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IN THE CITY OF NEW YORK

Department of Earth & Environmental Sciences

NY-NJ Mineral Field Trip

Arthur D. Storke Memorial Expedition

August 2-4, 2013

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Front page: Trip Participants at Barton Garnet Mine (Gore Mountain, NY)

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Preface

By Alexander Lloyd

What is a mineral? Introductory geology textbooks usually cite 5 characteristics that define a mineral: solid, inorganic, naturally occurring, crystalline structure, and representable by a chemical formula. This is a sufficient definition for academic pursuits, but to the general public minerals represent a whole lot more. Minerals can be the goal of resource extraction and can be exploited for specialized industrial applications. Some people believe that minerals have intrinsic mystical properties that can be a source of power or healing. And for others, the unique properties of minerals can serve as a reminder that there are countless phenomena left to explore in Earth Science.

Sometimes it is easy to forget the geologic wonders that exist in our own backyard, and it was this theme that guided our planning. The initial goal of this field trip was to explore famous mineral occurrences in the greater New York/New Jersey area in order to understand their origin from an academic perspective. The three destinations that we chose could easily be considered "Top 10" for many mineral aficionados in the New England area: the megacrystic garnet at Gore Mountain, NY; doubly-terminated quartz crystals at Herkimer, NY; and the fluorescent mineral capital of the world at Sterling Hill, NJ. Fortunately, our driving route took us through another region of geologic curiosities, the Adirondack Mountains physiographic province. Incorporating the Adirondacks allowed the students to expand the initial limited scope of this field trip to pursue other subjects including the orogenic history of New York State, metamorphism and melting during cratonic growth, and glacial peculiarities from the most recent ice age.

Our 3-day mineral-collecting field trip took place in August 2013 and was made possible by the Stroke Memorial Fund at Columbia University's Lamont-Doherty Earth Observatory. The trip was organized by a group of Ph.D. students from the Department of Earth and Environmental Sciences, and was accompanied by a student-led seminar series. This guide, prepared following the field trip, provides background information about geologic setting and mining history in New York/New Jersey area, and describes a number of interesting outcrops in the southern Adirondacks that recorded a billion-year geologic history of New York State.

