MINERALOGY AND GEOLOGY OF THE NEWCOMB AND SANFORD LAKE AREA

BY

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INTRODUCTION

For many years the titaniferous magnetite ores of the Lake Sanford District constituted the largest source of titanium in the world. Today these deposits still rank among the world's greatest operative titanium ores. They are located within the Marcy metanorthosite massif. Within the field trip area adjoining metamorphosed rocks, especially the Grenville marble, provide interesting and diversified contrasts in mineral content and pose challenging problems as to formation and origin.

REGIONAL AND STRUCTURAL GEOLOGY

Most of the region to be visited is part of the Marcy massif which along with the Grenville complex forms the core of the Adirondack Mountains. On the flanks of these precambrian rocks are gently dipping Paleozoic rocks mostly of sedimentary origin. No paleozoic rocks other than glacially transported are present in the area to be studied. Figure 1 shows quadrangles in the field trip area with names of authors of geological publications.

Simmons (1964) made a detailed gravity survey of the Adirondacks and adjacent areas. His analysis of the data obtained is shown in Figure 2. He concluded that the metanorthosite massif was a slab 1200 square miles in area increasing in thickness from a maximum of 3 km in the west to 4.5 in the east with two roots extending downward about 10 km. The metasediments in the southwestern portion of the study area are marbles and quartzites of the Grenville series which Isachsen and Moxham (1968) believe are rock roofs or roof pendants which have undergone slight erosion. See Figure 2.

Primary structures such as foliation and flow lines are seen in the metamorphosed igneous rocks. Balk (1932) considers these features to have formed before solidification of the molten material.

Folds on the scale of a few feet are seen in the Grenville marble. No large scale folding of the marble is evident. The contortions indicate that the calcium carbonate must have been in a plastic state. There is much conjecture as to the large-scale structure of the area as considerable data must still be accumulated.

At least three faults occur in the area. The general strike is NNE. The most detailed study of faults was made by Heyburn (1960) in the McIntyre development where they are exposed much better than elsewhere in the area. Data concerning them were also obtained from drill holes. The dip is mostly about 65 degrees northwest. One fault had a strike of N 84 W and a dip of 54 degrees to the north (Heyburn, 1960). Shear zones and major topographic lineaments are also present.

Balk (1932) and Heyburn (1960) agree on the trend of the joint systems. They located two sets, one oriented N 30° W and the other N 50° W.

Dikes have been reported on a small scale in geological reports of the different parts of this area. Miller (1919) located an intrusion of granite 5 feet wide in metanorthosite of the Whiteface type. Its contact was not sharp. This is near the Blue Ridge highway 1.5 miles west of the Boreas river.

Avenius (1948) and Balk (1932) discovered diabse dikes. Heyburn (1960) observed not only diabase dikes but pegmatite dikes and DeMatties (1974) found two norite dikes. The width of the dikes varies from a few inches to 10 feet and the length from a few feet to over 50 feet. Most of the dikes strike NE-SW. DeMatties (1974) noted one that had a strike of N 65° W and dip of 27° NE.

During the pre-Paleozoic, the portion of New York state comprising the area to be visited was covered with sediments believed to have been of marine origin. While no fossils were found in them, their widespread occurrence in adjacent areas and the presence of graphite disseminated throughout the Grenville marble, quartzite, and some of the gneisses present in the Grenville series indicates that there was some type of life during that period. Graphite is not a constituent of limestone but the remains of living things like blue-green algae after having undergone decomposition to carbon or hydrocarbon could become graphite after metamorphism.

Blue-green algae as well as other forms of microscopic life have been found in Early, Middle, and Late pre-Paleozoic. Perhaps the decomposed remains of clusters of these organisms yielded graphite under conditions which converted the calcareous sediment of the ocean to the coarse crystalline calcite of today's Grenville marble.

The sediments making up what is called the Grenville Series began to undergo uplift, deformation, and intrusion by magma about one billion years ago and continued to be exposed to these forces for almost a third of a billion years. This event is called the Grenville orogeny. Sedimentary rocks were completely metamorphosed to marble, schist, and gneiss. The degree of metamorphism was too strong to produce slate. Isotopic studies have provided the dates of the Grenville orogeny (Dott and Batten, 1971), but the time during which the sediments were deposited has not as yet been determined because "dates obtained from such rocks (the metamorphic and igneous) generally record only the last readjustment of the isotopes during an episode of heating". (Dott and Batten, 1971) The conclusion is that the sediments were deposited longer than one billion years ago, but how much longer as yet is unknown.

Intrusions of the anorthosite and granite-syenite magmas into the limestone, shale, and sandstone took place during the orogeny with the entire mass then undergoing the metamorphic events. Evidence for this is seen in the inclusions of marble in some of the formerly igneous bodies and in the granulation, foliation, and other features of the metanorthosite and its phases.

Considerable erosion of the Grenville occurred since there are large areas, especially the high ones, where there is no Grenville today. In addition, marble is not very resistant to weathering or erosion under moisture conditions.

During the Paleozoic era, seas surrounded and perhaps covered the Adirondacks after the area had undergone subsidence. Remnants of the Potsdam sandstone, Little Falls Dolomite (?) (Miller, 1919) of the Late Cambrian occur south of the study area in the Schroon Lake quadrangle. To the east, outside of the study area in the Champlain Valley, Middle Ordovician rocks occur. However, within the study area no Paleozoic rocks in situ have been discovered. Balk (1932) believes that Paleozoic rocks were removed from the Newcomb quadrangle by erosion.

There is no evidence as to deposition for the remainder of the Paleozoic and the entire Mesozoic. However, considerable erosion occurred along with uplift, faulting, and jointing. Considerable evidence is present for glacial activity during the Pleistocene such as striations, even on the highest peaks, erratics, moraine, till, extinct lakes extant during the Pleistocene, and lakes formed by damming of rivers by deposition of glacial drift.

LITHOLOGY

Figure 3 shows the rocks in the field trip area.

Metanorthosite

Metanorthosite is the most abundant and most continuous bedrock in this region. It differs from anorthosite found in localities other than the Adirondacks in that it has undergone metamorphism. This nomenclature was first used by Isachsen and Moxham (1968). It has also been called Marcy anorthosite since it outcrops in abundance on Mount Marcy. Megascopically most of the rock is labradorite with grains of this plagioclase feldspar close to 1 inch long. Miller (1919) has reported lengths up to one foot on the ridge 1 mile north-northwest of Blue Ridge. (See map)

Heyburn reports that in the Sanford Lake area to the north the Marcy-type anorthosite is mostly porphyritic. The laboradorite or andesine phenocrysts are also very coarse attaining slightly over 3 inches in length, with only a very few reaching 10 cm. Just west of Sanford Lake Avenius (1948) noticed that labradorite phenocrysts were smaller with maximum size at 6 cm.

