PRECAMBRIAN GEOLOGY OF THE WHITEHALL AREA, SOUTHEASTERN ADIRONDACKS

by
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INTRODUCTION

At the easternmost edge of the Adirondack Highlands, between Fort Ann and Whitehall (Fort Ann and Whitehall 7.5' USGS sheets) is a tilted (?) fault block of severely deformed, granulite facies metamorphic rocks of Middle Proterozoic age, called the Pinnacle Range by Hills (1965). The gently sloping eastern side of this block is nearly a dip slope in many locations, and the rocks throughout are not far below the Proterozoic - Paleozoic unconformity, which is exposed at Stop 2. The northern end of the block is a zone of intense ductile shear at least several hundred meters thick that we will refer to as the Whitehall Deformation Zone (WDZ).

Only parts of the area have been mapped in detail. The southern half was mapped by Hills (1965), and the northern third by Stracher (1986, 1989). The map of Fisher (1985), at a scale of 1:48,000 is based on Hills' map and reconaissance mapping by the New York State Geological Survey in 1982 and 1983. A somewhat different picture is presented by the 1:250,000 map of Thompson et al. (1990). Both the Fisher and Thompson maps cover large areas of which the Pinnacle Range is only a small portion; clearly more work is needed to reconcile the differences. Figure 1 shows the general geology of the Pinnacle Range; Figure 2, from Stracher (1992), shows the geology of the northernmost portion, including the WDZ.

The trip will focus on the extraordinary deformational features of the WDZ, as well as on evidence for a retrograde metamorphic event of probable Taconic age. Stop 1 will be a walking traverse in the most strongly deformed part of the WDZ. Stops 2 through 5 will examine road cuts along NY Route 4, from south to north.

LITHOLOGY

Metasedimentary rocks. Metasedimentary rocks in the southeastern Adirondacks consist of large volumes of metapelitic rocks, now metamorphosed to gneisses ranging from migmatitic (sillimanite)-garnet-biotite-quartz-plagioclase ("Kinzigite") to (graphite)-sillimanite-garnet-quartz-K feldspar ("Khondalite"). These are interlayered with calcite marbles (some with late dolomitization) and calcsilicate rocks, and quartzite. This suite of metasedimentary rocks differs from that found farther north and west in the Adirondack Highlands in having a much greater proportion of metapelites relative to carbonates and quartzites.

Metaigneous rocks. Nearly all the varieties of metaigneous rocks found elsewhere in the Highlands are also present here. Olivine metagabbros (Stops 1, 3, and 4) are abundant both as small lenses and in larger plutons. These gabbros, which are lithologically and geochemically similar to those found throughout the Highlands (Stracher, in prep.), are the only rocks that retain primary igneous textures; they appear to have behaved as rigid units in the region-wide ductile deformation. Small amounts of metanorthosite are also present, notably at Battle Hill just north of Fort Ann. Gabbroic anorthosite gneiss is present at Stop 5, as is a mafic gneiss similar to the jotunites commonly associated with anorthosite suites. Charnockite (Stop 5) and megacrystic biotite granite (Stop 4) are the most common felsic lithologies. The anorthosite, jotunite, and charnockites are probably part of the ca 1160-1130 Ma Anorthosite-Mangerite-Charnockite-Granite (AMCG) suite. Metatonalites, found only in the southern and southeastern Highlands, are also present here and in the area north and west of the Pinnacle Range mapped by Berry (1960). They are significant in that they have been dated at 1330-1307 Ma (McLelland and Chiarenzelli, 1990), substantially older than the AMCG suite.

Unmetamorphosed dikes. Diabase dikes, probably latest Proterozoic to early Cambrian, are common throught the eastern Adirondack Highlands (Isachsen et al 1988; Coish and Sinton 1991). The follow the dominant NNE trend of brittle faults that probably originated at the time of the opening of the Iapetus Ocean.

