Trip B-2

METAMORPHIC PETROGRAPHY BETWEEN TUPPER LAKE AND BLUE MOUNTAIN LAKE

Robert Badger and James Carl
Department of Geology, SUNY Potsdam
Potsdam, NY 13676
badgerrl@potsdam.edu

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 at 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.

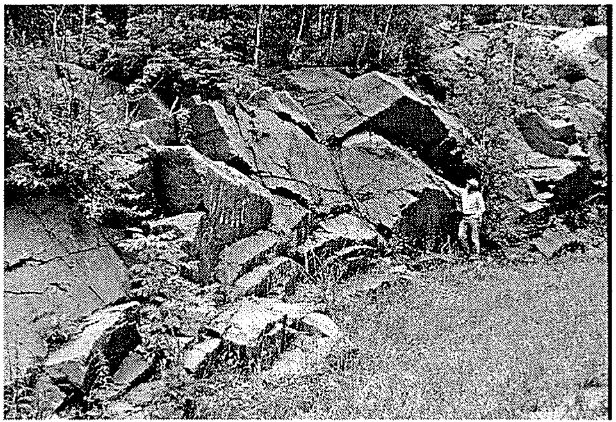

Figure 1-2. Blocks of meta-syenite displaying joint surfaces.

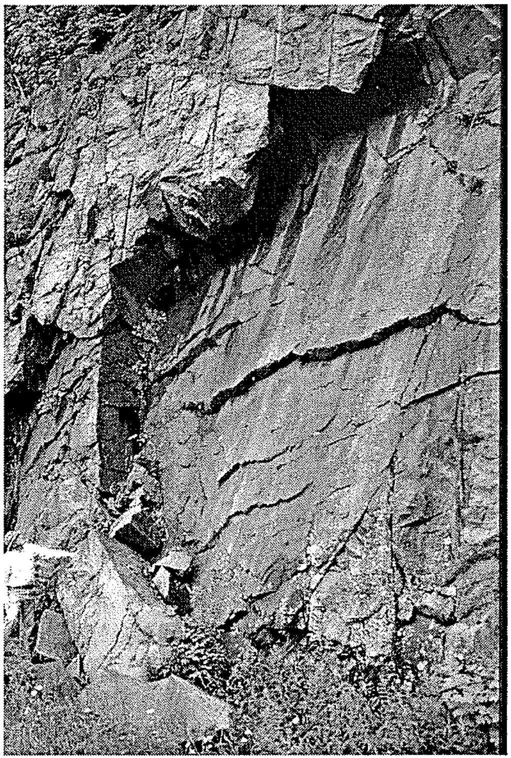

Figure 1-3. Site of rock fall along joint surface in July 2000.

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).

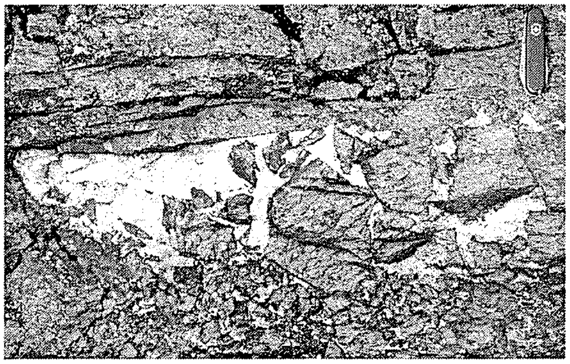
Figure 1-4. Brecciated meta-syenite with calcite zone. vein filling.


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.