DeMatties (1974) who studied the geology in the area north of Miller and south of Heyburn and Avenius found very coarse labradorite up to 15 cm with many around 2.5 cm. In his area the color varied to greenish gray. He observed that "a relict porphyrytic texture" occurred locally in the metanorthosite.

Color varies from light to dark bluish gray. Polysynthetic twinning as evidenced by striations is often visible. Usually less than 10% of the metanorthosite consists of other minerals of two different sizes. The larger are hornblende and pyroxene, the smaller biotite, garnet, pyrite, pyrrhotite, ilmenite, and magnetite.

Isachsen and Moxham (1968) state that "gabbroic or noritic metanorthosite commonly (though not invariably) occur along the borders" of metanorthosite. De Waard and Romey (1968) define norite "as a plutonic rock, magmatic or metamorphic, which has the composition of a gabbro or diorite, and in which hypersthene is a major dark constituent." The terms gabbroic anorthosite, gabbroic metanorthosite, border phase anorthosite, and Whiteface-type anorthosite have all been used in the literature to describe the same rock.

It is lighter in color than metanorthosite, being whitish to greenish gray. On Whiteface Mountain it is the predominant rock. Labradorite phenocrysts average a smaller size than in Marcy-type metanorite and the maximum size rarely exceeds 2 cm so that the texture is finer. Foliation is often present. DeMatties (1974) considers the range of ferromagnesian minerals in gabbroic metanorthosite as between 10 and 22.5%.

The Whiteface-type anorthosite which has less than 10% mafic minerals megascopically is very similar to the Marcy-type anorthosite. However, the Whiteface-type anorthosite which has more than 10% ferromagnesian minerals but less than 22.5% can be considered as gabbroic metanorthosite (DeMatties, 1974). There is a gradation from one Whiteface type into the other, but microscopic examination for distinguishing each is essential. Microscopically both types exhibit more alteration, more crushing, more distortion.

Mineralogically the Whiteface and Marcy metanorthosites are quite similar. As the ferromagnesian minerals increase there is a decrease in the labradorite and an increase in sericite or scapolite or both.

Metanorite

A distinct area of metanorite has been mapped and described by DeMatties (1974). It may occur in other parts of the field trip area, but has not been mapped as an individual unit. It is mostly black, at times foliated, consisting of mainly pyroxenes (32-49.6%), plagioclase feldspar (12.5-32.8%), garnet (5.4-16.8%), opaque minerals (14.6-22.8%), amphibole (hornblende), chlorite, and apatite. The last three generally comprise well under 10% of the metanorite. The pyroxenes consist of clinopyroxene and hypersthene with the former usually the dominant of the two, the ratio of monoclinic to orthorhombic being from slightly over 4 to 1 to 0.85 to 1. Microscopically sericite, hematite, and alkali feldspar were noted. The type of plagioclase feldspar is andesine since its anorthite content varies from 35 to 56%. Included among the opaque minerals are magnetite, ilmenite, goethite, hematite, and sulfides.

There is a gradation from metanorite into anorthositic metanorite. DeMatties (1974) considers the boundary between the two as 35% ferromagnesian mineral content, under this value and over 22.5% being anorthositic metanorite and over 35% being metanorite. The decrease in ferromagnesian minerals is compensated by an increase in plagioclase feldspar content.

Charnockitic, granitic, and quartz syenitic gneisses

What Miller (1919) and Balk (1932) have called the syenite-granite series, today appear on the New York State Geological Map as "charnockitic, granitic, and quartz syenitic gneisses variably leucocratic containing varying amounts of hornblende, pyroxenes, biotite; may contain interlayered amphibolite, metasedimentary gneiss, migmatite."

Charnockite is defined (De Waard and Romey, 1968) "as a plutonic rock, magmatic or metamorphic, which has the composition of a granite and contains hypersthene." Within the northern quarter of the Schroon Lake quadrangle which comprises the lower part of the southeastern portion of the study area, Miller (1919) mapped two areas of granite. One is almost one mile southwest of Sand Pond and 1.4 miles due south of Wolf Pond to the south of Blue Ridge Road. The other body of granite is adjacent and to the south and west of Cheney Pond (the south Cheney Pond). Both granite stocks are separated by a mass of gabbro. An analysis of a specimen from the granite close to Sand Pond (Miller, 1919) revealed 62% microperthite, 30% quartz, 6% oligoclase, 1.5% biotite, with magnetite, apatite, and zircon present in very minor amounts. Its color when fresh is pinkish gray, and weathered it is light brown. Granulation and foliation may be present.

In the portion of the Newcomb quadrangle present in our area of study Balk (1932) found the syenite-granite series to be extremely variable in composition. He did not map separate regions of granite and syenite as Miller. It occupies parts of the southern and southwestern portion of the area to be visited. The color ranges on fresh surfaces from dark green to grayish white to pink depending upon whether or not much quartz is present. In general the granitic members are lighter (Balk, 1932). Weathered surfaces present a grayish white at times with a slight yellowish tint. In the more acid phase, quartz was most abundant, followed by microcline, orthoclase, and a small amount of hornblende and biotite. Just to the west of Newcomb outside our area a specimen of the more acid phase of the syenite-granite series yielded mostly quartz, microperthite, orthoclase, a little oligoclase, augite, and garnet. Also slightly outside of the area syenite grading into granite was observed (Balk, 1932), No difference in age could be determined from the outcrops. The granite had mostly quartz, then microcline, microperthite, biotite, and some hornblende.

Undivided and mixed gneisses

On the New York State Geological map designated under undivided and mixed gneisses is a hybrid rock mangeritic to charnockitic gneiss with xenocrysts of calcic andesine and locally xenocrysts of anorthosite. With increasing percentage of the anorthosite component, it passes gradationally into anorthositic rocks. In the lowest south central portion of the study area Miller (1919) mapped some of these rocks as the Keene gneiss. It consists of 75% oligoclase-labradorite, 8% garnet, 7% quartz, 4% monoclinic pyroxene, and 2% or less of each of the following: magnetite, zoisite, and apatite. Fresh rock has a greenish gray color and it weathers brown. It is medium-grained in texture and may have xenoliths of labradorite up to an inch in length. Miller (1919) believes that this gneiss is transitional between anorthosite and syenite-granite since its position falls between the two.

De Waard and Romey (1968) define mangerite as "a plutonic rock, magmatic metamorphic, which has the composition of a quartz monzonite and contains hypersthene." Megascopically it may be impossible to distinguish hand specimens from members of the syenite-granite series, but microscopically Miller claims that it is possible.

Balk (1932) has mapped the same type of rock as the Keene gneiss and called it syenite-granite with labradorite crystals, or phenocrysts.

