# ROCKS AND PROBLEMS OF THE SOUTHEASTERN ADIRONDACKS

PHILIP R. WHITNEY
Geological Survey, New York State Museum*

## Purpose of the Trip

This trip is a roadcut tour of the easternmost fault block of Proterozoic rocks in the Southeastern Adirondacks, and has two major purposes. For beginners in Adirondack geology, the trip will provide an introduction to the major rock types of the area, as well as to many of the characteristic structural features. For the advanced student or professional, the emphasis will be on the numerous unsolved or partially solved problems presented by these extremely complex rocks.

## Introduction

This article is not a report on a finished project, because the writer has not done detailed mapping in the area. The discussion therefore consists largely of preliminary descriptive material, based on a few reconnaissance traverses by the writer and colleagues, plus more detailed examination of the rocks at the scheduled stops, and some very preliminary petrographic work. Previous work in the area includes mapping by Hills (1965) in the southern part of the Pinnacle Range, and by Berry (1961) in the portions of the Whitehall and Putnam quadrangles W and N of the trip area.

## Location

The rocks seen on this trip are exposed in roadcuts along Routes 4 and 22 in the Fort Ann and Whitehall 7 1/2 minute quadrangles. They are part of a tilted fault block of Precambrian rocks at the southeastern edge of the Adirondack Highlands, which has been called the Pinnacle Range by Hills (1965). The eastern side of this block is close to the contact with overlying Paleozoic rocks; the unconformity itself is exposed at stop 3.

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## Rock Types

1. "Gray Gneisses". This is an extremely heterogeneous group of gneisses in which the characteristic mineral assemblage is biotite-quartz-plagioclase, with widely varying amounts of K feldspar, hornblende, pyroxene, garnet and sillimanite. Retrograde chlorite is locally present. The gray gneisses form a continuum ranging from essentially granitic or charnockitic gneisses at one extreme to aluminum-rich metapelites at the other. More work is needed before these rocks can be subdivided into consistent mapping units. The rocks have characteristically strong compositional banding and are dominantly gray. Most are migmatites with varying amounts of white-to-pink quartzofeldspathic leucosome. Whether these migmatites originated by partial melting or by metamorphic differentiation, they appear to be early since the leucosomes have been involved in all recognized phases of folding. Garnet-bearing gray gneisses are referred to as kinzigites in some of the Adirondack literature.

2. Metapelites. In addition to the aluminum-rich (garnet + sillimanite bearing) gray gneisses, a still more aluminous metapelite also is common in the southeastern Adirondacks. The dominant minerals are quartz, K feldspar, sillimanite and garnet, the latter having a distinctive lavender color. Biotite and plagioclase also may be present in small amounts. Graphite commonly is present, locally in major amounts. This rock, called the "Hague Gneiss" in Alling's (1927) initial attempt at stratigraphy in the Adirondacks, is often associated with a graphite-rich unit called the "Dixon schist", which has been mined for graphite at numerous locations in the SE Adirondacks. While common in the SE Adirondacks, these aluminous, graphitic metapelites are only known in sporadic thin layers elsewhere in the Adirondack Highlands and Northwest Lowlands.

3. Marbles. Marbles in the southeastern Adirondacks comprise both calcitic and dolomitic varieties, both commonly with numerous tectonic inclusions. Calcsilicate mineral assemblages generally are consistent with granulite facies metamorphism, but some dolomitic marbles register anomalously low metamorphic temperatures. The marbles exposed at stop 7 are of this type, and may be either Precambrian marbles tectonically remobilized at relatively low temperatures, or Paleozoic dolostones interleaved with Precambrian gneisses during the Taconic event. This problem currently is under investigation, and will be discussed at stop #7. The marble layers, based on the abundance of rotated inclusions and local crosscutting of foliation in the adjacent silicate rocks, may have been

zones of substantial shear displacement, "lubricated" by the easily recrystallized carbonates. It is significant that the carbonate rocks rarely show the extreme grain size reduction frequently observed in almost all of the silicate rocks.

4. Quartzites. Like the metapelites, quartzites also are more common in the southeastern Adirondacks than elsewhere in the region. These quartzites are commonly quite pure (> 90% quartz) with minor feldspar, garnet, sillimanite, biotite, chlorite and muscovite. They occur both as thick units (30-100 m, e.g. Stop 10) and also as thinner bands interlayered or interleaved with other rocks.