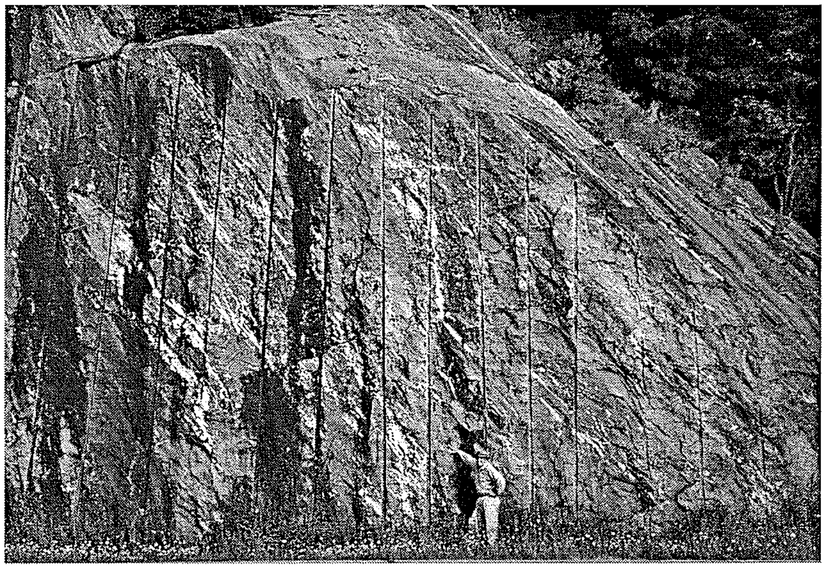

Figure 2-1. Calc-silicate outcrop at Stop 2. Jim Carl for scale.

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, $CaMgSi_2O_6$ (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, $CaMg(CO_3)_2$, and the so-called impurity—a little quartz sand, SiO_2. Note that the formula of diopside, $CaMgSi_2O_6$, 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 diopsidic 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.

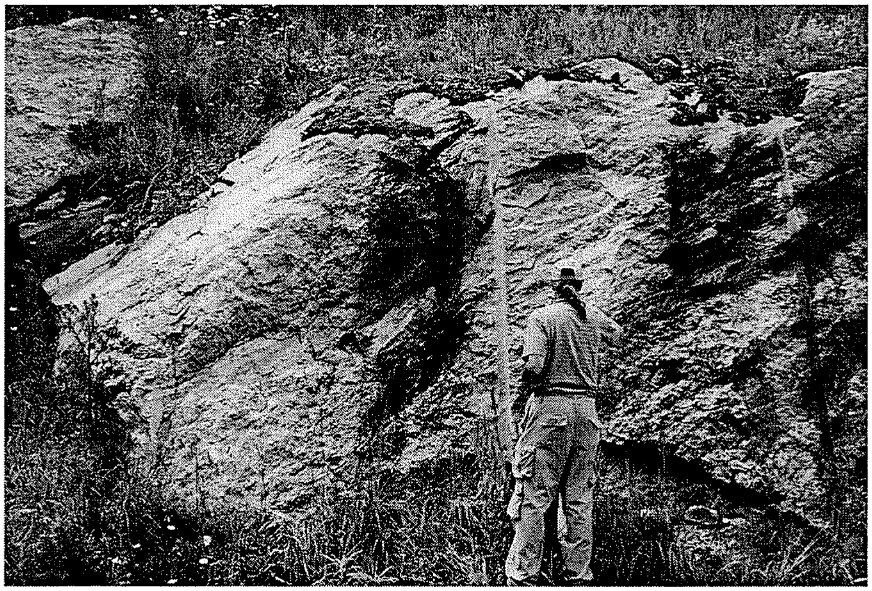

Figure 3-1. Impure marble outcrop at stop 3. Rob Badger for scale.

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.