Gabbro or Metagabbro

In the central part of the study area occur some outcrops of gabbro or metagabbro. Miller (1919) found that the composition of the Cheney Pond (southern Cheney Pond) stock was 45% labradorite, 20% hypersthene, 18% garnet, 6% biotite, 4% olivine, magnetite, and a very small quantity of pyrite. This rock could very well be termed a norite because of its hypersthene content. Miller believes the garnet to be of secondary origin. The texture of the gabbro is medium to moderately coarse. A fresh surface is dark gray to almost black and it weathers to a deep brown. In some specimens hornblende or ilmenite or both may be present. Typically it is not foliated. Interestingly, the labradorite has very minute dark inclusions. Other facies of the gabbro occur "as the highly foliated border facies amphibolite."

Balk (1932) reported that the augite, hypersthene, and olivine greatly diminish in quantity and may even disappear as the gabbros grade from their cores to their border into a schistose phase and amphibolites. There is an increase in the amphibole, garnet, and biotite as this transition progresses. Miller (1919) believes that the gabbro is younger than the anorthosite, whereas Balk (1932) disagrees. In the Newcomb area glacial deposits cover most of the amphibolite.

Grenville Marble and Quartzite

The Grenville Marble and Quartzite are present in the western eighth of the study area. Large outcrops of the marble are visible along Route 28 starting about 2 miles east of Newcomb and one mile east of the Hudson River. This marble differs from the Vermont marble of West Rutland and Proctor in that the calcite grains are considerably larger. Indeed, the could consider this calcite with inclusions. The individual calcite grains range to 1 cm in length. Graphite flakes and crystals ranging from 2 to 5 mm are disseminated throughout the marble. The marble is mostly white, but locally may be stained a light yellowish brown from oxides of iron. In one outcrop close to a schist and gneiss the marble has a black stain.

Occasionally parts of the marble are dominated by other minerals. A great variety of minerals have been reported (Balk, 1932) from the marble in this area including apatite, biotite, chondrodite, diopside, feldspar, garnet, graphite, magnetite, phlogopite, pyrite, pyroxene, pyrrhotite, quartz, scapolite, sphene, spinel, tourmaline, tremolite, and zircon. Most of these minerals are less than 1 mm in length but locally may be considerably larger. Balk (1932) described a deposit of tourmaline, unfortunately exhausted, on the south shore of Harris Lake at Newcomb. Brown and green tourmaline crystals up to 8 inches long, 4 inches wide, and having a girth of 12 inches occurred in the marble associated with albite, blue apatite, graphite, hematite, pyrite, pyroxene, scapolite, smoky quartz, sphene, and zircon.

Slightly west of the study area where the "old wagon road crosses the channel between Rich Lake and Harris Lake" at the dam is an outcrop containing small blue apatite crystals and wollastonite (Balk, 1932).

There is little quartzite exposed in the study area. Balk reports that most outcrops where the quartzite is found also have impure marble interbedded. The quartzite is stained yellow or brown because of iron oxides. Many of the minerals listed with the marble occur. In addition the apatite and sphene are locally more abundant.

GEOLOGY OF THE SANFORD LAKE MINERAL DEPOSITS

History

While hunting beaver in 1826 Louis Elija, an Indian guide, discovered an outcrop of iron ore at what is today Lake Henderson(named after the son-in-law of Archibald MacIntyre, both original developers of Elija's discovery). David Henderson was so impressed with the ore sample which Louis Elija had brought him that he accompanied him on a tiring journey to the wild and isolated outcrop. Hyde (1974) quotes from Henderson's letter to MacIntyre:

> "We found the breadth of the vein to be about fifty feet!--traced it into the woods on both sides of the river. On the one side went eighty feet into the wood, and digging down about a foot of earth, found the pure ore bed there--and let me here remark this immense mass of ore is unmixed with anything--in the middle of the river where the water runs over--the channel appears like the bottom of a smoothing iron--on the top of the vein are large chunks which at first we thought stone, but lifting one up and letting it fall it crumpled into a thousand peices of pure ore. In short, the

thing was past all our conceptions--We traced the vein most distinctly--the sides parallel to one another, and running into the earth on both sides of the stream. We had an opportunity to see the vein nearly five feet from the surface of it on the side of the ledge which falls perpendicular into the water."

Ore was mined in the early 1830's and the first iron successfully produced in 1838. Ten years later titanium was discovered in the ore. In the 1850's mining and smelting reached a peak but became completely inactive with the financial panic of 1857. Activity resumed in 1894, but ceased in about 1913 because of problems including the presence of titanium which impaired the smelting processes then known (Gross, 1968).

National Lead Company, now called NL Industries, Inc. purchased the mining area for its titanium content in 1941. Ironically, the substance which once was very undesirable because of the metallurgical problems it posed, reversed its position and exceeded the iron in value. The MacIntyre Development has been in continuous operation since 1941 and for many years was one of the leading producers of titanium in the world. It "continues to be one of the principal sources of titanium dioxide in the world" (MacIntyre Development N L Industries, Inc., p. 1).

Relationship of Local Geology to Regional Geology

Basically the only differences between the geology of the 24 square miles of the Sanford Lake District and the regional geology are the lack of members of the Grenville Series and the syenite-granite series and the occurrence of the ore bodies. There may be ore bodies present outside of the Sanford Lake District in the field trip area, but as yet none have been discovered. DeMatties (1974) is of the opinion that they may occur to the south of the present mining area.

Ore Body Descriptions

Figures 4, 5, and 6 show the ore deposits and the rocks in which they occur.

Gross (1968) has established TiO_2 content for mapping purposes as follows:

Classification	% TiO_2
anorthosite	0.0 - 5.4
gabbro	5.5 - 9.4
low grade protore	9.5 -13.4
medium grade ore	13.5 -17.4
high grade ore	17.5 plus

Two major types of ore bodies occur. One is found in the anorthosite and the other in the gabbro. Both types occur in the Sanford Hill Pit and the South Extension Pit. Mining ceased in the former in 1966 and is now going on in the latter. The ore bodies are massive irregular lenses. A further distinction is that the anorthositic type of ore occurs in a footwall and the gabbroic type of ore occurs in a hanging wall.

In the footwall type of ore there are sharp contacts with the metanorthosite, whereas in the hangingwall type of ore there is a gradation into the gabbro (Heyburn, 1960). Each type of ore body contains very poor and high grade material, the ore in the gabbro occurs in the form of darker layers or bands to a content of 17.5% TiO_2. Generally, when this amount is exceeded, the gangue amounts to less than 30% and there are no ore layers. The layers of ore in the gabbro, according to Gross (1968) range from microscopic to tens of feet. Stephenson (1945) mentioned one locality where almost 200 feet of solid ore were found.

Gross, who has been associated with the mining of the titaniferous magnetite for more than 30 years, has observed (1968) that "all bodies of this ore are associated with gabbro masses...The one factor governing the location and form of the ore bodies is the presence and flow structure attitudes of the gabbro bodies."