5. Granitic and Charnockitic Gneisses. Quartzofeldspathic gneisses of granitic (sensu lato) composition are abundant in the supracrustal rocks throughout the Adirondack Highlands; volumetrically they are relatively less important in the SE. These rocks can be roughly divided into five categories:

   (a) Hornblende granitic gneisses: quartz - 2 feldspar - hornblende ± biotite ± clinopyroxene ± garnet gneisses; commonly pink, gray or white.

   (b) Charnockitic gneisses: quartz - 2 feldspar - hornblende - clinopyroxene - orthpyroxene ± biotite ± garnet rocks. Except for the presence of opx and a generally slightly lower quartz content, these rocks closely resemble the hornblende granitic gneisses mineralogically. The difference in some cases may result from no more than a difference in the metamorphic fluid phase, with $CO_2$-rich fluids favoring the charnockite assemblage (Newton and Hansen 1983). Outcrop-scale gradations between the two are common in the Adirondacks. Charnockites have a characteristic greenish color, probably resulting from late development of chlorite along grain boundaries and microcracks in the feldspars (Oliver and Schultz 1968).

   (c) Biotite granitic gneisses: quartz - 2 feldspar - biotite ± hornblende ± garnet gneisses. Where strongly foliated, these may grade into K-feldspar-rich gray gneisses and migmatites. Among the more massive biotite granitic gneisses, one distinctive facies contains abundant K-feldspar megacrysts, which have been interpreted elsewhere as either relict phenocrysts or as porphyroblasts.

   (d) Leucogranitic gneisses. These are quartz - K feldspar gneisses with a variety of minor accessory minerals, commonly including magnetite. These rocks often have a sugary granoblastic texture and prominent amphibolite interlayers. An albite-rich facies, possibly originating as an analcite tuff, is present locally.

Among the above, on this trip we will see a strongly deformed, leucocratic biotite granite gneiss (stop 5) and a charnockitic gneiss (stop 7).

6. <u>Anorthosite Suite</u>. Meta-anorthosite, anorthosite gneiss, gabbroic anorthosite gneiss, and associated gneisses of ferrograbbro and ferrodiorite composition are of widespread occurrence in the Adirondacks. Rocks of the anorthosite suite underlie much of the High Peaks area, and also are abundant in the Central Highlands near Speculator and Indian Lake. Smaller, sill-like bodies and lenses of meta-anorthosite occur locally throughout much of the Adirondacks. The larger bodies are marked by large negative gravity anomalies. In the SE Adirondacks, scattered outcrops of highly deformed anorthositic gneiss occur along the west side of the Pinnacle Range, and near Fort Ann (stop 1). A larger meta-anorthosite body exists just to the W on Buck Mtn. adjacent to Lake George. The presence of a gravity low centered near Whitehall, with dimensions comparable to those associated with large anorthosite bodies elsewhere, suggests the presence of anorthosite in the subsurface in this region. Anorthosites are plagioclase-rich rocks (anorthosite strictly defined contains 90% or more of plagioclase) with varying amounts of clino- and ortho-pyroxene, garnet and hornblende, as well as occasional minor quartz. Relatively undeformed meta-anorthosite often contains abundant andesine megacrysts; these are only rarely present in the highly deformed anorthositic gneisses in the trip area.

7. <u>Olivine Metagabbros</u>. These rocks occur in numerous bodies throughout the Eastern and Central Adirondack Highlands, ranging from a meter or two up to several kilometers in largest dimension. They commonly show relict igneous (cumulate or diabasic) textures in the interiors of the larger bodies. Primary igneous minerals are plagioclase, olivine and intercumulus clinopyroxene. Under hand lens or microscope, they exhibit "corona" structures of metamorphic minerals. These multilayer reaction rims are of two general types. One consists of layers of pyroxene and garnet between olivine and plagioclase; the other of layers of biotite, hornblende and garnet betweeen ilmenite and plagioclase (Whitney and McLelland 1973, 1983). The latter type appears as prominent dark spots on both weathered and broken surfaces. These rocks, many of which are actually metatroctolites, appear quite mafic at first

glance, but normally contain 50-80% plagioclase. The plagioclase is, however, dark with a characteristic gray-green color resulting from fine-grained (1-5 micron) spinel inclusions. These inclusions form within the plagioclase during metamorphism according to the partial reaction.

$$\text{Plagioclase} + Mg^{2+} + Fe^{2+} + Na^{+} = \text{Spinel} + \text{More Sodic Plagioclase} + Ca^{2+}.$$

This partial reaction is a part of the complex multivariate reactions responsible for the coronas (Whitney and McLelland 1973, 1983). These rocks are best displayed at stop 8, but finer grained, partly recrystallized equivalents form the large lenses at stops 4 and 5. Photomicrographs of thin sections of these rocks will be passed around during the trip.