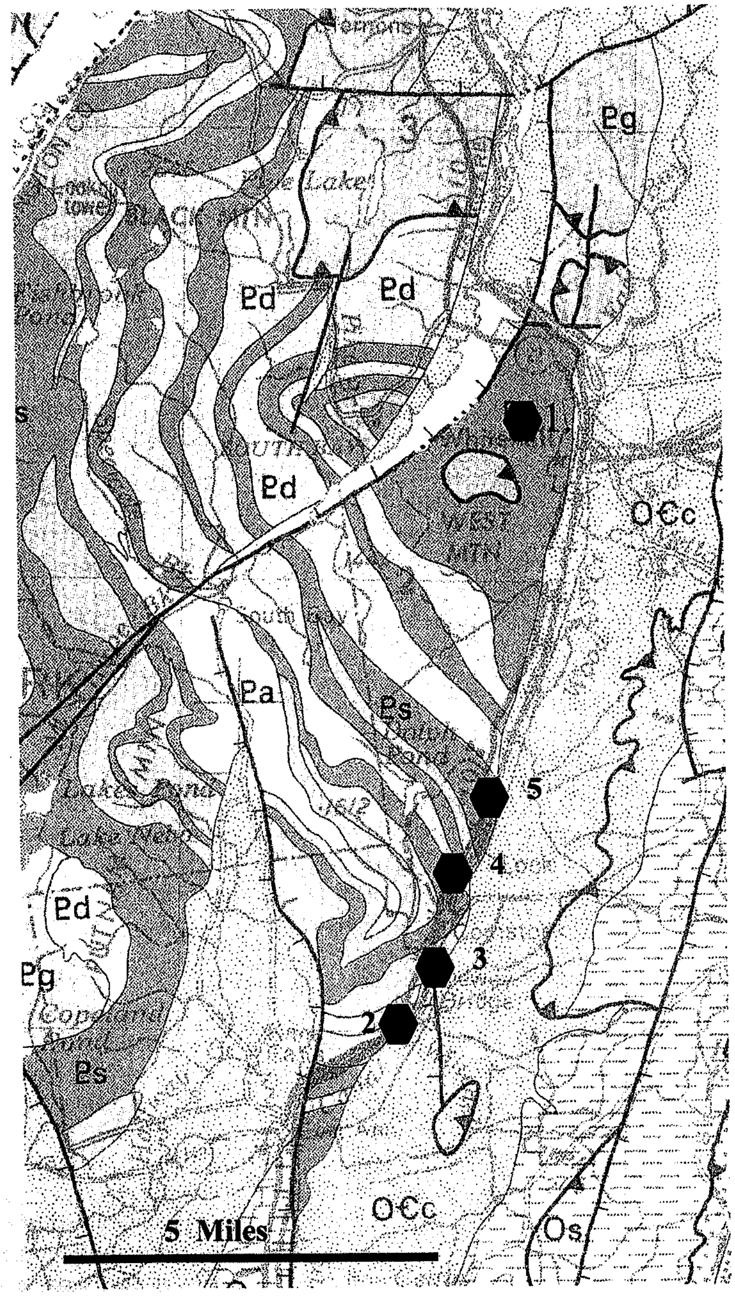

Figure 1. General geology of the pinnacle Range, from Thompson et al. (1990), showing field trip stops. Pa: metanorthosite and related rocks, Pd: Metagabbro and metadiorite; Pg: felsic gneisses; Ps: metasediments. Numbered spots are field trip stops.