The following are examples illustrating the content of ores and gangue: (Heyburn, 1960)

	*(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
sulfides	1.5	1.6	1.1	1.7	2.8	1.8	4.0	8.1	3.5	7.4	8.6	4.5
pyroxenes	6.6	3.0	7.7	4.7	6.3	9.8	17.1	15.2	24.8	20.8	19.4	23.9
amphiboles	2.3	3.2	3.1	1.5	3.0	1.7	5.9	16.2	9.9	6.7	9.1	4.2
biotite	0.8	1.0	1.2	1.1	0.5	1.0	2.0	4.3	3.9	5.0	1.4	2.6
garnet	8.1	3.0	4.0	3.4	4.7	5.7	21.1	15.0	13.1	14.8	14.4	13.7
feldspar	19.2	8.2	13.8	10.3	15.2	21.0	49.9	41.2	44.8	45.3	47.1	51.1
black opaques ilmenite	35.9	36.2	38.6	36.5	37.2	22.2						
magnetite	25.7	43.8	30.5	40.8	30.3	36.8						
TOTAL	100.1	100	100	100	100	100	100	100	100	100	100	100
TiO_2	18.9	19.2	38.6	18.8	19.5	20.6						
Fe	32.3	45.5	30.5	46.2	35.4	31.2						

*(1)(2) North End Hangingwall Ore
(3)(4) South End Footwall Ore
(5)(6) Sanford Ore Body Extension
(7)(9) Gangue Minerals in Hangingwall ore samples calculated from (1)(2)
(8)(10) Gangue Minerals in Footwall ore samples calculated from (3)(4)
(11)(12) Gangue Minerals in Sanford Body Extension calculated from (5)(6)

Stephenson (1945) has worked out the mineral paragenesis of the Sanford Lake District as follows:

plagioclase feldspar(earliest)

apatite

hypersthene

augite

hornblende

garnet

ilmenite-magnetite(latest)

Biotite is both primary and secondary. Gross (1968) states that as a primary mineral it forms after the garnet. As a secondary mineral it forms from hornblende. Other alteration minerals are chlorite, carbonates, and scapolite, which are post ore. The sulfides of iron-pyrrhotite and pyrite according to Gross (1968) are formed just after the ilmenite-magnetite.

Theories of Ore Formation

Stephenson (1945) assigns the origin of the ores to magmatic segregations in gabbro and magmatic injections in the anorthosite, both processes being related. He noticed that ore lenses in gabbro "are associated with all of the ore bodies." "The ore residuum of gabbro supplied the ore constituents which form large masses in the anorthosite." He believed that where the anorthosite had solidified it was replaced by the ore residuum.

Kays (1965) disagrees with Stephenson since he found (1) that the transition from anorthosite to gabbroic anorthosite to gabbro was gradational, (2) no evidence that there was intrusion by gabbro, (3) magnetite those to ilmenite ratios in anorthosite ores differed from in gabbros, thereby precluding differentiation of the gabbro to produce anorthositic ore, and (4) relations "between plagioclase composition and the amount of ferromagnesian silicates plus garnet."

Gillson (1956),believes that the anorthosite was solid before the ore was formed, and that the ore bodies were formed by pneumatolytic replacement. His supporting evidence includes (1) localization of ores which indicated that deposition was not widespread, (2) parallelism of the rock zones and faulting influenced ore deposition, (3) garnet and scapolite cannot have been formed by filter-pressing, (4) paragenesis indicated that the ore minerals formed after the plagioclase feldspar and garnet, whereas if there had been magmatic segregation, the ore minerals according to Bowen's studies would have formed prior to the other minerals, (5) the presence of veins containing plagioclase feldspar richer in Na than the labradorite illustrates the mechanism whereby "much of the original feldspar was replaced by andesine. This process he calls andesinization." Gillson states that the final step in the formation of the ores was by deposition from solutions whose access was structurally controlled.

Kays (1965) objects to parts of Gillson's conclusions in that (1) labradorite can be converted to andesine without the intervention of solutions rich in sodium. The formation of andesine "occurred when the initial plagioclase was granulated by the pervasive shearing that is associated with the localization of ore." (2) iron, magnesium, and titatinium were already present in the rocks and not introduced by solutions from outside these rocks.

In Kays' own words, "the Sanford Hill deposit is the result of two main events. The first, presumably magmatic event, determined the geochemistry of the area and the gross structure of the anorthosite; the second retrograde matamorphic event determined the mineralogical and structural details of the ore deposit." He advocated a redistribution of the iron, magnesium, and titanium with reactions producing the ferromagnesium minerals and resulting in a concentration of the magnetite and ilmenite.

Heyburn (1960), because of the close association between ore and gabbro which he noted, is of the opinion that they are either contemporanious or practically contemporaneous. He states, "The iron and titanium probably were intruded with the gabbro and segregated with the aid of volatiles to form the ore bodies." The ore in the anorthosite is younger and formed by replacement. Evidence of volatile activity according to Heyburn is "the occurrence of garnet along the contact between ore and anorthosite and also by the presence of secondary biotite."

DeMatties (1974) made a detailed petrographic, mineralogical, and quantitative chemical analysis of samples gathered from the region just south of the mining area, and found that there was an increase in concentration of titanium dioxide and iron to a maximum in the vicinity of the center of the metanorite and that there was no structural control involved. This observation constitutes part of his reasoning for classifying the ore deposit as late magmatic. He states, "Field relationships indicate that these bodies form both segregations as well as injections within metagabbro and metanorthosite respectively."

It is most informative to consider the views of Stanford O. Gross, chief geologist of NL Industries. He has studied the ore deposits for a much more extensive period than any other geologist. Gross (1968) states: "After many observations, it is clearly evident that many theories can be proved if only a portion of the conditions are, or can be, taken into consideration. After a number of years working at the operation, the question of ore genesis becomes more and more complex. No one theory can explain satisfactorily all of the rock and mineral relationships now in evidence."

MINERALOGY

In the following discussion, G refers to occurrence in the Grenville marble, S in the Lake Sanford district, and O in the field trip area other than Grenville and Lake Sanford.

Apatite $Ca_5(F,Cl,OH)(PO_4)_3$ Hexagonal Dipyramidal

G Apatite generally occurs as blue crystals 1 mm and smaller (Balk, 1932). "On the south shore of Harris Lake at Newcomb was a famous tourmaline locality now exhausted, also found at this spot were blue apatite, sphene, zircon, muscovite, smoky quartz, scapolite, albite, graphite, hematite, pyroxene, and pyrite. Tourmaline crystals were brown and green 8 inches long and 4 inches wide." Outside and to the west of the field trip area occurs wollastonite and small crystals of blue apatite in "the ledge at the dam where the old wagon road crosses the channel between Rich Lake and Harris Lake."