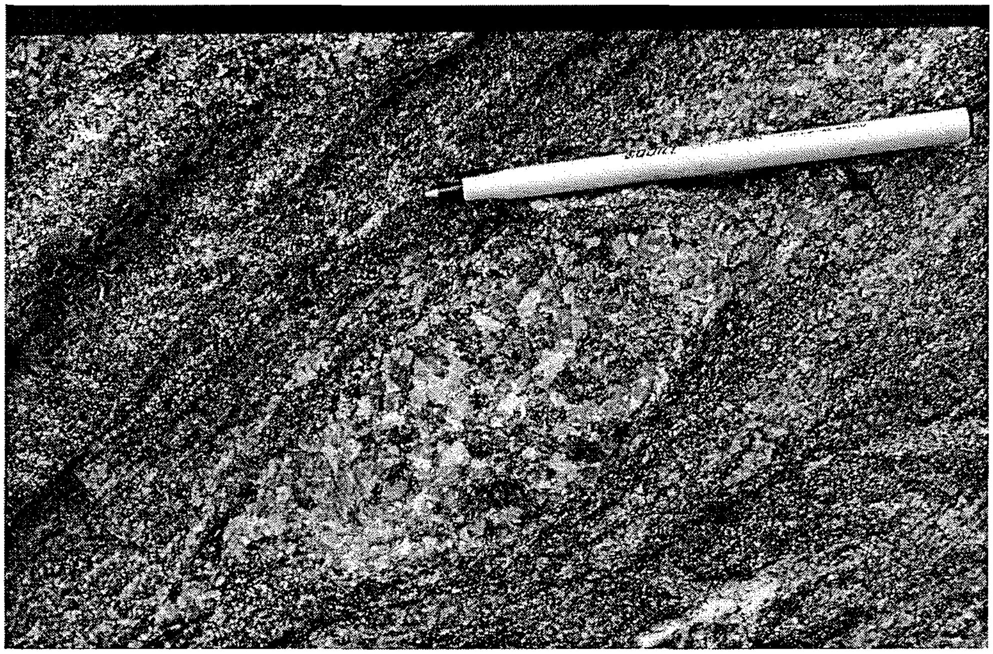

Figure 3-3. Pod of quartz with reddish-lavender garnet, quartz and feldspar, within hornblende gneiss.

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 potasssium 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

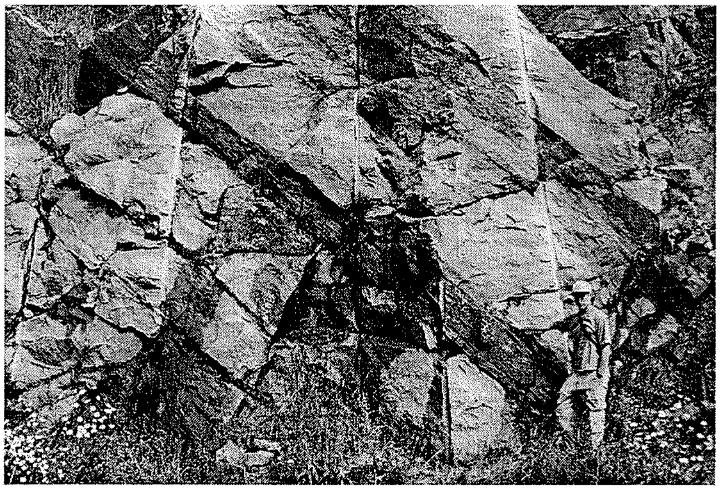

Figure 4-1. Amphibolite dike cutting garnetiferous pink and light gray granitic gneiss.

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.