8. <u>Mafic granulites and amphibolites</u>. This diverse group of rocks is composed largely of plagioclase and mafic minerals, the latter including varying proportions of hornblende, biotite, clinopyroxene, orthopyroxene and garnet. Lesser amounts of quartz and K feldspar are locally present. The relatively competent behavior of these rocks, especially the quartz-free varieties, has resulted in their common presence as boudins and lenses as well as layers. Note the contrasting mineralogy and texture of different mafic bodies even within a single outcrop (stops 2, 4, 7). These may represent different ages of mafic intrusives. Relict igneous textures are commonly preserved in the larger bodies. Some of these mafic rocks are visibly gradational into olivine metagabbros. Those amphibolites and mafic granulites not clearly associated with the olivine metagabbros may represent mafic volcanics in the supracrustal sequence, pre-metamorphic dikes or sills, or mafic members of the anorthosite suite.

## <u>Ductile Deformation</u>

The rocks of the Pinnacle Range, like many in the southeastern Adirondacks, show abundant evidence of severe ductile deformation. At least three generations of folds that fold an earlier foliation have been reported in this part of the Adirondacks (McLelland and Isachsen 1980). These comprise isoclinal, overturned to recumbent folds with E to SE trending axes (F2) including large, regional nappelike structures. These are folded by more open, generally upright folds (F3) with axes parallel or subparallel to F2. A later generation of open, upright folds (F5) has N to NE-trending axes. Carefully observe evidence for folding on this trip, and determine whether it can be fitted into this general conceptual framework.

At least the earliest folds have been overprinted by intense ductile shearing that reflects a period of regional rotational strain. This is recorded in the rocks by the development of enhanced foliation, grain size reduction (mylonite zones are abundant in the SE Adirondacks) and widespread occurrence of stretching lineations. These lineations are most commonly expressed as quartz ribbons (e.g. at stop 5), but lineations defined by streaks of mafic minerals or by oriented elongate minerals (e.g. sillimanite at stop 6) also are common. The lineations generally are parallel to F2 fold axes, possibly as a result of rotation of the folds into their present positions during the rotational strain event (McLelland 1984). A major thrust fault mapped by Berry (1961) in the Putnam quadrangle just NW of the trip area, probably is associated with this event. Another major thrust (or the same one downfaulted by later normal faults) has been mapped by Turner (1984 pers. comm.) in the Silver Bay quadrangle just west of Lake George. In both places charnockitic gneisses have been thrust over metasedimentary rocks similar to those seen on this trip. Strain indicators such as rotated feldspar porphyroclasts, suggest a SE-over-NW sense of rotation. No unambiguous indicators have been found to date in the immediate trip area, but elsewhere in the SE Adirondacks the sense is clear. This major strain event may have coincided in time with the development of the Carthage-Colton mylonite zone in the NW Adirondacks, and both may be associated with a doubling of the continental crust by the thrusting of one (or more) thick slabs of crust over the terrain now exposed in the Central Adirondack Highlands (Whitney 1983). There is also evidence of a later period of shearing at much lower temperatures, possibly coinciding with Taconic deformation which is recorded in the Paleozoic rocks just to the East. This later movement, which may have remobilized pre-existing shear zones, will be discussed at stops 4, 7 and 10.

## Metamorphism

Very preliminary observations point to the superimposition of at least three periods of metamorphism in the southeastern Adirondacks. The first is an early, shallow contact metamorphism (Bohlen, et al. 1985) associated with the intrusion of the anorthosite suite. This is represented by the calcsilicates adjacent to the mafic gneiss horizon at stop #7. The inferred original assemblage grossular-diopside-wollastonite in this rock is the same as that which occurs in much larger deposits close to the contacts of the main anorthosite massif in the northeastern Adirondacks. The second metamorphic event was the regional hornblende granulite facies metamorphism which has affected the entire Adirondack region.