S Gross (1968) noted that apatite occurred in all rocks of the Sanford Lake area as anhedral grains associated with labradorite and andesine usually present to the extent of less than 1 per cent, but at times increasing to 10% by volume in gabbro having a high ore content.

Biotite, muscovite, phlogopite

G Each occurs in very small amounts predominantly less than 1 mm in diameter.

S The only mica observed was biotite. It was found in gabbro both devoid of ore and rich in ore as a primary mineral and alteration product of hornblende. It rarely exceeds a few percent.

O South of the Lake Sanford Ore deposits DeMatties (1974) observed up to 4% biotite in Whiteface metanorthosite. Biotite easily visible to the unaided eye forms a large part of the amphibolite.

Calcite $CaCO_3$ Hexogonal Rhombohedral Trigonal Pyramidal

G By far the most abundant mineral in the Grenville marble. In samples studied in this area so far, it ranges from 51 to 85% by weight. Crystals have not been observed, but it is certain that they are present. Balk (1932) reported some calcite crystals several miles south of the field trip area in the southern part of the Newcomb quadrangle. The calcite is a creamy white. Occasionally there are yellow-brown stains due to staining by goethite.

S It occurs as a secondary mineral along faults and joints.

Chlorite $Mg_3(Si_4O_{10})(OH)_6$ Monoclinic Prismatic

S It occurs as a secondary mineral along faults and joints.

Chondrodite $Mg_5(SiO_4)_2(F,OH)_2$ Monoclinic Prismatic

G Occurs as yellow-brown grains, usually 1 mm or less.

Garnet

A group of silicates most of which also contain Al. Those having Al also have either Mg, Mn, Fe, or Ca. Those not having Al have Ca and either Fe or Cr. The Mn and Cr types of garnet have not been reported from the field trip area.

Isometric Hexoctahedral Class

G Disseminated as anhedral red, orange, and orange-red grains 1 mm and less.

S Present in all Lake Sanford area rocks mostly microscopic but can constitute up to 8.1% where rich in ore (Heyburn, 1960). Composition is mixed grossularite-andradite-almandite (Gross, 1968).

O Some of the outcrops along the Blue Ridge road contain megascopic garnet but not in crystals. Grains are up to 5 mm in length.

Graphite Hexagonal Dihexagonal Dipyramidal

G It is scattered throughout the Grenville marble, offering a striking contrast with its silvery metallic luster and perfect basal cleavage. When size greater than 10 mm, often its luster is dull black and sooty, but in the smaller flake form always metallic. Since the graphite is so soft (hardness ranging from 1 to 2), its crystal shape is easily distorted. However, by dissolving away in dilute HCl (one part acid to six parts water by volume) the surrounding calcite, usually fine hexagonal crystals of graphite can be obtained.

The crystals are very thin, tabular, and have (0001) as the prominent face. Most of the flakes are smaller than 2 1/2 inches in diameter.

Amphiboles

S The only amphibole other than hornblende reported in the Lake Sanford area was altered beyond recognition except for its cleavage (Stephenson, 1945).

Hornblende Monoclinic Prismatic

S Has been reported from all rocks of the Lake Sanford area being most abundant in the gangue associated with the ore

minerals. Its color is green and brown. It is a primary
S mineral and a secondary, the latter as an alteration product of pyroxene. The brown color is more abundant in the more basic rocks.

It is also present in the charnockitic, granitic, and
O quartz syenitic gneisses as well as the amphibolite facies of the gabbro.

Tremolite Monoclinic Prismatic
G Has been reported in the Grenville marble.

Hematite Fe_2O_3 Hexagonal Rhombohedral Scalenohedral

DeMatties (1974) reported hematite as a secondary mineral from the oxidation of magnetite. It may occur alone as a
S pseudomorph, or associated with magnetite forming rims around magnetite grains. It is a minor mineral, but locally may be present to the extent of 4.1%.

Pyroxenes

S The following pyroxenes have been found: augite, clinopyroxene, diopside, hypersthene, orthopyroxene, and pyroxene.

Clinopyroxene Monoclinic Prismatic

Present in all rocks of Lake Sanford area being up to
S 30% by volume of the gabbro and diminishing to less than 5% of the anorthosite (Gross, 1968).

Orthopyroxene Orthorhombic Dipyramidal
S Most abundant in gabbros rich in ore.
O Most abundant in metanorite (DeMatties, 1974).

Diopside Monoclinic Prismatic

Parts of the Grenville marble have abundant diopside, but in the field trip area crystals and gem variety diopside
G have not been found. The Grenville marble containing the crystals of gem variety diopside is located about 66 miles to the northwest near DeKalb. The diopside in the field trip area is dispersed as grains up to 2 mm in diameter.

Magnetite Fe_3O_4 Isometric Hexoctahedral

Magnetite intergrown with ilmenite and ulvospinel occurs in sizes ranging from microscopic to larger than 50 feet on
S edge. It can be easily separated from ilmenite, but not from ulvospinel. Crystals are unknown in the Tahawus and Blue Ridge area.

G It occurs in quartz in grains generally less than 1 mm in maximum dimension and is never megascopic.

Rocks such as gabbro and gneisses occuring along the Blue
O Ridge road have very small quantities of magnetite present mostly disseminated as grains, but occasionally massive enough to support a small bar magnet. Crystals have not been observed.

Maghemite Fe_2O_3 Isometric Hexoctahedral

This is a secondary mineral formed from magnetite. It has not been reported as yet. Slightly softer than magnetite,
S brown, brown streak, ferromagnetic. Palache, Frondel, and Berman (1944) state "the brown alteration product of many magnetites, especially on specimens found near the surface, is
O apparently maghemite." Ramdohr (1969) states that the color may "even be bluish-black." When heated, the maghemite alters rapidly to hematite. There is reason to believe that this mineral is present especially since Ramdohr (1969) notes, "impurities such as V and Ti appear to favor the formation of maghemite from magnetite and make the maghemite more stable."

Ilmenite Fe_2TiO_3 Hexagonal Rhombahedral

Ilmenite is weakly magnetic. It occurs almost entirely intergrown with magnetite and ulvospinel. According to Gross (1968), its grains are smaller than magnetite's and it can be recognized megascopically only "in coarse-grained anorthositic ore by its high luster and conchoidal fracture compared to the dull luster and parting planes of magnetite." In addition, a tiny bar magnet held against the bottom part of a mass of ilmenite will not be supported and fall when the ilmenite is almost as large as the magnet, whereas if there are both ilmenite and magnetite of equal grain size, the magnet will be supported. Indeed, if the ore is fine-grained, it is not possible to distinguish the ilmenite and magnetite megascopically. The easiest method of finding the ilmenite is to use a small bar magnet about 1" x 0.2" x 0.2" and apply it to the specimen. A most generous supply of ore specimens is provided by N L Industries at the visitors overlook. However, since many are too large to carry, it is advisable to bring along a sledge hammer, chisel, and safety glasses. The specimens containing ilmenite in this size are scarce, but with patience the collector will be rewarded.