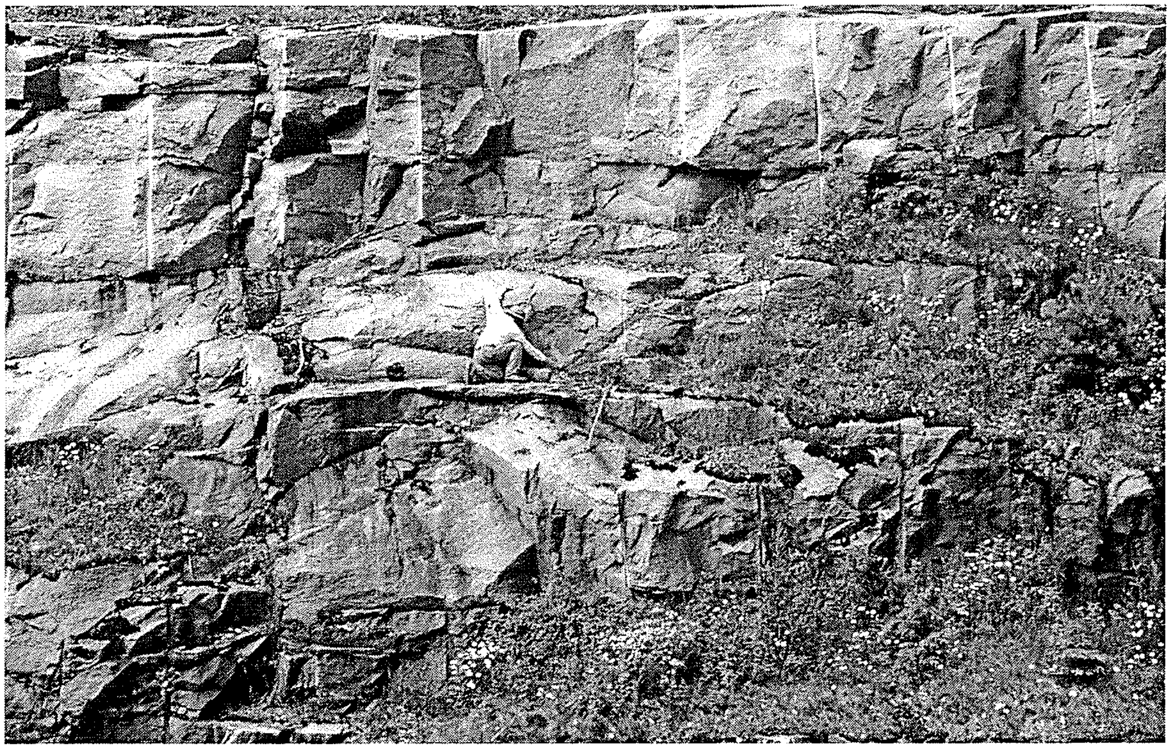

Figure 5-1. Granitic gneiss at Stop 5 showing horizontal sheeting joints. Jim Carl is pointing to a thin mafic dike that cuts diagonally across the outcrop.

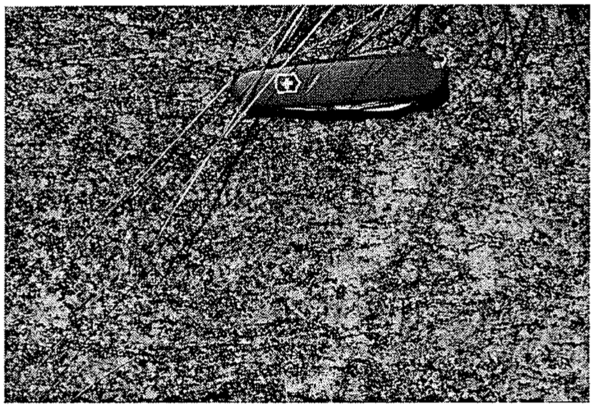

Figure 5-2. Alkali feldspar-quartz-hornblende gneiss at Stop 5. Note parallel alignment of hornblende grains.

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.

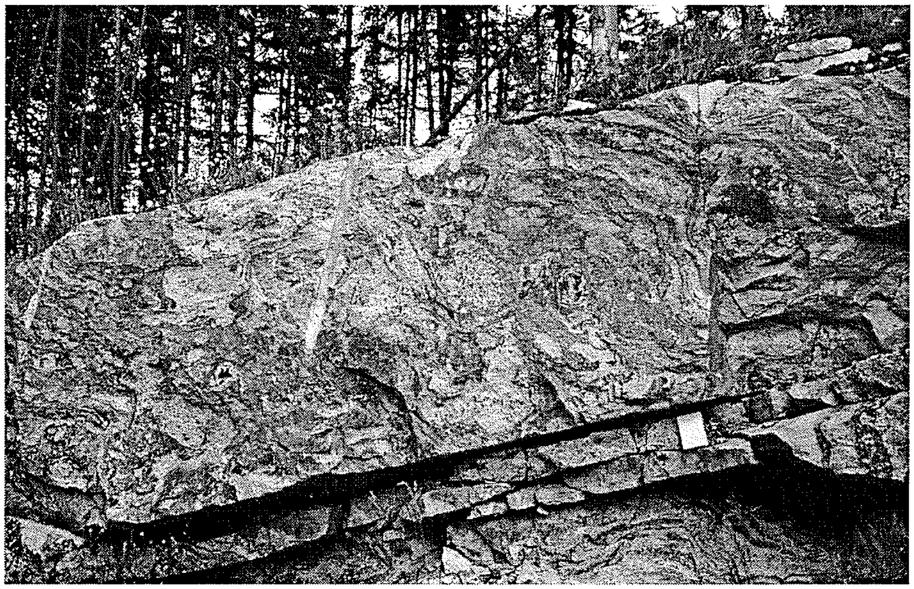

Figure 6-1. Mottled feldspar-hornblende-quartz gneiss at stop 6. (See front cover for color photo)

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.