Temperatures and pressures in this event ranged from about 650° and 6.5 to 7 kb in the northwest lowlands to close to 800° and 7.5 to 8 kb in the Central Highlands (Bohlen, et al. 1985). Few specific data are available for the SE Adirondacks, but the general pattern of pressures and temperatures in the Adirondacks as a whole as obtained by Bohlen and co-workers is consistent with P and T in the SE Adirondacks somewhat lower than in the Central Highlands but still well within granulite facies limits. Recent work by Glassley (pers. comm. 1985, see discussion under Stop 5) indicates that metamorphic temperature here may have been as high as $810 \pm 40^{\circ}$ C at pressures of $7.5 \pm 0.5$ kb. This is consistent with the mineral assemblages found in the anorthositic gneisses (stop #1), charnockitic gneisses (stop #7), olivine metagabbros (stops #5 and #8) and metapelites (stops #6 and #9). A third, retrograde metamorphism has affected some, but not all, of the rocks in this area. Green gneisses interlayered with the quartzite at stop 10 locally contain chlorite, epidote, and muscovite. Quartzofeldspathic mylonites on West Mountain contain abundant, well-crystallized chlorite parallel to the foliation. Ultramafic lenses in the mafic gneisses at stop 4 contain a relatively low temperature mineral assemblage (chlorite-actinolite-serpentine-talc) also suggesting retrograde metamorphism. Other rocks, however, show no clear evidence of retrogression, aside from local development of chlorite. If the retrograde effects are not attributable to hydrothermal activity near late, brittle faulting (an hypothesis that needs to be tested by detailed mapping) they may reflect a second period of movement at lower temperatures, in the high strain zones. This movement may have been localized in the quartz- and carbonate-rich rocks. One curious fact which supports the latter interpretation is the presence of dolomitic marbles at stop 7 which contain angular fragments, some of them polycrystalline, of quartz in unreacted contact with dolomite. This could be explained by a late strain event localized in the marble, at relatively low temperature, during which fragments of quartz-rich rock were entrained in the rapidly deforming marble. Elsewhere in the area where less marble was available strain associated with this late, possibly Taconic event may have been localized instead in quartz-rich units, with simultaneous formation of retrograde chlorite parallel or subparallel to the pre-existing foliation.

ROAD LOG

| Miles from Start | |
|---|---|
| 0 | Exit 20 on Northway. Exit and turn L (North) on Route 9. |
| 0.6 | Jct. of 9 and 149. Take R (East) on 149. |
| 10.6 | Outcrops of Cambro-Ordovician Beekmantown carbonates. |
| 12.4 | Jct. of 149 and 4 in Fort Ann Village. Take L (North) on 4. As you leave the village, notice the range of hills straight ahead. The eastern slope is a dip slope on a fault block of Precambrian rocks (known as the Pinnacle Range) bounded on the West by the Welch Hollow Fault (Hills, 1965). The Paleozoic rocks previously noted are on the downthrown (W) side. This is the easternmost of several such fault blocks, all showing a gentle, regional eastward dip of 10-15° on the Precambrian rocks and overlying Paleozoics. The eastern slope of this block is a dip surface close to or at the unconformity, which will be seen in outcrop at Stop 3. Is the tilt of this surface a result of a rotation of the fault blocks, or a reflection of the Tertiary-Recent doming of the Adirondacks (Isachsen 1975)? |
| 13.2 | Stop #1. Turn into parking area on R (SE) side of road and cautiously cross road to outcrops on opposite side. A plaque on the face of the outcrop commemorates the Battle of Fort Ann (July 8, 1777). The rocks here are intensely foliated and fractured representatives of the anorthosite suite. Although the characteristic andesine megacrysts found in anorthosites elsewhere in the Adirondacks are absent here, they can be found sporadically in other outcrops along the West side of the Pinnacle Range. Minerals in the anorthosite at this stop consists of recrystallized and sericitized plagioclase, hornblende, clinopyroxene and garnet. Large garnets (please do not sample) are surrounded by leucocratic haloes which locally obliterate the foliation, which suggests that the garnet grew at the expanse of mafic minerals which define the foliation, and that it postdates at least the first deformation. |

At the eastern end of the outcrop is a large mass of gabbroic rocks (plagioclase-clinopyroxene-garnet-ilmenite) which displays little or no foliation, and around which the foliation in the anorthositic gneiss is deflected. Also present in the outcrop are a breccia zone and numerous closely spaced fractures with a general northeasterly trend; a major high angle fault may exist roughly parallel to the road.

13.4 Outcrops in woods to L of road are coarse marble with numerous detached and rotated blocks of amphibolite and gneiss around which the foliation of the marble is wrapped.

13.9 Flat Rock Rd. on R.

14.0 Stop #2. Roadcut on R (SE) side of road. Strongly foliated quartz- 2 feldspar-pyroxene-hornblende-garnet gneisses, ± biotite. Leucocratic bands contain numerous pyroxene megacrysts, both clino and ortho, the latter showing characteristic rusty weathering color. These rocks are close to the charnockitic end of the migmatitic gray gneiss spectrum. Note the presence of at least two types of amphibolite. One is relatively coarse grained, boudinaged and injected with leucocratic veinlets. The foliation within the boudins is locally truncated by that in the enclosing gneisses. The other amphibolite is dark, fine-grained, biotite-rich, and lacks the leucocratic veining and prominent foliation of the coarser amphibolite. The fine-grained, massive amphibolite forms a megaboudin or recumbent fold (which is it?) near the center of the cut. Do these amphibolites represent one, two, or more generations of mafic intrusives?