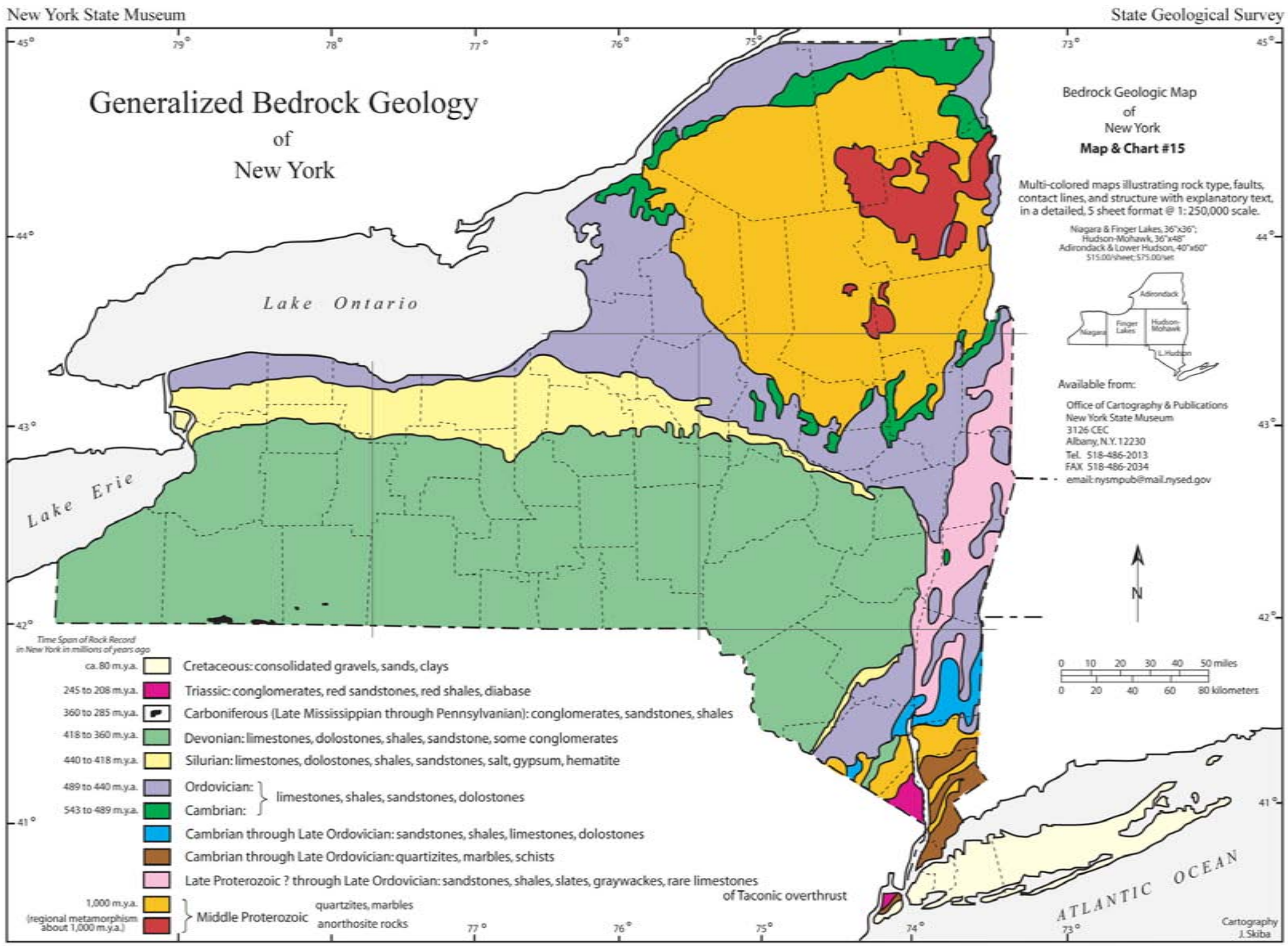

Figure 1. Simplified Geologic Map of New York State [1].

Geologic Setting

Geologic History of New York State

By Natalia Zakharova

Precambrian

The geologic history of the northeastern United States begins with the Precambrian Grenville rocks that are now exposed in the Adirondack Mountains and the Hudson Highlands (Figure 1). These crystalline basement rocks are an extension of the Grenville province, the youngest part of the Canadian Shield that lies along the eastern edge of Canada (Figure 2). These rocks record a long Precambrian history, which probably included repeated epochs of sedimentation, deformation, and metamorphism. Many of the Grenville rocks had their beginning as sediments in the seas adjacent to the North American continent in middle Proterozoic, eventually deformed by the Grenville Orogeny, a major mountain-building event in the Late Proterozoic that reset radiogenic ages of these rocks to ~1.0 billion years [2]. The orogeny had multiple phases and ended about 950 million years ago with the formation of the supercontinent Rodinia (*for more details, see p.12)*. Here, the Precambrian was also characterized by the formation of stromatolites, the most ancient record of life on Earth, which were formed by mounds of cyanobacteria (*see p. 25*).

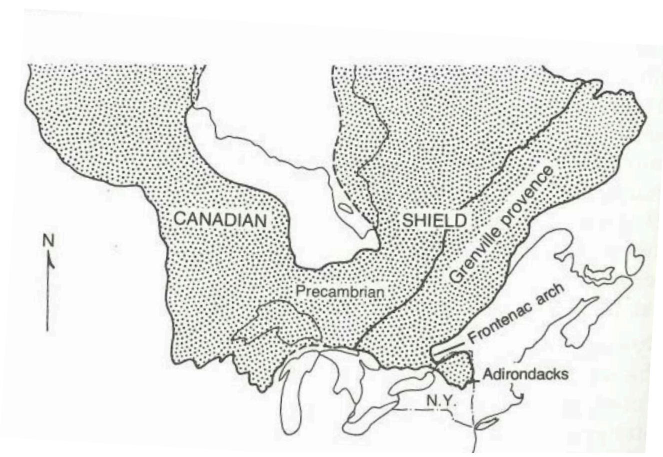

Figure 2. Schematic map of the Canadian Shield, the vast terrane of Precambrian bedrock that forms the nucleus of North America [2].

The northern continents in Rodinia did not separate until ~650 Ma. By then, as much as 15 miles of rock had been eroded from the Grenville orogenic belt. Although the original mountains were never that high, they were continuously growing due to isostatic rebound while being eroded away. The Grenville rocks that we see on the surface today are 'exhumed' deep roots of those ancestral mountains.