Ulvospinel Fe_2TiO_4 Isometric Hexoctahedral

Ulvospinel is a mineral which was first known synthetically, later suspected being present in some magnetites, and finally found in Swedish magnetite ores. Its occurrence has been reported in over 25 localities such as Africa, Australia, China, and the moon. However, special techniques employing oil immersion, magnification in the order of 1000 times, and meticulously polished surfaces are essential for its identification.

Ramdohr (1953) was the first to find ulvospinel at Tahawus. It has about the same magnetic intensity as magnetite so cannot be separated by this property. There may be MgO, Al_2O_3, and V_2O_3 present in very minute amounts in the ulvospinel. It occurs in magnetite to the south of Lake Sanford area in very minute veinlets (DeMatties, 1974), anhedral grains, exsolution lamellae, and exsolution nets. Ramdohr (1953) states that at times magnetite has been found to contain "as much as 30% of extremely fine grained ulvospinel."

Pyrite Isometric Diploidal

G Where exposed on the surface of the Grenville marble pyrite has been oxidized to goethite often staining the white calcite a rust color. Where embedded in the calcite so that it has been protected from chemical weathering, it often occurs as crystals cube, pyritohedron, modified cubes and pyritohedrons, metallic luster, brassy yellow ranging from microscopic to megascopic.

S Gross (1968) states that pyrite and pyrrhotite "are most frequently associated with minerals of the reaction zone between ore and anorthosite. Pyrite occurs as very thin late veinlets that cut ore and gabbro" mostly thinner than 0.6 inch. The sulfide minerals are widely disseminated in many of the Lake Sanford rocks, but rarely exceeds one per cent.

Pyrrhotite Hexagonal Dihexagonal Dipyramidal

G Metallic luster, dark brown on tarnished surface and pale bronze-yellow, almost silver on fresh surface; massive, in grains longer than wide, but mostly under 1 mm; ferromagnetic; may appear to be magnetite to the unwary, but color considerably lighter and much softer.

Quartz Hexagonal Trigonal-Trapezohedral

S A very minor mineral

G Occurs as grains disseminated in the Grenville marble. Most abundant in the quartzite member of the Grenville Series.

O Present in the charnockitic, granitic, and quartz syenitic gneisses.

Scapolite

A series of minerals ranging in composition from calcium aluminum silicate with chlorine, carbonate, and sulfate to sodium aluminum silicate with chlorine, carbonate, and sulfate. The last three can completely substitute for one another.

Tetragonal Dipyramidal

G Reported as being present.

S Stephenson (1945) found scapolite as an alteration product of plagioclase feldspar with the scapolite "occurring as scaly aggregates along the borders of the grains." It is also common in the "reaction zones between the ore and anorthosite."

Sphene $CaTiSiO_5$ Monoclinic Prismatic

G Wedge-shaped brown to very light brown crystals mostly smaller than 0.5 mm in diameter. Very difficult to see crystal faces. Largest size seen in this region are about 1 mm in diameter. The crystals are roughly circular in shape. One cleavage has been observed.

Plagioclase feldspar

Andesine 50-70% albite 30-50% anorthite

Present to a small extent in the metanorthosite making up some of the smaller and medium-sized grains especially in the groundmass;
S more abundant than labradorite in the metanorite (DeMatties, 1974), and in the diorite (Avenius, 1948). Heyburn (1960) found andesite of a brownish pink color in two pegmatite dikes.

Labradorite 30-50% albite 50-70% anorthite

This is the most abundant feldspar in the field trip area. It constitutes the major mineral in the ore-barren metanorthosite. It is also present in the ore as phenocrysts. The author has seen and
S collected magnificent specimens containing phenocrysts of labradorite exhibiting polysynthetic twinning embedded in titaniferous magnetite. Some of the plagioclase feldspar inclusions attain lengths of 6 inches. The color varies from blue to dark gray, almost black.

Specimens of labradorite may be collected in outcrops on the
O eastern half of the Blue Ridge road. They are also available in rounded pebbles, cobbles, and boulders in the gravel pits just east of Newcomb.

Potash Feldspar

Microcline $K(AlSi_3O_8)$ Triclinic Pinacoidal

Avenius (1948) reported this feldspar as being present in what he called diorite and others gabbro near northern Cheney Pond. Stephenson (1945) determined that microcline constituted about 1/4
S of the syenitic phase of the gabbroic anorthosite. DeMatties (1974) noted that it is present in the Whiteface metanorthosite facies. Potash feldspar has been found in all of the rocks of the Sanford Lake area, but only in a few places as mentioned above has it been identified as microcline.

Balk (1932) found microcline "medium-grained, in a well-foliated
G lime-silicate rock" visible only microscopically in a scapolite rock where "the main highway on the west shore of the Hudson crosses the 1500 foot contour line."

Orthoclase $K(AlSi_3O_8)$ Monoclinic Prismatic

O Miller (1919, p. 41) reported orthoclase in granite intruding anorthosite 1 mile south of Sand Pond.

Spinel

A group of Isometric Hexoctahedral oxides usually containing at least two of the following: Al, Cr, Fe, Mg, Mn, and Zn. Minor amounts of a green spinel which Stephenson (1945) identified as her-
S cynite $FeAl_2O_4$ with MgO bounds some of ore minerals, but width of grains is less than 0.5 mm. "Lamellar intergrowths of spinel parallel to the cube direction in magnetite may occur" (Stephenson, 1945). Undoubtedly this is ulvospinel that Ramdohr identified.

Pleonaste

An iron spinel and at times almost transparent. Also occurs
S in minute quantities in the Lake Sanford area ores. Ramdohr has identified it as being present. (Ramdohr, 1953)

Very minor amounts of spinel occur in the Grenville marble.
G The author has seen minute pink octahedrons (much smaller than 0.1 mm) in the Grenville marble between Whitehill and Ticonderoga, but they are very rare.

Wollanstonite $CaSiO_3$ Triclinic Pinacoidal

G Has been reported in the Grenville marble.

Zircon $ZrSiO_4$ Tetragonal Ditetragonal Dipyramidal

G Has been reported in the Grenville marble.

Among the very minor minerals reported from the Lake Sanford area are barite, chalcopyrite, epidote, leucoxene, molybdenite, orthoclase, prehnite, quartz, scapolite, and sphalerite.