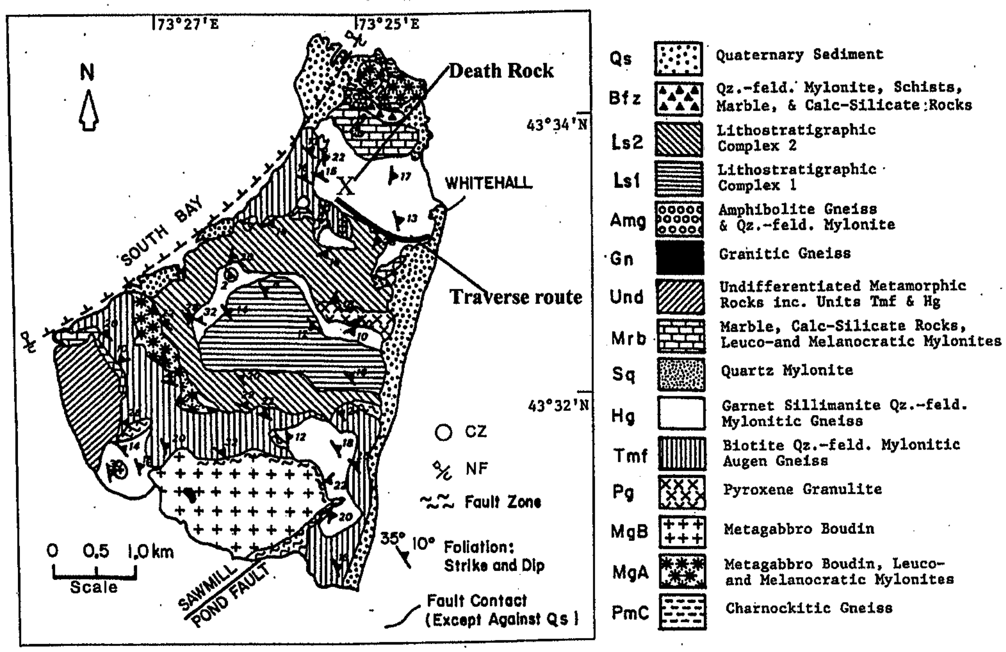

Figure 2. Geologic map of the West Mountain Area, after Stracher (1992), showing route of Stop 1 traverse.

METAMORPHISM

Traces of four separate metamorphic events are present in the Pinnacle Range and in the area immediately to the north and west. The earliest, of probable Elzevirian (pre-1180 Ma) age, has been documented by McLelland et al. (1988) at Dresden Station in the Putnam 7.5' quadrangle, where deformed and metamorphosed metapelites have been intruded and crosscut by olivine metagabbro dated at 1144 +/- 7 Ma (McLelland et al. 1996). The second event is indicated by contact metamorphosed marbles and calcsilicates (Stop 5) adjacent to meta-intrusive rocks that are probably part of the AMCG suite. The third event is the Ottawan granulite facies metamorphism, variously estimated at 1090-1030 Ma (McLelland et al. 1996) and 1050-1000 Ma (Florence et al, 1995). Accompanied by severe deformation, it has overprinted the prior two events and largely obliterated their effects except at scattered locations. The pressure-temperature regime has not been studied in detail; except for two undergraduate theses there is no published data that we are aware of. Zeckhausen (1982), using various geobarometers and geothermometers estimated peak metamorphic conditions of 810 +/- 40 °C and 9 +/- 1 kbar. The pressure estimate was subsequently reduced to 7.5 +/- 0.5 kbar by Glassley (pers. comm., 1985). Clechenko (1999), using different reactions and calibrations, estimated 710 +/- 50 °C and 6.5 +/- 1.5 kbar. The fourth "metamorphism", locally overprinted the granulite facies rocks with low-T (<400 °C) assemblages. It was probably a far-field effect of the Taconic Orogeny (Whitney and Davin , 1987).

STRUCTURE

The rocks seen on this trip are on the upper limb of a large, reclined isoclinal fold that has a southeast-plunging hinge and an east-dipping axial plane (McLelland 1996; Thompson et al. 1990). All show evidence of intense ductile deformation, locally mylonitic, that has produced strongly foliated "straight" gneisses and a pronounced stretching lineation defined variously by quartz blades and ribbons, elongate trains of mafic minerals including garnet, and oriented sillimanite or hornblende. Only the interiors of olivine metagabbro lenses and large tonalite bodies have escaped the pervasive shearing. The deformation increases in intensity northward, becoming pervasively mylonitic in the WDZ on West Mountain near Whitehall (Stop 1). The WDZ is characterized by pervasive structural discontinuities between internally deformed blocks of granulite facies rocks whose fabrics exhibit high ductile strain and extreme grain-size reduction. The discontinuities form anastomosing arrays resulting from intense stuctural slicing (Stracher, 1992). Kinematic indicators in the sheared rocks throughout the area show a statistical east-over-west sense of shear. Of particular interest in this regard are the large metagabbro lenses at Stop 4, which appear to be large-scale kinematic indicators. Possible Taconic structural effects include slight updip movement along foliation planes marked by low-temperature slickensides (Stop 5) and possible hydrofracturing of rocks near the unconformity surface (Stop 2) followed by filling of the fractures with dolomite-cemented clastic debris (Whitney and Davin, 1987).