The next major event was splitting of the continent that contained the Grenville belt, producing first a rift zone, and then an ocean basin called "proto-Atlantic" or Iapetus[1]. Late Precambrian and early Paleozoic sediments and volcanic material were deposited in and beside this ocean, and one or more volcanic island arcs may have been present farther to the east. Thus began another tectonic cycle that would involve long-

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[1] after the Titan Iapetus who, according to the Greek mythology, was the father of Atlas. Atlas, in turn, gave the name to the Atlantic that translates as 'the Seas of Atlas'

term erosion and sediment deposition on the continental margins as the ocean basin widened, followed by another episode of closing accompanied by volcanism and mountain-building. This cycle was interrupted by an incomplete plate convergence about 575 million years ago that resulted in the Avalonian orogeny. In New York, the Avalonian orogeny caused deformation and metamorphism only in the Precambrian rocks of the Hudson Highlands and the Manhattan Prong.

Paleozoic

The Iapetus Ocean continued to widen during late Cambrian and early Ordovician periods. As the New York landscape was eroded to a low level, the state was gradually submerged beneath the shallow, westward-transgressing Potsdam sea, in which a great thickness of sediments accumulated. The earliest unit in the marine-transgressive sedimentary sequence is the Potsdam Sandstone (*e.g., see p. 38*) that lies unconformably on the Precambrian metamorphic rocks. It was deposited in near-shore coastal environments as sea level rose to gradually inundate the craton of the paleocontinent of Laurentia. Formed from sediments eroded off unvegetated terrestrial landscapes, it consists almost entirely of sand-size quartz grains held together by quartz cement [3]. The Potsdam sandstone is found primarily north and west of the Adirondack Mountains. Outcrop exposures of the Potsdam Sandstone occur throughout the Saint Lawrence lowlands, western Lake Champlain Valley, and northern Mohawk Valley.

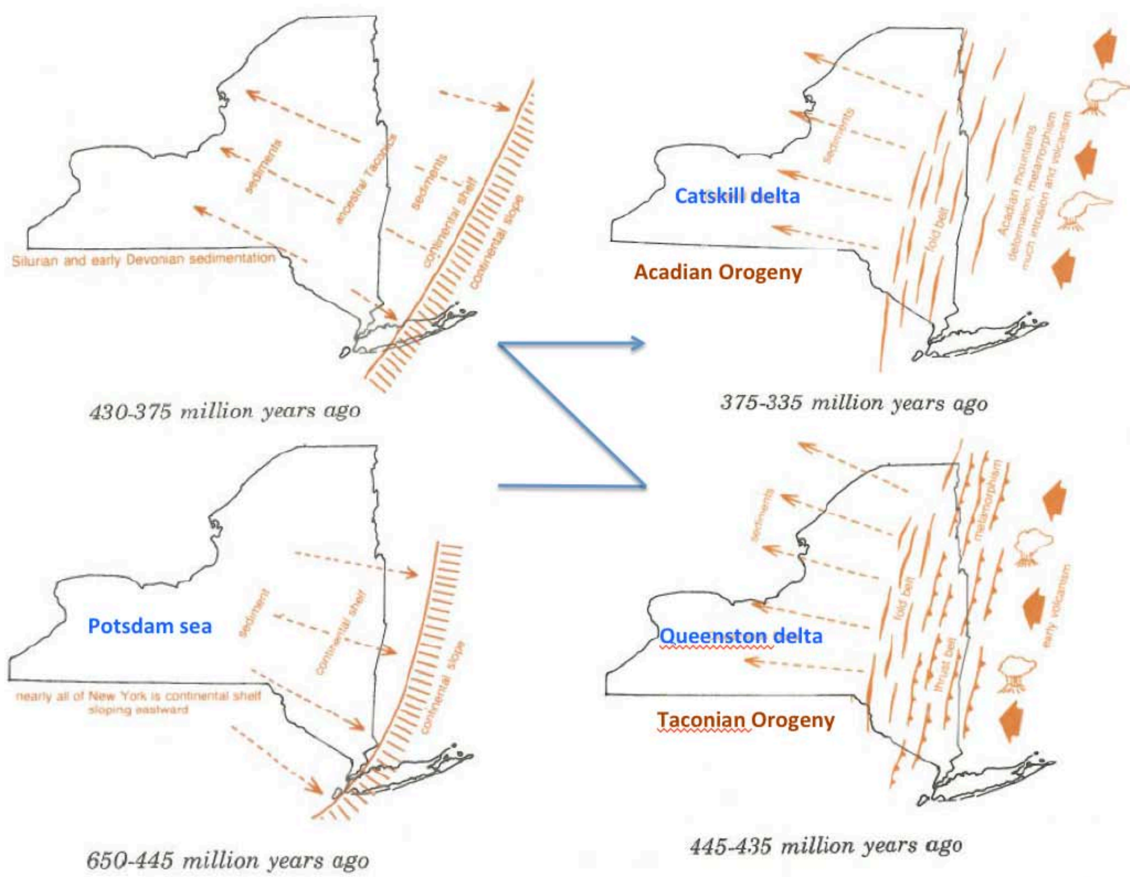

Figure 3. Schematic tectonic setting in New York during the Paleozoic (modified from [2]).