Numerous complex minor folds are present within the gneisses; also observe the warping of the foliation by larger, open folds. Measure and record lineations and attempt to relate them to the fold axes of both types. Is more than one lineation present in these rocks?

Thin, folded dark bands near the N end of the cut are a peculiar, fine grained carbonate-rich rock with poorly oriented biotite.

14.2 Stop #3. Turn off main road and park on dead end road which leads downhill toward the Champlain Canal.

The outcrop on the R side of Rte. 4 just beyond the intersection exposes the unconformity between Proterozoic and Paleozoic rocks (missing: roughly

500 million years of the geologic record, and 20-25 km of Proterozoic rock). The Paleozoic rocks here are coarse arkosic sandstones and quartz-pebble conglomerates of the Cambrian Potsdam Formation, locally with carbonate cement. Measure the strike and dip of the unconformity surface, and compare this with the 10-15$^{O}$ easterly slope of the fault block as observed driving N out of Fort Ann.

Observe the lack of evidence for deep weathering of the Precambrian rocks beneath the contact, and the absence of a paleosol layer. This suggests deep erosion and scouring (by waves? ice?) shortly before deposition of the Potsdam.

Walk a few meters along the S face of the outcrop, towards the canal. Note the complex fracturing of the gneisses, and the filling of the fractures with dark, fine-grained dolomitic rock. The significance of this feature is unclear, and it will be discussed in more detail on the trip. Note the deeply weathered zone where these rocks are exposed at the surface.

After examining the unconformity, cautiously cross the road to the cut in complexly deformed gray gneisses on the opposite side. Measure several lineations here and compare with what you saw at Stop #2. Note not only differences in orientation, but also in the nature of the lineation.

14.4 Outcrops at edge of woods on R are fine-grained white arkosic Potsdam sandstones.

15.7 Outcrops on L are extensively fractured granitic gneisses close to a NS brittle fault.

15.8 Road crosses small pond.

15.9 Stop #4. Pull off on R side as close to the guard-rail as possible. The rocks immediately to the R are strongly foliated biotite-quartz-2 feldspar-garnet gneisses. This version of the gray gneiss is commonly referred to as "kinzigite". Present in this outcrop are thin quartzo-feldspathic pegmatites in various stages of tectonic disintegration and reorientation. The large K-feldspars survive the tearing-apart process better than quartz, and remain visible as large porphyroclasts, either in strings or as isolated individuals. Be alert for evidence of tectonic rotation of these feldspars, which can be a useful indicator of the sense of shear.

Also observe the variable shape and appearance of the garnets: some are rounded and others elliptical; some are nearly inclusion-free while others are "spongy". Careful study of this variation might, if combined with probe analysis of garnet compositions, yield information on the interrelation of metamorphism and deformation of these rocks.

From here, walk northward along the road past a gap in the outcrop, then enter the S end of a long cut. The first rocks are strongly foliated and lineated gray gneisses with lenses and pods of calcsilicates. Roughly 30 m. northward and uphill, these overlie amphibolitic rocks, which comprise most of the remainder of the cut. The bulk of these rocks are strongly foliated garnet amphibolites and mafic gneisses. Numerous lenses and pods of calcsilicates, garnet hornblendite, and ultramafic rocks are present. (Students: the coarse grained ultramafic pods are a fine opportunity to test your mineral recognition skills). About 90 m. northward along the cut a large pod of calcsilicate granulite (grossular-diopside-quartz) is visible in the mafic gneisses on the opposite side of the road. Near the N end of the cut, still on the R (E) side, two large pods or megaboudins of massive, relatively fine grained, garnet-rich metagabbro are surrounded by strongly foliated amphibolites. The transition between foliated and unfoliated rock is very abrupt. Patches of tourmaline- bearing pegmatite are present at the broken(?) end of one of the megaboudins.

16.3 Jct. of Rtes. 4 and 22; Rte. 22S crosses canal just E of here and goes past the State Prison at Comstock; Continue N on combined 22N and 4.