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ROAD LOG

Miles	Increment	
0.0	0.0	Assemble at the parking lot at McDonalds in Whitehall. Carpool if possible; parking is difficult at Stop 1.
0.65	0.65	Traffic signal at intersection of Rtes. 4 and 22; in Whitehall; continue on 22 (Broadway).
0.95	1.2	Turn L on School St.
1.2	0.25	**Stop 1.** Park well off the road wherever space permits. A well-worn trail leaves this dead end road on the R. We will follow this trail W, updip along a dip slope about 0.8 miles to a point just S of Death Rock (Fig. 2). Numerous outcrops in and near the trail are garnet-sillimanite-K feldspar-quartz metapelites, locally containg calcsilicates, quartzites, and graphitic schists, the "Hague Gneiss" of Alling (1917). Elsewhere, these rocks are host to graphite deposits (Alling's "Dixon Schist") that were worked commercially in the nineteenth century. Foliation and lineation are exceptionally well-developed and the rocks exhibit severe grain-size reduction with locally mylonitic textures. The ESE-plunging lineation seen here is typical of much of the southeastern Highlands. Be alert for kinematic indicators. Approaching the height of land S of Death rock, the trail passes outcrops of biotite gneiss with K-feldspar megarcrysts, some of which appear to be rotated porphyroclasts. Well exposed within the biotite gneiss to the N of the trail is a large lens of olivine metagabbro. Foliation in the gneiss wraps around the gabbro lens. Later, at stop 4 we will see more such gabbro lenses that provide (given certain assumptions) clear evidence of shear sense. Further north, at Dresden Station in the Putnam 7.5' Quadrangle, similar metapelites with less extreme deformation are crosscut by 1144 +/- 7 Ma olivine metagabbro, a key piece of evidence for early (Elzevirian?) deformation and metamorphism in the Adirondacks (McLelland et al. 1988, 1996). Our interpretation is that the Whitehall shear zone, of probable Ottawan age, overprints the earlier deformation with resulting loss of the crosscutting relations. After examining the metagabbro and its surroundings, backtrack along the trail to return to the vehicles.

1.5	0.30	Turn R on Broadway from School St.
1.8	0.30	Traffic signal; continue S on Rtes. 4 & 22.
2.45	0.65	Retrieve parked vehicles at the Golden Arches. Coffee and rest stop. We will the proceed to the southernmost stop on Rte. 4 and then work back north.
8.4	5.55	Rtes. 4 & 22 diverge at Comstock; continue S on 4.
10.55	2.15	Turn **L** onto Flat Rock Road; park on R shoulder.

Stop 2. The outcrop on the east side of Route 4 just north of the intersection exposes the unconformity between the Proterozoic gneisses and the Middle to Upper Cambrian Potsdam Sandstone. Missing: roughly 500 million years of the geologic record and 25-30 km of rock. The Potsdam here consists of coarse arkosic sanstones and quartz-pebble conglomerates, locally with carbonate cement. Good exposures of Potsdam are present in railroad cuts a short distance east and downhill. The dip of the unconformity surface is 10-15° east, roughly parallel to the eastern slope of the Pinnacle Range fault block. The unconformity is exposed again at a location 18.6 miles N along Rte. 22 from the intersection of Rtes. 4 and 22 in Whitehall; there, foliation in the gneisses is perpendicular to layering in the potsdam, and pockets of radioactive conglomerate are present at the unconformity surface. If time permits at the end of the trip this can be included as an optional extra stop for those heading N.

A short distance eastward along the S face of the outcrop, the gneisses are complexly fractured and the fractures are filled with a dark, fine-grained clastic rock rich in ferroan dolomite (Fig. 3). In thin section, abundant shreds of fresh biotite and angular grains of feldspar "float" in a matrix of dolomite. What is the origin of this fracture filling? The clastic grains are too fresh to be the result of weathering, and too quartz-poor to be clastic dikes of Potsdam age. Are they simply the host gneiss pervasively shattered by hydrofracturing caused in turn by tectonic overpressures during overriding of the area by Taconic thrust slices? The western edge of the Giddings Brook slice is less than five miles east of here. Ferroan dolomite is ubiquitous as fracture fillings here and at the next three stops, easily visible due to rusty weathering. In the next cuts to the south on the E side of the highway, folded, biotite-rich mafic layers in gneiss contain thin (submillimeter) dolomite veinlets parallel to foliation. In cuts directly across from this stop, crosscutting veins (Fig. 4) contain both dolomite and adularia (low-T K feldspar).