In the middle Ordovician, the proto-Atlantic ocean began to close, leading to the Taconian orogeny (~445-435 Ma). This was the first of a series of mountain building collisions that contributed to the formation of the Appalachians throughout the Paleozoic Era. At the beginning of the Taconian orogeny, shortening was accommodated by a large offshore thrust zone, with the eastern segment being thrust over the western segment. Partial melting along this subduction zone led to a formation of a volcanic island arc, and volcanic material and black muds were added to the sediments of the continental margin situated over eastern New York State. By the late Ordovician, the ancestral Taconic mountains began to rise, the island arcs were shoved against and welded to the continent, and the ocean basin was consumed. As the Taconic mountains rose, they were eroded and sedimentation shifted westwards, displacing a shallow sea and forming the immense Queenston Delta (from Queenston formation exposed in the Ontario Lowlands, Figure 1) that reached beyond modern Niagara Falls. The Taconian orogeny, therefore, not only produced high mountains and caused metamorphism throughout western New England, but also completely reversed the sedimentation pattern in New York from slow eastward deposition on a continental shelf to rapid westward deposition form the mountain toward continental interior (Figure 3). At the end of the Taconian event, however, the delta plain was itself uplifted and subjected to significant erosion, producing the Taconic unconformity, subsequently covered by Silurian and early Devonian sediments.

During the Silurian and early Devonian, renewed crustal stretching led to reopening of the proto-Atlantic and the formation of a passive continental margin, slightly further east than before (Figure 3). However, it did not continue for long, as the tectonic forces were reversed again, and closing of the southern Iapetus Ocean in the middle Devonian led to yet another orogeny. All of New England and the eastern edge of New York were intensely deformed again by the Acadian orogeny (~375-335 Ma). The North American continent collided with the Avalon terrains (comprised of the modern-day Northern France, Belgium, England, Wales, and parts of Ireland, Newfoundland, and Nova Scotia). The collision formed a loftier range of mountains east of the eroded Taconics. Deformation associated with the uplift was overprinted on all rocks at least as far west as the Adirondacks but metamorphism only reached the very eastern part of the state. The new mountains again reversed the direction of sedimentation eastward, and another great delta, the Catskill Delta, was formed (Figure 3). The middle and late Devonian strata deposited in the delta form the entire southern tier of New York in the Allegheny Plateau (Figure 1).

The final closing of the Iapetus Ocean was caused by the collision of the North America proto-continent (Laurentia) with Africa, which was part of a larger supercontinent (Gondwanaland) in Late Paleozoic. During this time, all of the Earth's continents were coalescing to form a single, great supercontinent, Pangaea (Figure 4). In eastern North America, the formation of Pangaea corresponded to the Alleghenian Orogeny (~325-260 Ma), the mountain-building episode associated with the formation of great folds and thrust faults throughout the southern and central Appalachian Mountains. The immense region involved in the continental collision, the vast temporal length of the orogeny and the large thickness of the deformed sediments and igneous rocks suggest that at the peak of the mountain-building process, the Appalachians likely once reached elevations similar to those of the Alps and the Rocky Mountains before they were eroded [4]. The Alleghenian Orogeny was followed by an extensive period of erosion. Sediments that were carried westward during subsequent erosion of the Appalachians contributed to the formation of the Allegheny Plateau in western New York. Much of the modern New York landscape is the product of slow erosion since Alleghenian time.