16.7 Stop #5. S end of next major road cut. Pull over close to guardrail. Cross the road and walk N along the W side. At the S end are more gray gneisses, here with a distinct reddish tinge caused by an abundance of garnet. The gray gneisses here are nearly devoid of K feldspar. They become more strongly foliated toward the contact with overlying pink granitic gneisses. The contact itself is extremely sharp (but note the late spherical, undeformed garnets, some of which are situated directly on the contact). The pink granitic gneisses, which contain biotite, chlorite and garnet, are strongly foliated, approaching mylonitic texture in places, and display prominent quartz ribbon lineation. The less deformed parts of these gneisses contain K-feldspar megacrysts (phenocrysts? porphyroblasts?) in various stages of deformation and recrystallization.

Continuing N, pass a large gabbro pod, broken at the base and injected with granitic material, in part pegmatitic. Look S across the road; the similarly shaped body of gabbroic rock in the pink gneisses is probably the same pod. Then re-enter gray gneisses, here with somewhat more K feldspar, which is concentrated in the leucosomes. Notice the prominent discontinuity in the foliation which is visible for some distance along the cut. Even though little textural evidence (e.g. grain size reduction) for shear displacement exists along the discontinuity, other explanations for this feature are even more difficult to defend. Toward the N end of the cut is another body of gabbroic rock, which also appears to continue on the opposite side of the road. These mafic rocks, which intrude both the gray and pink gneisses, are generally fine grained and massive with a distinct relict igneous texture. Much garnet is present in the form of indistinct coronas. These rocks are the equivalent of the coronitic olivine metagabbros, a more typical example of which will be seen at Stop #8. These gabbroic bodies (several are present here) are lensoid to sigmoidal in cross section but apparently elongated in a roughly N-S direction. Their crudely sigmoidal shape yields opposite estimates of shear sense depending on whether they are pre- or syn-tectonic in origin.

Cross the road to the E side, and note the prominent minor folds in the migmatitic gray gneisses near the N end of the cut. Also note the open, upright folds, which warp the foliation of these rocks, then compare the orientation of these with the recumbent, isoclinal minor folds and with the lineation. Then walk S along the E side and return to the starting point. The petrology of the rocks at this outcrop has been studied in detail by William Glassley and students at Middlebury College. Dr. Glassley (pers. comm. 1985) reports the following:

"Garnet-clinopyroxene and garnet- biotite temperatures were computed from microprobe data. Average temperatures from eight samples ranged from 770 C to 850 C, with a strong mode at 810 C. Pressures, calculated from the assemblages garnet-plagioclase-clinopyroxene-quartz and garnet-plagioclase-orthopyroxene-quartz using the method of Newton and Haselton, averaged 7.5 kb + .5 kb.

Two unusual assemblages can be found along the contact between the two gneiss units. Within 50 cm of the contact occur 1-3 cm long augen which contain the assemblages clinopyroxene-garnet-rutile and biotite-sillimanite-hercynite-kspar-garnet. The former assemblage is a typical eclogite assemblage. Garnets from these eclogitic lenses are similar to those reported from basal gneiss eclogites in Western Norway. The clinopyroxenes, however, are poor in jadeite component, with only 5% of this component present. The sillimanite- spinel-bearing assemblage is clearly consumed and biotite and sillimanite are being generated. The significance of this assemblage for P-T conditions remains obscure, in that we do not yet have compositional data for all of the minerals in the assemblages nor do we have water fugacity values that would allow calculation of the equilibrium conditions."

17.0 Stop #6. (Optional) Pull onto R shoulder and briefly examine the outcrops.

The rock here is a pale gray biotite-quartz-2 feldspar-garnet-sillimanite-graphite paragneiss with thin layers and lenses of calcsilicates. Compared to the previously examined "kinzigites", this rock is finer grained, more aluminous, and has distinctive lavender garnets. The abundant white layers look like leucosomes in a migmatite, but they contain significant amounts of sillimanite and are thus probably more aluminous than minimum-melt granite. Note the flattening of the quartz in these layers. Look carefully for lineations defined by sillimanite and quartz.

The protolith of these rocks must have had a significant argillaceous component, as indicated by the presence of both garnet and sillimanite. The lavendar-colored garnets are typical of many Adirondack metapelites, a more extreme example of which will be seen at Stop #9.

17.4 South end of next set of roadcuts.

17.6 Stop #7. North end of roadcut. Pull off road on R and cautiously cross to outcrops at N end of cut on west side; walk S along outcrop. Probably the best way to appreciate these rocks is to move rather rapidly to the S end, scanning the rocks on both sides as you go for major lithologic changes, and then return northward looking at the rocks in detail.