Except for recent weathering of the fracture fillings, there is little evidence for extensive weathering of the unconformity surface, indicating a relatively short interval between erosion of the Proterozoic rocks and deposition of the Potsdam.

Turn around and proceed back N on Rte. 4.

10.8	0.25	Outcrops at the edge of the woods on R are fine-grained white Potsdam ss.
12.1	1.3	Outcrops on L are extensively fractured granitic gneisses close to a N-S fault.
12.2	0.1	Road crosses small pond.
12.3	0.1	Turn **R** on Kelsey Pond Road (dirt track leading to a quarry). Park on R.

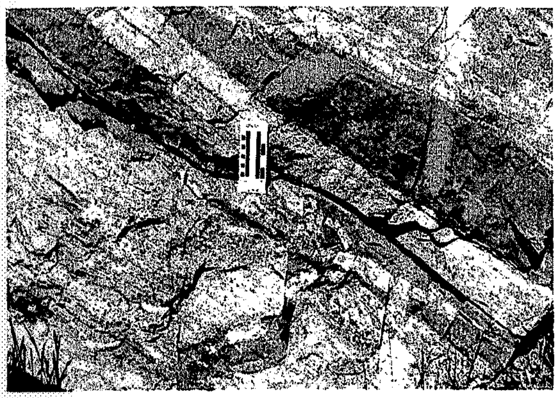

Figure 3. Dolomite-filled fractures in gneiss, Stop 2.

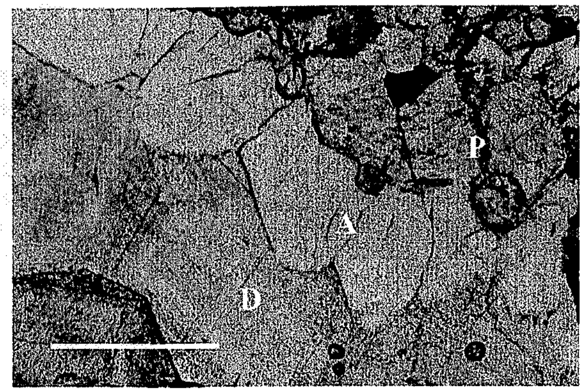

Figure 4. Fracture filling with ferroan dolomite (D), Adularia (A). P = plagioclase in host gneiss. Scale bar = 0.5 mm.

TABLE 1

	FA204.6	FA204.7
SiO_2	31.6	35.15
TiO_2	0.17	0.79
Al_2O_3	17.78	17.35
Fe_2O_3t	9.02	7.5
MnO	0.07	0.05
MgO	23.41	24.32
CaO	4.63	1.85
Na_2O	0.01	0.06
K_2O	0.97	3.55
P_2O_5	0.05	0.1
LOI	12.94	9.43
Total	100.65	100.15
Rb	37	208
Sr	63	120
Ba	37	283
Zr	53	86
Y	31	19
Nb	8	8
Ga	41	33
Cr	21	89
Ni	23	182
V	107	125
Ce	45	284

Table 1 . Chemical analyses of ultramafic lenses, Stop 3.

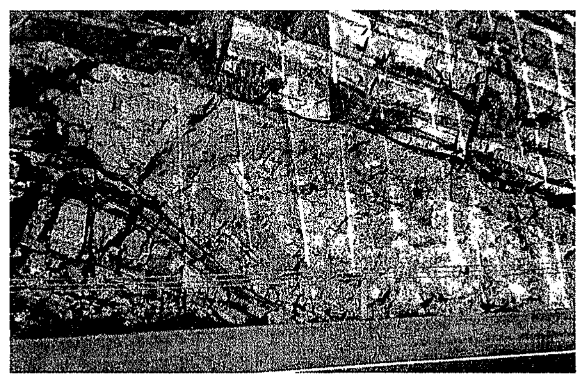

Figure 5. Marble lens in paragneiss, Stop 5. Darker border of lens is dolomite marble; interior is calcite marble.