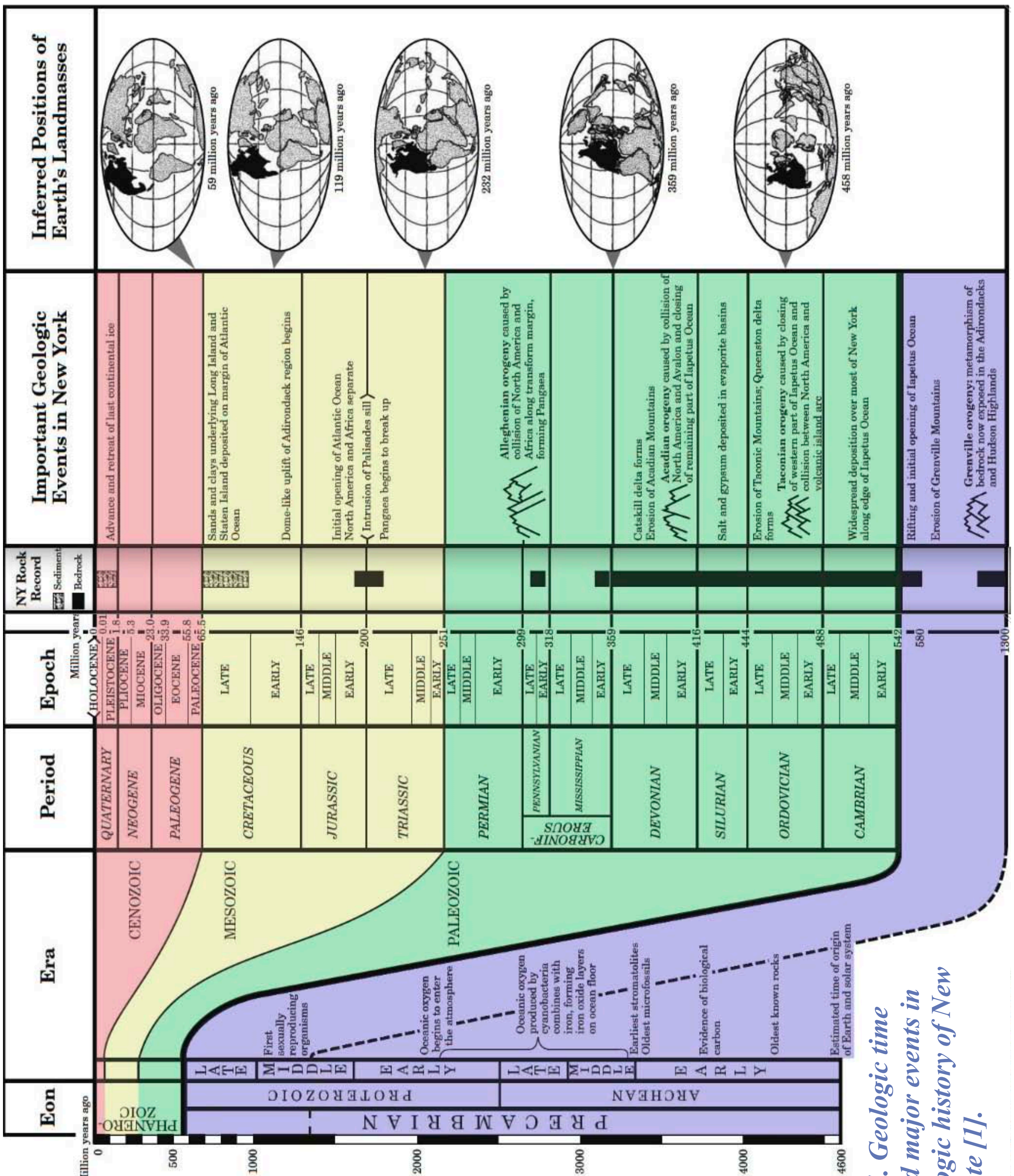

Figure 4. Geologic time scale and major events in the geologic history of New York State [1].

Mesozoic & Cenozoic

Pangaea began to break up about 200 Ma to form the modern continents, and the newly born Atlantic Ocean started to form from a rift zone between Africa and Europe on one side, and the Americas on the other. The Late Triassic-Early Jurassic Newark basin (stretched form southern New York to northern Pennsylvania) is a characteristic half-graben rift basin filled by non-marine sediments (red beds) and igneous rocks formed during the continental breakup. Bounded by the Ramapo border fault on the northwestern side, the Mesozoic rocks lie unconformably on Precambrian and Paleozoic basement. One of the famous geological features within the Newark Basin is the Palisades diabase sill that forms prominent cliffs along the Hudson River north of Manhattan.

Later in the Jurassic, the Atlantic Ocean began to open forming the present continental shelf, slope, and rise. The oldest dated rocks at the bottom of the shelf sediments are Jurassic, but the oldest visible at the present land surface are mid-Cretaceous and Cenozoic shelf deposits. Most of the region was eroded in later Mesozoic and Cenozoic time; yet the Appalachian belt still stands moderately high and must have been differentially uplifted.