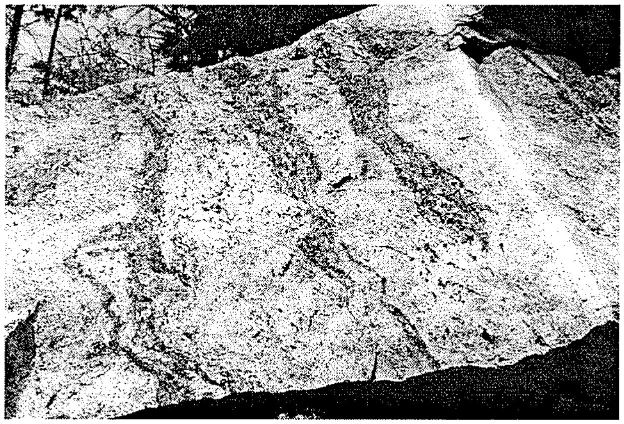

Figure 6-2. Dark bands of hornblende gneiss segregated from lighter feldspar rich zones.

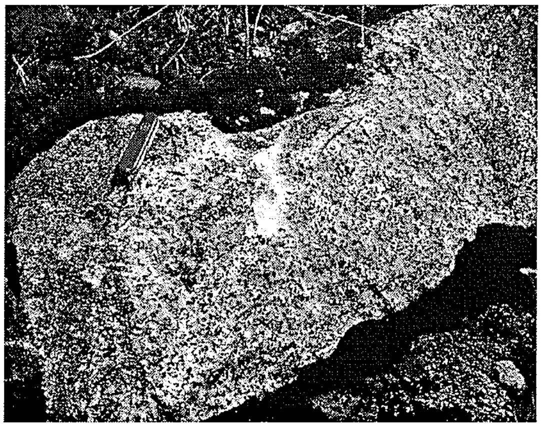

Figure 6-3. Calc-silicate xenolith (to right of knife) in contact with its meta-intrusive host.

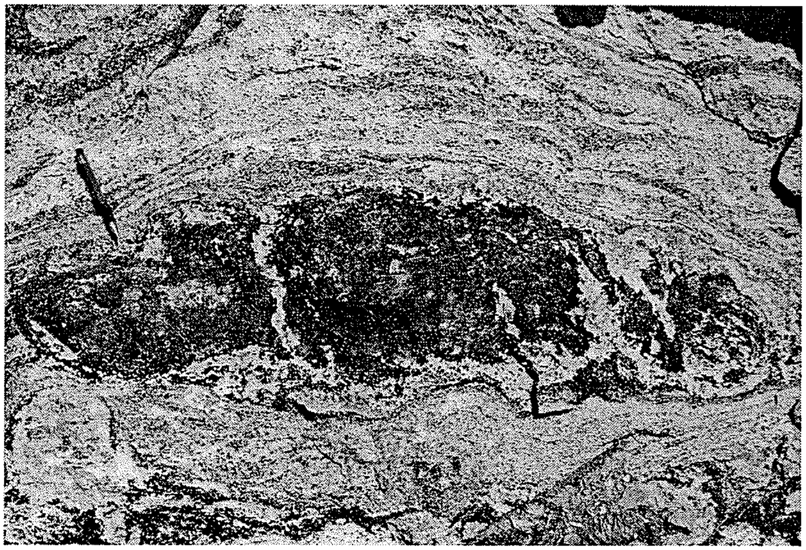

Figure 6-4. Xenolith of garnet-diopside gneiss within its intrusive host.

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 nches 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.

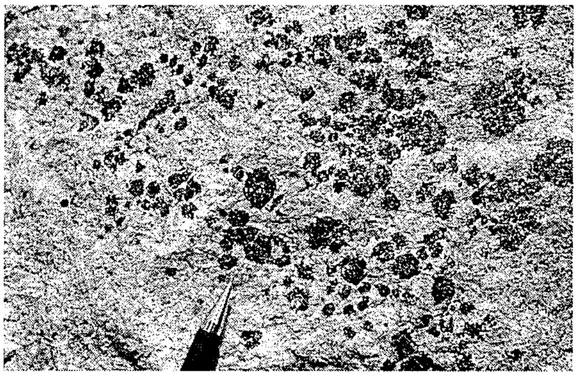
Figure 6-7. Garnet grains in pink feldspar gneiss at south end of outcrop at Stop 6.

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.