The sequence of rock types going S on the W side is as follows:

A Interlayered (or interleaved?) marbles and paragneisses

B Garnetiferous quartzofeldspathic gneisses intruded by unmetamorphosed mafic dikes

- Gap -

C Charnockitic gneiss

D Thin marble with numerous exotic blocks

E Mafic gneiss

F Calcsilicates and marble

G Interlayered (interleaved?) Paragneiss, charnockite, marble and calcsilicate with amphibolite boudins. An unmetamorphosed mafic dike forms the face of much of this section of the cut.

Details (walking N)

G. Note the wide variety of rock types, including charnockitic gneisses, amphibolites, marble (carefully examine the marble/amphibolite contact), lineated sillimanite bearing metapelites, and calcsilicates. Note the local slickensides along foliation surfaces as well as on vertical fractures. Has there been late movement parallel to the foliation?

F. This thin calcareous unit consists of marble near the base and a complex calcsilicate zone adjacent to the contact with the overlying mafic gneiss. Major minerals in the calcsilicate zone are grossular, diopside, quartz, calcite and K feldspar, with lesser amounts of plagioclase and chlorite as well as several minor phases yet to be identified. Some evidence indicates that wollastonite was initially present but none has yet been positively identified. The calcsilicates probably originated by contact metamorphism at the time of intrusion of the igneous precursor of the overlying mafic gneiss. This contact is irregular and appears to have been folded. The thickness of the calcsilicate layer varies widely, both in this outcrop and on the opposite side of the road.

E. This mafic gneiss contains plagioclase, clinopyroxene, hornblende, biotite, garnet and minor quartz and K feldspar. The composition is probably similar to a monzodiorite. Similar rocks elsewhere in the Adirondacks have been called "jotunite" and are associated with the anorthosite suite of rocks. The rock is well foliated throughout, but becomes more so towards the sharp upper contact. On the opposite (E) side of the road, a detached sliver of the mafic gneiss is found in the overlying marble, and contains carbonate-filled fractures.

D. The next unit upward is a thin (generally $<$ 1 m) band of marble with numerous rotated fragments of other rocks. No calcsilicates are developed near the sharp contact with the mafic gneiss beneath, and the foliation both in the mafic gneiss and in the overlying charnockitic gneiss is strongly developed and parallel to the marble band. In the outcrop on the opposite side of the road, foliation in the charnockite is locally truncated by the marble. This marble is a good example of a possible detachment zone, with relative movement of uncertain direction and magnitude, between the mafic gneiss and the charnockite. The absence of a contact metamorphic zone of calcsilicates at the upper contact of the mafic gneiss may result from its having sheared off during displacement. Alternatively, this marble may be a tectonically emplaced younger rock (see discussion under unit "A", below). Considerable displacement may have taken place along most or all of the marble layers in this outcrop.

C. Above the marble is a thick unit of charnockitic gneiss. This rock, close to granite in composition, consists of quartz, microcline, plagioclase, hornblende, garnet, clinopyroxene and orthopyroxene. The orthopyroxene is extensively chloritized, which is characteristic of many Adirondack charnockites. The typical green color is well developed toward the center of the unit. Near the northern end of the outcrop both green and white varieties are present, with diffuse color boundaries which crosscut foliation.

Immediately beyond the charnockite unit is a gap in the outcrop, possibly indicating the presence of a fault or thick marble layer.

B. Following the gap is a short section of well foliated, garnetiferous quartzofeldspathic gneisses similar to the charnockite but with green color less well developed. Note the unmetamorphosed mafic dike just back from the face of the outcrop, and roughly parallel to it. A few meters farther N is a complex vertical fault with a zone of carbonate-cemented breccia.

A. The last section of the outcrop, roughly 100 m long, consists of interlayered (interleaved?) paragneiss and marble, with minor amphibolite and thin calcsilicate bands in the paragneiss. Contact surfaces are frequently slickensided and/or coated with graphite. At least two types of marble are present; one is dark, relatively fine grained, brown-weathering dolomite marble, which has a slightly fetid odor when struck with a hammer; the other is coarser grained, has a somewhat lighter color and considerable calcite as well as dolomite. Both marbles contain abundant rounded to angular silicate rock and mineral fragments, including quartz, feldspar and serpentine, and larger rotated blocks of various rock types including amphibolites, serpentinite, paragneiss and calcsilicate granulite. Quartz, dolomite and serpentine coexist in these rocks with no evidence of mutual reaction, indicating that the rock as presently constituted has never undergone high temperature metamorphism. Temperatures must have been sufficiently low to prevent reaction of quartz with either dolomite or serpentine. It is probable that these marble zones, as well as those of units G, F and D, are tectonic breccias formed along thrust faults or low-angle normal faults under conditions that permitted the carbonates to recrystallize and deform in ductile fashion, while silicates behaved in a more brittle manner. The interleaved paragneisses, by contrast, are similar to the gray gneisses seen in previous stops, have a high-T metamorphic assemblage and show little evidence of retrogression.