The Adirondack dome uplift started some time in Late Cretaceous or Tertiary. The age, rate and cause of the uplift is the subject of some debate but it is usually attributed to influence of a hotspot that the North American plate might have passed millions of years ago. Repeated surveys in 1950-1980 demonstrated that Adirondacks are rising at the rate of up to 2-3 mm per year [5], which is many times faster than the erosion rate. The pattern of the observed differential uplift also suggested a tectonic rather than glacio-isostatic mechanism.

The last major geologic event in the northeastern United States was the Pleistocene continental glaciations. Terminal moraines record two major Wisconsin advances and at least two older ones (probably Illinoian and Kansan); only central and southern New Jersey and the bulk of Pennsylvania were spared. In New York, only features of the latest Wisconsin glaciation are preserved. It climaxed ~20,000 years ago, when the ice sheet was more than a mile thick in places, and extended roughly to the Missouri and Ohio Rivers, and to Long Island (Figure 5). The ice retreat is well recorded by glacial till and moraines, which spread unevenly over the glaciated area, disrupting the drainage and producing the many lakes of New England and New York. The Finger Lakes are spectacular testimony of the Ice Age: the lakes occupy troughs first carved by streams, then gouged by creeping tongues

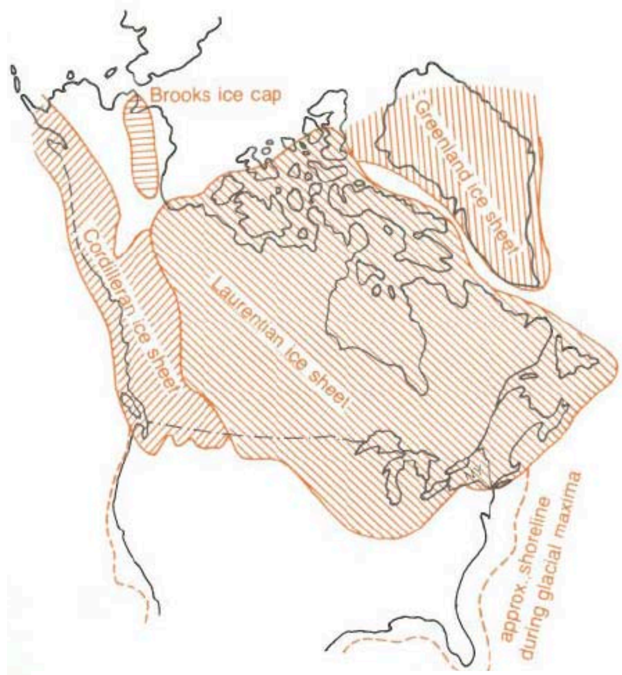

Figure 5. Maximum extent of the Wisconsin ice sheets in North America [2].

of ice, and finally, dammed in the south by the Valley Heads moraine. Much of Long Island and Cape Cod are also made of the terminal moraine deposits that indicate the farthest extent of the ice sheet. Some of New York's most spectacular gorges and waterfalls are secondary products of the Ice Age as well. For example, Niagara Falls began when Wisconsin ice backed off the Niagara scarp, and subsequent falls migration produced the 7-mile-long Niagara gorge. The Hudson Valley is actually a fjord, i.e. a U-shaped valley carved by a glacier. Many smaller glacial features, such as glacial erratics, striae, and potholes, are also found all over New York State (e.g., see p.28).

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New York State has been on the forefront of the geologic history of North America, and its rocks record some of the most ancient as well as the most recent events in the continent's growth and evolution. Starting with the Grenville orogeny a billion yeas ago, repeated episodes of deformation and metamorphism created some unique mineral assemblages not found anywhere else in the world. This not only makes New York State an interesting place for geological studies but also provides a fascinating mineral-collecting opportunities, some of which are described in the following sections of this guide.

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The Grenville Orogeny

By Margaret Reitz

The Grenville Orogeny is a worldwide mountain building event that took place between 1.3 and 0.9 billion years ago. Small cratons collided to form the supercontinent Rodinia. In eastern North America, Grenville-age rocks (mostly metamorphic ages) are found from Mississippi to Newfoundland. The largest exposure of the Grenville Orogeny in the United States occurs in the Adirondacks (Figure 2) [1].

Prior to collision, the edge of Laurentia is hypothesized to have been a passive margin (Figure 6*a*) due to the substantial volume of granodiorites, presumed to have formed from melting and recrystallizing passive margin sediments [1].