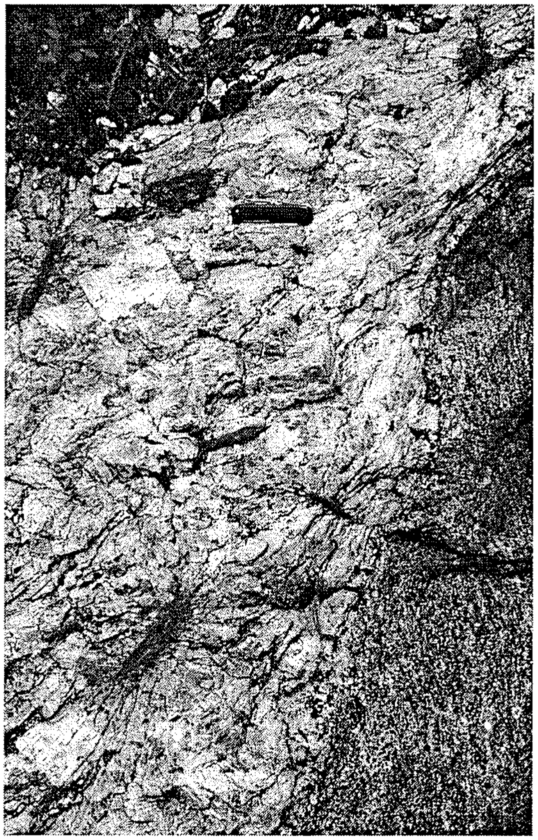

Figure 7-2 Coarse pegmatite dike at Stop 7. Hornblende-garnet-biotite gneiss on right.

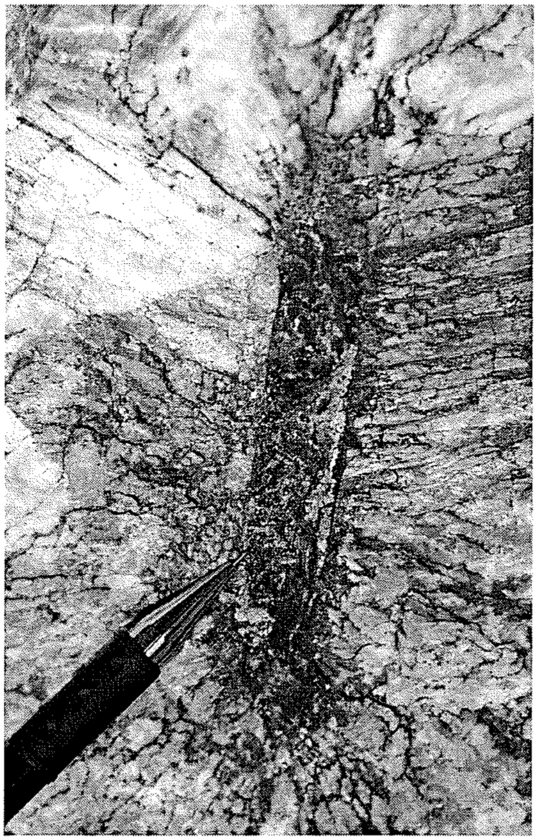

Figure 7-3. Hornblende grain in pegmatite of previous figure.

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.

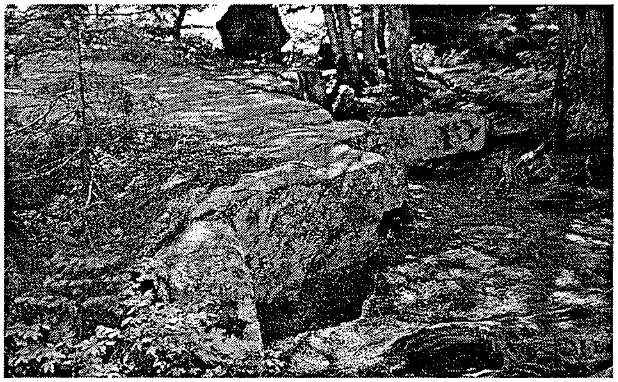
Figure 8-1. Prominent jointing at outcrops near Buttermilk Falls. Joint planes intersect at nearly right angles, and blocks have broken away to leave vertical walls.


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.