Stop 3. Walk N on the E side of Rte. 4 to the roadcuts. The rocks at the south end of the cut on the east are migmatitic, strongly foliated (sillimanite)-garnet-biotite-quartz-two feldspar paragneisses. Present in the outcrop are several thin quartz-microcline pegmatites in various stages of tectonic disintegration. Large microcline crystals survive the tearing-apart process better than quartz, and locally form large porphyroclasts. Rotation of such feldspar porphyroclasts can provide sense-of-shear indicators under favorable circumstances, but the orientation of the rock face is nearly perpendicular to lineation, limiting their usefulness here.

Observe the variable shape of the garnets: some are equigranular, others are elliptical or flattened. Some are inclusion rich while others are nearly devoid of inclusions. Careful study of these variations, combined with microprobe analysis, might yield information on the relative timing of deformation and metamorphism.

From here, continue north (uphill) along the east side of the road; stay away from traffic. Following a gap in the outcrop, the next rocks are strongly foliated and lineated garnet-rich paragneisses with local lenses of calcsilicate rock. Roughly 30 m. north, these are underlain by mafic gneisses that comprise most of the remainder of the cut. These include numerous lenses and pods of calcsilicates and garnet hornblendite. A large, orange inclusion of grossular-diopside-quartz calcsilicate granulite is visible in the mafic gneisses on the opposite (W) side of the road. Near road level on this side, two coarse-grained ultramafic lenses contain the unusual assemblage actinolite-phlogopite-serpentine-talc-chlorite-diaspore. The purplish-red "mineral" is not garnet but a fine-grained aggregate of diaspore and an opaque mineral (retrograded spinel?). The lenses are surrounded by a zone of biotite-rich "blackwall". Two analyses of the ultramafic rock are given in Table 1; note the exceptionally high Al_2O_3 and MgO. Suggestions as to what these unique rocks are (were?) are welcome.

Near the north end of the cut, still on the east side, two large pods or megaboudins of massive, fine-grained, garnet-rich metagabbro are enclosed in strongly foliated amphibolites. The transition between foliated and unfoliated rock is abrupt. Patches of tourmaline-bearing pegmatite are present at the broken (?) end of one of the pods.

12.85	0.55	Intersection of Rtes. 4 & 22 in Comstock. Continue N on 4.
13.2	0.55	**Stop 4.** Park as far off the road as possible at the S end of a large, 2-sided cut.

Cautiously cross road and walk N along the W side. The first rocks are garnet-rich biotite-quartz-plagioclase paragneisses, overlain by pink, inequigranular, strongly foliated garnet-biotite granitic gneisses ranging in texture from augen gneiss to mylonite and displaying prominent quartz-ribbon lineation. The contact between these two rocks is sharp, but note the spherical, undeformed garnets directly on the contact. Going north, the pink gneiss is followed by a deformed lens of metagabbro, broken near road level and injected (?) with heterogenous, locally pegmatitic granitic rock. Looking S across the road and roughly parallel to strike, a similarly shaped gabbro is probably a continuation of the same body. Structurally above the metagabbro migmatitic paragneiss reappears. Note the prominent discontinuity in the foliation. Toward the north end of the cut is another gabbro body, also with a continuation on the opposite side of the road. These biotite-ilmenite-hornblende-two pyroxene-garnet-plagioclase metagabbros are fine-grained and massive with relict igneous textures except in immediate proximity to contacts. Although relict olivine is lacking in the gabbros at this location, larger metagabbros elsewhere in the Pinnacle Range block contain olivine and are compositionally indistinguishable from olivine metagabbros elsewhere in the eastern and central Adirondack Highlands.

Consider the implications of the roughly sigmoidal shape of the metagabbro lenses. Opposite sense of shear is indicated depending on whether emplacement of the gabbro was pre- or syn-tectonic. If the former, the SE-over-NW shear sense is consistent with most (but not all) other kinematic indicators in the area. Cross the road and walk back S to the vehicles.