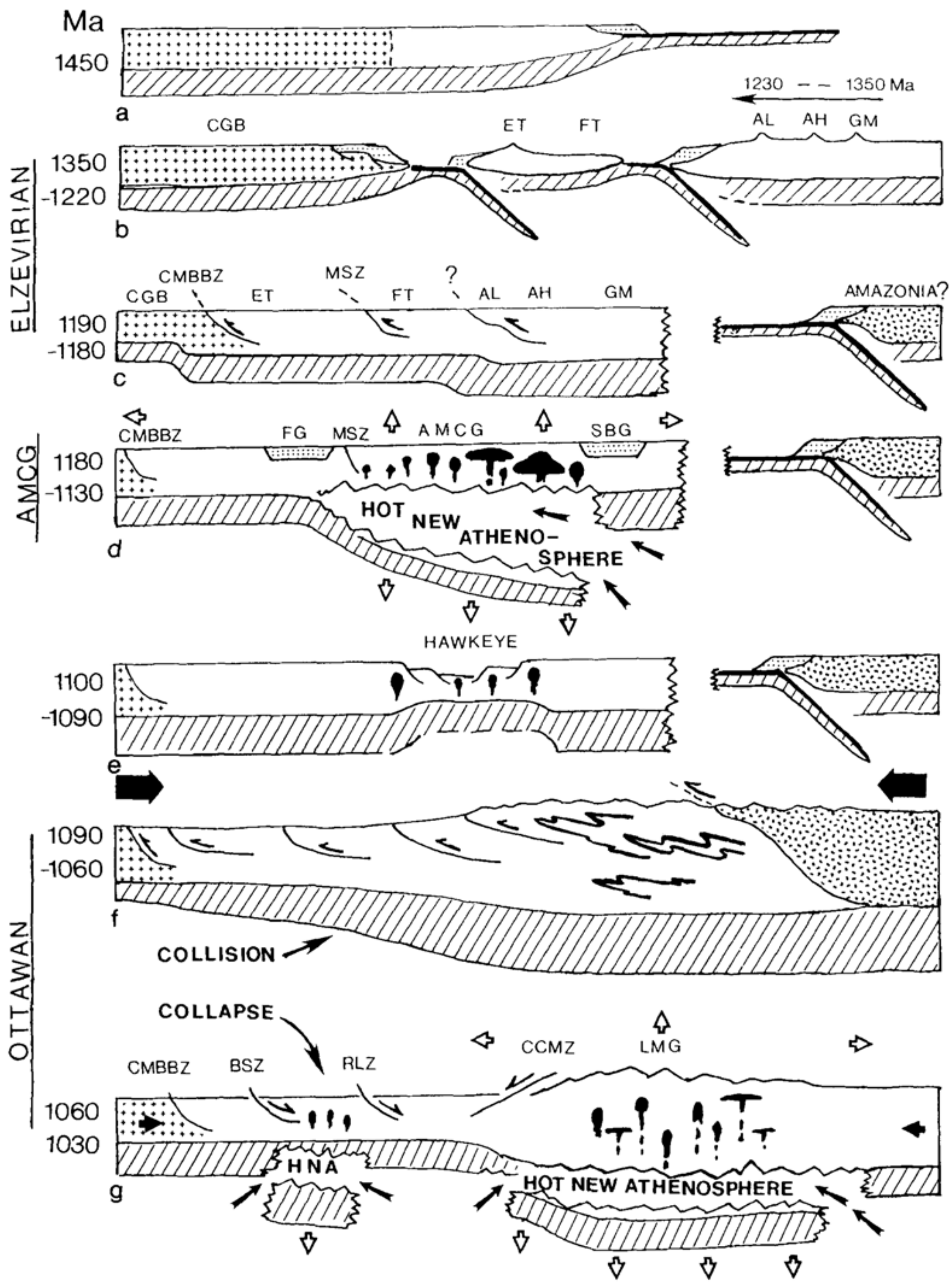

Figure 6. Schematic NW-SE plate tectonic reconstruction of the Grenville Orogenic cycle [3]. Diagonal ruling = lithosphere; small dots = sediments; crosses = ~1450 Ma gneisses of the Central Gneiss Belt (CGM); unpatterned = crust of the Adirondack-Central Metasedimentary Belt (CMB) region possibly including ~1450 Ma basement; random dashes = eastern colliding mass, possibly Amazonian; black = oceanic crust. AMCG = Anorthosite-Mangerite-Charnockite-Granite Suite; CCMZ = Carthage-Coltoon Mylonite Zone; CMBBZ = Central Metasedimentary Belt Boundary Zone; CGB = Central Gneiss Belt; CGT = Central Granulite Terrane; ET = Elzevir Terrane; FG = Flinton Group (Mazinaw Terrane); FT = Frontenac Terrane; MSZ = Maberly Shear Zone; SBG = St. Boniface Group (St. Mauricie region).