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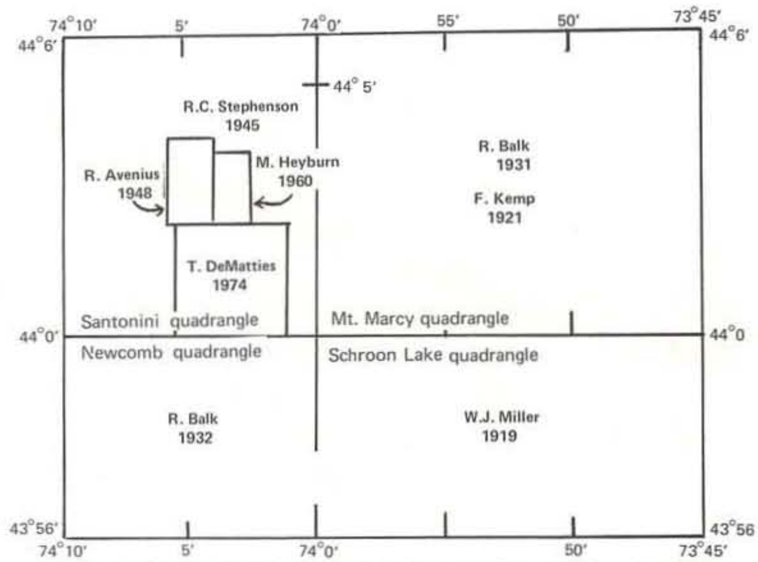


Figure 1. Quadrangles in field trip area with names of authors of geological publications

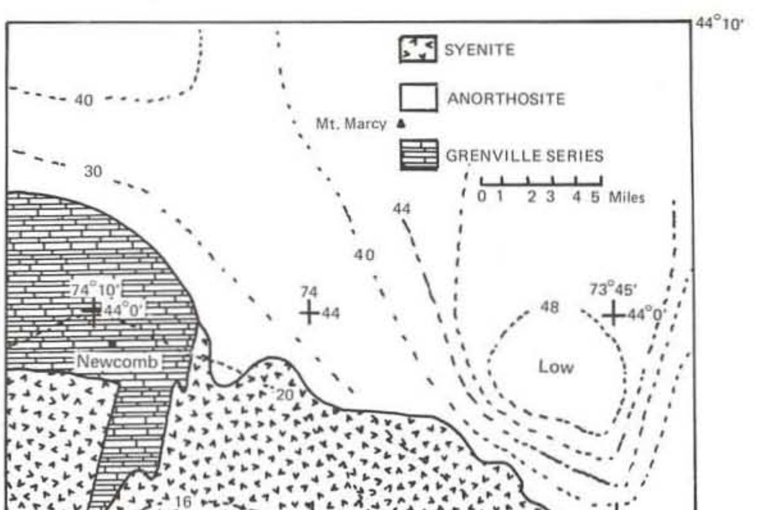


Figure 2. Marcy metanorthosite massif with adjoining rock types and isogravity lines. *(After Simmonds 1964)*

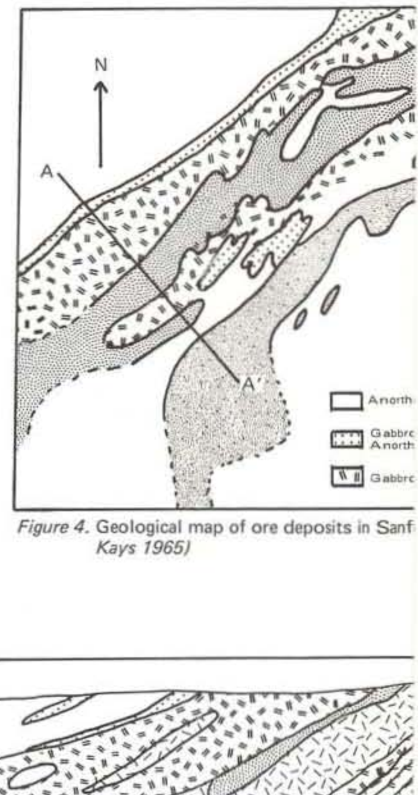


Figure 4. Geological map of ore deposits in Sanf
Kays 1965)

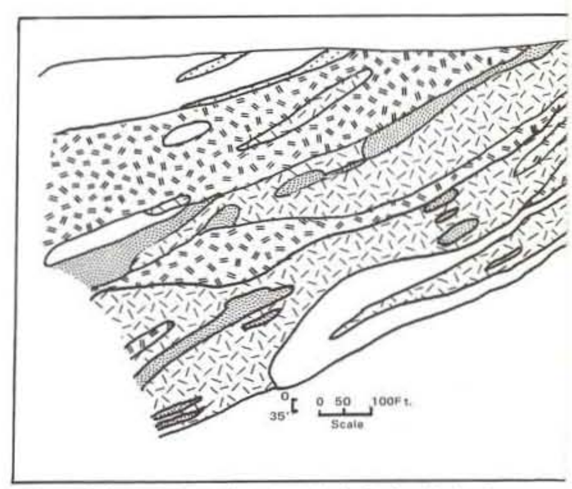
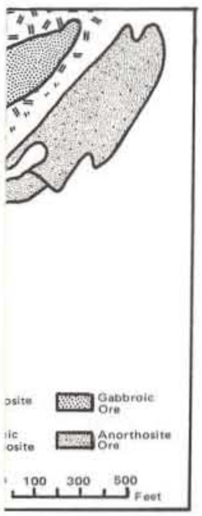
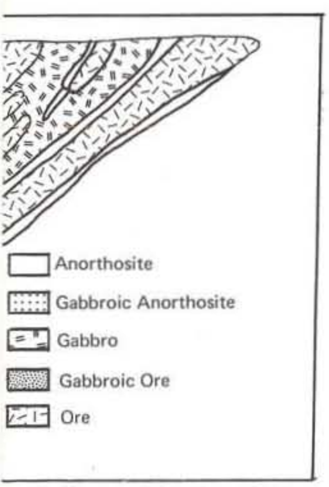