13.5	0.3	Outcrops on L are pale gray, migmatitic, graphite-biotite-sillimanite-quartz-2 feldspar migmatitic paragneisses.
13.7	0.2	South end of the next set of roadcuts. An operating stone quarry is just behind the cut on the L.
13.9	0.2	**Stop 5.** North end of the same cuts. Park off road on R and cautiously cross. We will start at the north end and walk south on the west side. Beware of high-speed trucks; stay well off the road. The rocks here include many of the lithologies found throughout the Adirondack Highlands, interlayered or tectonically interleaved. Foliation and compositional layering strike consistently NE with a gentle to moderate SE dip; walking S along the cut we will be traversing the section from structurally higher to lower. The northernmost rocks are interlayered marbles and paragneisses. Marble layers and lenses contain rotated inclusions of amphibolite, paragneiss, serpentinite, and calcsilicate granulite as well as coarse fragments of quartz and microcline suggesting tectonically disrupted pegmatites. Some amphibolite inclusions are surrounded by pyroxene-rich reaction haloes. Interiors of marble layers are calcite marble containing diopside, phlogopite, scapolite, quartz, microcline, and graphite. Near contacts with paragneiss, calcite is replaced by dolomite (Fig. 5), diopside is extensively serpentinized, and there is evidence of cataclastic deformation. In thin section, dolomite is in unreacted contact with quartz and microcline, consistent with low-temperature dolomitization superimposed on granulite facies rocks. Small lumps of cherty silica appear in thin section to be void fillings. Contacts between dolomitic marble, rusty brown on weathered surfaces, and the paler calcite marble are relatively sharp and easily seen. Marble-paragneiss contacts are commonly marked by thin graphite films, possibly originating through concentration of graphite through dissolution of marble by solutions channeled along the contacts.

Paragneisses contain the assemblage biotite-garnet-quartz-plagioclase $\pm$ sillimanite and abundant fine-grained quartzofeldspathic leucosomes that may have been anatectic melts or intrusive granite sills, subsequently grain-size reduced during deformation. Near contacts of paragneiss with marble, celadonite and dolomite are locally present, especially in thin, dark layers layers within the paragneiss. Somewhat surprisingly, biotite and other silicates are ordinarily fresh and unaltered.

Continuing south along the cut, garnetiferous quartzofeldspathic gneiss underlies the paragneiss and marble. The contact is offset by a small normal fault adjacent to a zone of dolomite-cemented breccia. Note the unmetamorphosed diabasic dike just back from the face of the roadcut and roughly parallel to it.

Following a covered interval, outcrop resumes in strongly foliated charnockitic (garnet-two pyroxene-quartz-plagioclase-perthite) gneiss, underlain by a thin dolomitic marble layer containing numerous rotated fragments of various silicate rocks. The marble here is parallel to foliation in the gneisses both above and below it; across the road the it locally truncates foliation in the charnockite. The marble may have acted as tectonic grease along a small thrust fault. The marble in turn is underlain by mafic garnet-hornblende-pyroxene-plagioclase gneiss with minor quartz and K feldspar, similar in most respects to the jotunite associated with many anorthosite bodies.

Immediately beneath the mafic gneiss is a layer of calcite marble and calcsilicate rock containing scapolite, clinopyroxene (Di_{56}), calcium garnet (Gr_{91}), and, locally, wollastonite. The localized occurrence of wollastonite in the marble, and the iron-poor garnet, suggest that the wollastonite here is of contact metamorphic origin, in contrast to the metasomatic wollastonite ores in the northeastern Highlands.

The structurally lowest rocks are a complex sequence of interlayered paragneisses, garnet-sillimanite-quartz-K feldspar metapelite, marble, boudinaged amphibolite, and gabbroic anorthosite gneiss, the latter most clearly seen across the road. Note the aligned, matchstick-size sillimanite crystals present on some foliation surfaces in the metapelite. Prominent fracture surfaces parallel to foliation and compositional layering are coated with chlorite and calcite and display slickensides with an updip sense of movement. Prior to DOT renovation of the roadcut, slight updip offset was visible on a vertical diabase dike that strikes NNE parallel to the road. The orientation of the slickensides is subparallel to the well developed, ca. S50°E granulite facies mineral lineation. This suggests that some foliation surfaces formed during Grenvillian deformation served to localize later, probably Taconic, movement.

END OF TRIP