Once the critical threshold was reached, ice in the Independence River and Moose River basins, and probably the West Canada Creek basin as well, stagnated in place (Fleisher and others, 1991). Ice north of the divides remained active, thus maintaining the ice margin in the Forked Lake depression that dammed Glacial Lakes Raquette and Fulton. At first, the Hudson-Champlain Lobe continued to supply active ice in the Lake Durant depression to the east. But this ice began to stagnate and disintegrate causing the demise of GLR. Perhaps Moose River ice was large enough and thick enough to maintain independent flow for a brief time, but there is no confirming evidence. This then was the beginning of Adirondack Mountain deglaciation.

Why should the Raquette depression be first? As soon as peaks such as West Mountain and Blue Mountain cut off ice supply from the north, ablation must have accelerated south of the divide. In the Beaver River basin to the west there is abundant evidence of large quantities of meltwater beneath the ice. Connally and Cadwell (1991) reported sandy, laminated, subglacial meltout till in many lowlands in both the Beaver River and Moose River basins. Thus, we suggest that meltwater, having nowhere to go, began accumulating subglacially in the Raquette Lake depression.

During initiation of Glacial Lake Raquette, the Hudson-Champlain Lobe remained firmly in place in the Lake Durant depression. Raquette River ice also stayed firm in the Forked Lake depression. Moose River ice melted back only marginally, to the Eighth Lake depression. We suggest that large quantities of subglacial water at or near its melting point promoted rapid melting of ice overlying the Raquette Lake depression, initiating GLR at 1840 ft. A similar situation may have existed at the divide between the north-draining Oswagatchie River and the west-draining Bear River basins. However, it is reasonable to conclude that ice overlying the Moose River-Raquette River divide melted first. That is where the mountains are highest and so that is where the Adirondack ice probably was thinnest.

TIMING

It is impossible to establish an exact time when deglaciation began. However, it must have begun between 19,500 and 15,500 yBP (16.35 and 12.86 ka) and was completed in the Moose River basin by 15,500 yBP.

Deglaciation of the Adirondacks did not occur until after retreat of the last Valley Heads readvance into the western Mohawk Valley. The maximum extent of Valley Heads glaciation in south-central New York occurred at about 16,010 yBP (13.32 ka) according to Coates et al. (1971). However, the equivalent Kent Moraine ice in western New York had begun recession by 16,800 yBP (14.00 ka) according to White et al. (1969). The last readvances of the Ontario Lobe in the western Mohawk Valley were the Hinckley Readvance that deposited the Norway till and Barneveld Readvance that deposited the Holland Patent till of Ridge (1985, Fig. 21) followed by the final Rome Readvance (Muller and Calkin, 1993). There was no involvement of either Adirondack or Black River ice during these readvances.

According to Ridge (1997 and 2003), the Hinckley and Barneveld Readvances occurred at 14.5 and 13.5 ka, respectively. Thus, it is possible that deglaciation of the Moose River drainage basin began with the recession of the Oneida sublobe prior to the Hinkley Readvance.

Deglaciation of the central Adirondacks began with recession of Hudson River ice to the east, down the Rock River valley, prior to 15,500 yBP. That is the revised date reported by Connally and Cadwell (2004) for retreat of the Hudson-Champlain Lobe from the east edge of the Adirondacks. It is based on the date of Clark et al. (2001) for re-establishing Great Lakes drainage down the Mohawk Valley and out the Hudson Valley to the Atlantic. By that time the upper Hudson Valley drainage basin almost certainly was free of active ice, though areas of stagnant ice may have remained in protected areas (Fleisher et al., 1991).

Thus, at this time we conclude that initial deglaciation of the southwest Adirondack Mountains began by 16,800 yBP. Deglaciation began with the inception of Glacial Lake Raquette that straddled the divide between the Moose River and Hudson River drainage basins. It probably did not take long for the Moose River basin to become ice-free but 15,500 yBP seems to be the youngest limit.

ACKNOWLEDGEMENTS

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ROAD LOG

For the 93 miles to Stop #1, this trip follows the path of the Raquette River upstream to its origin at Raquette Lake. The route crosses the river several times; three times in the first 10 miles. There are many bedrock outcrops along the way. Although not the subject of this trip, it is interesting to notice that almost all exhibit a set of joints that dip toward the road, parallel to the rock surface.

At Blue Mountain Lake, mile 81.2, the road log starts to mention features pertaining to this fieldtrip.

Total Miles	Miles From Last Stop	
00.0	00.0	Proceed west on Barrington Drive toward Rout 56.
00.2	00.2	STOP SIGN Turn left (south) on Route 56. Follow Route 56 for 32 miles.
32.2	32.2	STOP SIGN Turn left (east) on Route 3. Follow Route 3 for 17 miles.
49.7	49.7	2 TRAFFIC LIGHTS Turn left, then right onto Route 30 at the top of the hill.
49.9	49.9	3 rd TRAFFIC LIGHT Turn left (south) following Route 30. Follow Route 30 for 33 miles.
71.2	71.2	Cross bridge into hamlet of Long Lake.
71.9	71.9	YIELD SIGN Follow Rt. 30 to right; Rt. 28N joins from left.
81.2	81.2	Start down steep hill into hamlet of Blue Mountain Lake.
81.5	81.5	Adirondack Museum entrance on is on the right.
82.4	82.4	Blue Mt. Lake is on the right; 1840 ft Blue Mountain delta in the woods at left.
82.6	82.6	INTERSECTION Continue straight (west) on Route 28; Route 30 leaves to left and passes Lake Durant, at 1,769 ft, the lowest of the lakes on the Marion River.
84.3	84.3	Look for an arête on the right.
90.6	90.6	Delta terrace sediments exposed.
92.9	92.9	Raquette Lake is on the right; 4.5 x 3.4 mi (7.3 x 5.6 km), present elevation of 1,762 ft.
93.2	93.2	Cross small bridge over South Inlet for Raquette Lake
93.8	93.8	STOP #1 Burke's Cabins are on the right; Burke's Marina on

the left. Park where you can but, NOT in the restaurant parking lot. We will look at the sediment behind the marina buildings and then find an open space to discuss Glacial Lakes Raquette and Fulton.