Figure 5. Cross section of ore deposits in Sanford Lake along area



ord Lake area *(After*



AA' in Figure 4 *(After Kays 1965)*

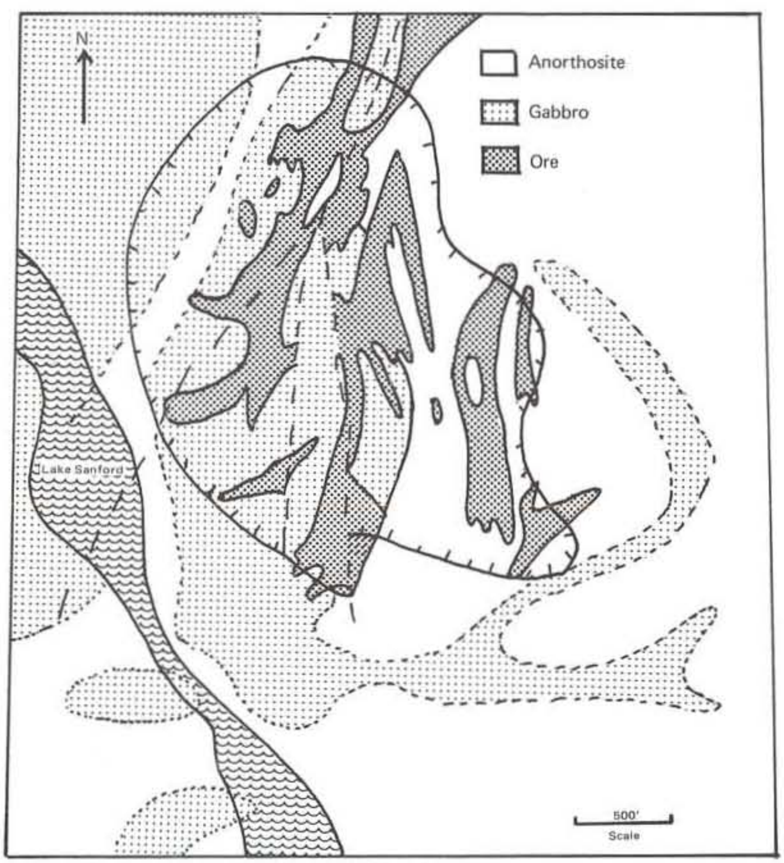
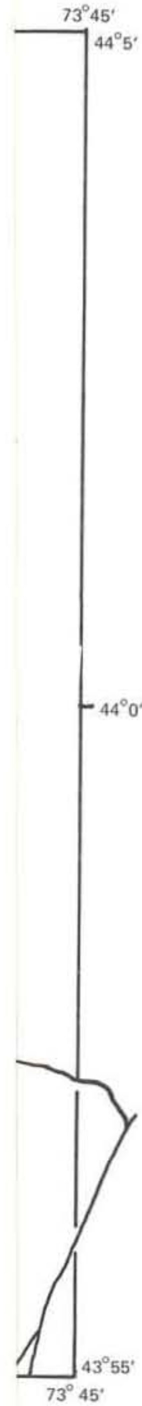


Figure 6. South extension pit Sanford Hill *(After Gross 1968)*



ROAD LOG

Mileage: Point to point	Mileage: Cumulative	Directions & Descriptions
0		LEAVE College, east on I-88, east on N.Y. 7 to Duanesburg right on U.S. 20 until I-87.
73	73	
99	172	Left on I-87 (Northway). Leave at exit 29. Second sign reads Newcomb. Turn left under Northway going west.
3.1	175.1	Bruce's Blue Ridge Store (only one for miles) on right.
3.0	178.1	Small bridge. On left sign "Trail to Hoffman Road 8.5 miles, Big Marsh Pond 3.5 miles."
8.3	186.4	Sign on left reads "Trail to Irish Town via Minerva Stream and Lester Dam 11 miles." Parking area on left.
4.4	190.8	Triangle formed by road intersections; stop sign; turn right to Tahawus. There are no side paved roads. Stay on paved road.
6.7	197.5	Left is to trails to Mt. Marcy and high peaks.
0.6	198.1	NL Industries Mineral Collecting Area. Continue past this point to parking area near office building. STOP 1 The trip from Oneonta will take about 4 hours and 15 minutes. We will meet at the mine at 11:00 a.m. Our leader for this part of the field trip will be Stanford O. Gross of NL Industries, resident Geologist and Mining Engineer. We will be here until 1:00 p.m. You will have an opportunity to collect at the Mineral Collecting Area until about 1:30 p.m.
7.3	205.4	Road south to triangle. Turn right to Newcomb.
0.1	205.5	Railroad crossing.

Mileage		
Point to point	Cumulative	Directions & Descriptions
3.0	208.5	On left Finch Pruyn Co.
1.5	210.0	Crossing the Hudson River
1.1	211.1	Turn left and park in Newcomb Central School parking area. STOP 2 Marble outcrops on east side of parking lot; massive grayish-white calcitic; portions stained a light yellow-brown; Present are graphite, calcite, and in small grains pyrrhotite, garnet, and sphene. Turn right on highway (Route 28N) going east.
1.1	212.2	Hudson River crossing.
1.5	213.7	On right is Finch Pruyn Co.
1.8	215.5	On left is road to Tahawus.
0.3	215.8	On left is another road to Tahawus.
0.5	216.3	Enter gravel pit. STOP 3 Well rounded boulders, cobbles, and pebbles of metanorthosite, gneisses, and other rocks in the area occur in this fluvioglacial deposit along with sand.
0.1	216.4	Turn right after leaving gravel pit.
0.4	216.8	Turn right.
0.3	217.1	Triangle.
0.8	217.9	Crossing railroad tracks.
0.1	218.0	Keep right to Northway (I-87), but do not take left which is back to Tahawus.
1.6	219.6	STOP 4 On both sides of the highway are large outcrops of amphibolite weathered a deep brown. A fresh surface is medium-grained grayish-brown with nodules of hornblende scattered throughout the

Mileage		
Point to point	Cumulative	Directions & Descriptions
		medium-grained material. Some of the amphibolite has a pinkish tint when there is more garnet present. Also present are biotite, garnet, plagioclase feldspar, and quartz. Some of the amphibolite nodules have been elongated producing a gneissic appearance. Some of the amphibolite has been intruded by numerous dolomite veins less than 2mm wide.
2.9	222.5	STOP 5 Parking area on right. Sign reads Trail to Irishtown via Minerva Stream and Lester Dam. On both sides of road extensive outcrops of garnetiferous gneiss. Occasional magnetite present with some hornblende and pyroxene. Some gabbro is also present in which magnetite and ilmenite are abundant.
0.2	222.7	STOP 6 On left is garnetiferous gneiss with some magnetite.
0.6	223.3	STOP 7 On left gabbro with garnet, pyroxene, very small amounts of magnetite and ilmenite with plagioclase feldspar as metacrysts. Gabbro is lighter than stop 5 occurrence.
2.1	225.4	STOP 8 Metanorthosite outcrops, weathered and fresh medium-grained; weathered metanorthosite is white and fresh surface is dark gray.
1.7	227.1	STOP 9 On left outcrop of coarse-grained metanorthosite. Phenocrysts are much larger than in previous outcrop.
6.2	233.3	On left Bruce's General Store, Blue Ridge, N.Y.

Mileage		
Point to point	Cumulative	Directions & Descriptions
2.4	235.7	On right is sign reading Northway (I-87S) Entrance. STOP 10 Across the street to the left about 50 feet east of the sign stating speed 40 mph is Stop 10. Diabase dike intruding metanorthosite. About half way up the hill the contacts between the diabase and metanorthosite are readily visible with the width of the diabase about 3 feet. There appears to be another dike several feet to the west which is broader, but there are no contacts visible. The first dike strikes almost due north.
0.1	235.8	Turn right to go south on I-87 toward Albany. If you wish to go north, continue east to entrance to I-87 North. Field Trip is concluded.