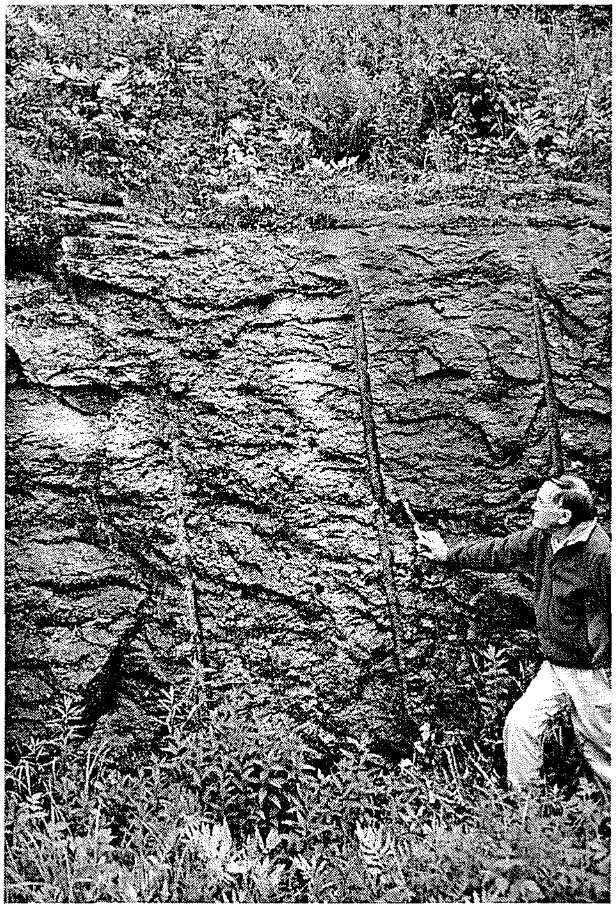

Figure 9-1. Pegmatite dike pointed out by Jim Carl at Stop 9.

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_2O_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_2O	12.96	12.19	12.15	12.80	13.12	13.15	13.01	13.01	12.98	12.98
K_2O	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_2O_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_2O	0.81	0.12	0.11	1.54	1.50	1.75	0.49	0.54	1.02
K_2O	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_2O_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_2O	0.00	0.00	0.03	0.00	0.01	0.00	0.02	0.00	0.02	0.01
K_2O	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.

REFERENCES

Carl, James D., 1988, Popple Hill Geniss as dacite volcanics, northwest Adirondacks, N.Y.: Geological Society of America Bulletin, v. 100, p. 841-849.

Chiarenzelli, J.R., and McLelland, J., 1991, Age and regional relationships of granitoid rocks of the Adirondack Highlands, New York: Journal of Geology, v. 99, p. 571-590.

Hamilton, M.A., McLelland, J., and Selleck, B., 2004, SHRIMP U-Pb zircon geochronology of the anorthosite-mangerite-charnockite-granite suite, Adirondack Mountains, New York: Ages of emplacement and metamorphism, *in* Tollo, R.P., Corriveau, L., McLelland, J., and Bartholomew, M.J., eds., Proterozoic tectonic evolution of the Grenville orogen in North America: Boulder, Colorado, Geological Society of America Memoir 197, p. 337-355.

Isachsen, Y.W., Landing, E., Lauber, J.M., Rickard, L.V., and Rogers, W.B., editors, 1991, Geology of New York: a simplified account: New York State Museum/Geological Survey Educational Leaflet No. 28, 284 p.

McLelland, J., 1992, Geological relationships of the anorthosite-mangerite-charnockite-granite (AMCG) suite and related ore deposites: New York State Geological Association Field Trip Guidebook, p. 1-46.

McLelland, J., Daly, S., and McLelland, J.M., 1996, The Grenville orogenic cycle (ca. 1350-1000 Ma): an Adirondack perspective: Tectonophysics, v. 265, p. 1-28.

McLelland, J., Chiarenzelli, J., Whitney, P. and Isachsen, Y.W., 1988, U-Pb zircon geochronology of the Adirondack Mountains and implications for their geologic evolution: Geology, v. 16, p. 920-924.

Roden-Tice, Mary, Tice, S. J., and Schofield, I.S., 2000, Evidence for differential unroofing in the Adirondack Mountains, New York State, determined by apatite fission-track thermochronology: The Journal of Geology, v. 108, p. 155-169.