The age of the tectonic interleaving of the gneisses and marbles may be either late Proterozoic or Taconic. The marbles themselves may be Proterozoic with retrograde serpentine after forsterite and entrained fragments of quartz and feldspar, or they may be Paleozoic carbonates with entrained fragments of ultramafic rocks. This question is now under study and will be discussed on the outcrop.

17.8 Whitehall town line

19.3 Stop #8 (Optional). Park as far off the road to the R as possible. Cross with great care to outcrops on the L, and examine them briefly. These are typical Adirondack olivine metagabbros, with well preserved igneous textures as well as coronitic reaction rims around olivine and ilmenite (see introductory section). The interiors of the olivine coronas here have been retrograded to chlorite and carbonate; otherwise the rocks are quite fresh.

20.7 Flat outcrops on slopes to the L are a dipslope on foliation in highly strained gneisses. A short distance N, on West Mtn., a mylonite zone close to 300 m thick is exposed. The hills across the valley to the R, and on Skene Mtn. straight ahead, are Cambro- Ordovician carbonates of the Whitehall Formation, resting on Potsdam sandstone.

22.6 Entering Village of Whitehall

23.2 Intersection of Rtes. 4 and 22; 4 goes E to Rutland, VT; Continue N on 22.

24.0 Stop #9. Pull off road to R close to smaller outcrop, and cross to larger cut on L. The rocks here are typical metapelites, consisting of quartz, K feldspar, sillimanite, lavender garnet and varying amounts of biotite and graphite.

24.7 Entering series of cuts in highly fractured metasedimentary rocks.

25.2 Stop #10. Entrance to abandoned quarry and Washington County Highway Dept. Garage. This is posted private property; if following this road log on your own, ask permission at large brick farmhouse 0.2 miles further along road on R. Be extremely careful climbing and hammering here - there is much loose rock and the quartzite is very splintery when hammered.

This thick unit of quartzite is interlayered with lesser amounts of a greenish rock which forms bands and streaks from a fraction of a millimeter up to several tens of centimeters thick, with knife-sharp contacts against the quartzite.

The quartzite, which is visibly foliated in hand specimen, comprises over 95% of strongly flattened quartz; small, flattened and elongated grains of K feldspar and sericitized plagioclase, lensoid garnets, green biotite and chlorite. The inter-layered green rock ranges from plagioclase-quartz-garnet- biotite-hypersthene gneiss to a retrograded epidote-chlorite-quartz-plagioclase rock with some muscovite and at least two minerals yet to be identified. Some well crystallized chlorite is present as flakes parallel to the foliation, but chlorite also occurs locally as an alteration product of garnet. Distribution of the retrograde assemblage within the outcrop has not been determined. If it is related to fracture patterns, it may be low temperature alteration along the E-W brittle fault which parallels the road. If not, it may be evidence for localized retrogression associated with renewed, layer- parallel shearing during the latest Proterozoic or during the Taconic event. Supporting the latter hypothesis are slickensides on foliation surfaces at an acute angle to the lineation.

All rocks at this site show extreme foliation and a well developed lineation, here close to E-W, with a 0-20$^{\circ}$ E plunge. Numerous minor folds are present. These are of two distinct types, both of which are recumbent with axes parallel to the lineation. One type consists of intrafolial, highly asymmetric, isoclinal folds defined by thin micaceous layers in the quartzite. Among folds of this type is an apparent sheath fold strongly flattened in the plane of foliation. The other type is not quite isoclinal, more symmetric, and visibly folds the foliation in the quartzite. The minor folds and petrofabrics at this outcrop have been described by Granath and Barstow (1980), who attribute the deformation primarily to a severe flattening strain.

Leave quarry and proceed N on 22N.

25.6 Crossing South Bay on Lake Champlain. The rocks underlying the valley to the North are Paleozoic strata downdropped along a major normal fault which here forms the western side of the Pinnacle Range.

Toward the south, this fault intersects the Welch Hollow fault at an oblique angle. The fault follows the shore of South Bay south of the bridge, then strikes inland and follows the line of cliffs visible to the north. Estimated vertical displacement on this fault based on offset of Paleozoic cover rocks is in the vicinity of 300 m. West of the bay, outcrops of gently E-dipping, highly deformed Precambrian rocks resume.

End of trip.

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