	00.0	Continue west on Route 28
94.3	00.5	Delta foreset beds may be exposed on the left.
95.7	01.9	INTERSECTION Continue straight ahead on Route 28. Historic Sagamore is to the left; to the right is the hamlet of Raquette Lake.
99.0	05.2	Eighth Lake , the highest of the Fulton chain, is on the right; 1.8 mi (2.6 km) long, present elevation 1,791 ft.
102.3	08.5	Cross an inlet to Seventh Lake ; 3.1 mi (5.0 km) long, present elevation 1,789 ft.
104.5	10.7	Pryor's Sea Plane rides on right are on Seventh Lake. Sixth Lake is the next lake seen through the trees; 0.9 mi (1.5 km) long, present elevation 1,789 ft.
105.8	12.0	Sixth Lake Road is on the right.
106.0	12.2	Fifth Lake is on the left, only 0.3 mi (0.5 km) long, present elevation 1,707 ft.
106.2	12.4	Enter the hamlet of Inlet.
106.4	12.6	Inlet public parking lot on the left at the head of Fourth Lake.
106.5	12.7	Fourth Lake is on the left; 6.0 mi (8.6 km) long, present elevation 1,707 ft.
108.4	14.6	Enter the hamlet of Eagle Bay
111.3	17.5	Fourth Lake still is on the left.
113.9	20.1	Third Lake is now on the left, but is not visible; 1.0 mi (1.6 km) long, present elevation 1,707 ft.
115.0	21.2	Second Lake now is on the left, but it also is not visible; 0.8 (1.4 km) long, present elevation 1,707 ft.
115.4	21.6	A new rock fall in 2004 was added to the talus on the right.
117.3	23.5	First Lake is visible on the left; 2.7 mi (4.4 km) long, present elevation 1,707 ft.
117.6	23.8	INTERSECTION immediately before right turn. Turn left (east)

between buildings.

- 117.7 23.9 **STOP #2** Here we will discuss the present day Fulton chain and their predecessors Glacial Lakes Inlet, Old Forge, and Thendara.
- 00.0 Return to Route 28.
- 117.8 00.1 STOP SIGN Turn right (north) onto Route 28.
- 117.9 00.2 INTERSECTION Turn left (west) onto North Street and traverse a 1720 ft terrace of Glacial Lake Thendara lacustrine sand.
- 119.5 01.8 Rise up the scarp to the 1740 ft lake terrace of Glacial Lake Old Forge lacustrine sand.
- 120.1 02.4 **STOP #3** Park where you can, then cross the bridge over the Moose River to view the sands of Lake Thendara.
- 00.0 Return east to Route 28.
- 122.3 02.2 STOP SIGN Turn right (south) on Route 28.
- 122.5 02.4 The hamlet of Old Forge is constructed on the 1740 ft terrace deposited in Lake Old Forge.
- 123.0 02.9 Descend to the 1720 ft terrace deposited in Lake Thendara.
- 123.3 03.2 Cross the Middle Branch of the Moose River.
- 124.1 04.0 Passing through the hamlet of Thendara
- 125.6 05.5 INTERSECTION Turn left (east)
- 125.7 05.6 Exposure of channel deposit of boulders on the left. STAY
LEFT
- to the active gravel pit of Heroux Construction Co.
- 125.8 05.7 **STOP #4** Park where you can. We will look at ice-contact lacustrine sediments, and extremely coarse channel deposits. Then we will discuss the history recorded here. On the way out, visit the outlet channel deposits for Glacial Lake Thendara (and perhaps Lake Old Forge, and even Lake Inlet before it) in the original sand pit on the left. Note the size of the “sediment” and speculate on the rate of flow as the lake(s) drained.

This is the last stop. Vehicles traveling back north will reverse the route. Those traveling east, west, or south will continue south (left) on Route 28, which will become Route 12 before intersecting with the New York State Thruway at Exit 31.

Workshop W-3

INTRODUCTION TO SCANNING ELECTRON MICROSCOPY

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Meet in Timerman Hall Room 122 at 8 am

This workshop introduces the principles of the scanning electron microscope, sample preparation and viewing techniques. Participants are requested (if they wish) to bring a sample (air dried) they will prepare for viewing with the SEM. They will be shown the various techniques used to mount samples on viewing stubs and how to gold coat them in a sputter coater. The routine techniques of using the SEM and photographing images will be demonstrated. Each participant will then have ample time using the instrument to scan and record sample images.

In addition to the participant's individual sample, additional geological specimens will be viewed (e.g., diatoms, radiolaria, fossil insects, petrified wood, and various rocks and minerals). The workshop provides an opportunity to view "The World of the Micron" not usually seen using other techniques.