Beginning around 1.33 Ga, an island arc is thought to have developed offshore, intruding the passive margin sediments (now metasediments, where preserved). Tonalites and quartz diorites are the dominant plutons formed during this time, which cut and crosscut basaltic dikes of similar ages. Although highly metamorphosed, the original mineralogy and textures of this calc-alkaline suite have been preserved due to their anhydrous and felsic composition [2]. This first deformation event is known as the Elzevirian Orogeny (Figure 6*b,c*). This orogeny is not marked by unique fabrics or mineralogies, rather by a presumed association of the above lithologies with collisional margins and the accretion of offshore terranes [3]. Docking of these terranes likely ended around 1.18 Ga, with high strain and northwest-directed thrusting documented in the Central Metasedimentary Belt of Ontario [3]. The Elzevirian Orogeny is hypothesized as the last Adirondack-wide deformation, whereas the tectonic history between the NW lowlands and the SE highlands differ after this event. Here, we will only discuss the evolution of the SE highlands, since this was the focus of the field trip.

Following the Elzevirian Orogeny, a significant, shallow magmatic event occurred throughout the highlands (Figure 3*d*). It is known as the AMCG (Anorthosite-Mangerite-Charnockite-Granite) Suite and is only found in Grenville-age terranes around the world. The most widely accepted petrological explanation of formation is given by Emslie [4]: The AMCG suite forms first as ponded mafic magmas at the base of the crust. The crystallizing plagioclase floats while the olivine sinks, leading to plagioclase magma saturation. Contemporaneous partial melting of the lower crust leads to formation of charnockitic and granitic magmas. Eventually, these magmas rise diapirically through the crust accompanied by the anorthositic magma below it. The tectonic explanation for melting is less clear because these are intraplate magmatic events not indicative of rifting. In fact, when rifting does occur near the anorthosite massifs, melting moves toward the plate boundary, away from anorthosite locations. Most recently, formation has been attributed to a post-orogenic crustal delamination brought on by the Elsevirian mountain building event [3]. These plutonic rocks underlie nearly all of the Adirondack highlands and are often overprinted by a later metamorphism event.

A clearly post-AMCG, but possibly pre-Ottowan Orogeny event in the Adirondacks is the emplacement of a lower crustal melt at 1.10 – 1.09 Ga, the Hawkeye Granite (Figure 6*e*). It may be the first sign of shortening associated with the Ottawan Orogeny, but since it is unique to the Adirondack region and these are anorogenic granitoids, a localized extension event is the favored hypothesis [3]. McLelland suggests it is a “far-field echo … of the continental extension” occurring in the Midcontinent rift system at the same time (Figure 7).

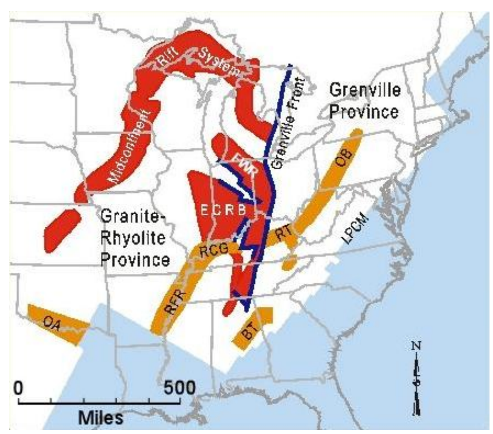

Figure 7. Location of the MC rift zone in the Proterozoic. Notice the spatial relationships of the Adirondacks to the MCRZ.

The main Grenville event occurred between 1.09 Ga and 1 Ga, known as the Ottawan Orogeny (Figure 6*f*). The AMCG and Hawkeye emplacements suggest a weak, hot crust and lithosphere at the beginning of the

Ottawan Orogeny. This orogeny is recognized by pervasive granulite facies metamorphism of the passive margin sediments and AMCG suite. Temperatures of 750-800˚C and pressures of 7-8 kbar [5] indicate a crustal thickness of 60-65 km by 1.07 Ga, double the current thickness and on par with the modern-day Himalayan Mountains. Shear zones, mostly located north and west of the Adirondack region and identified by mylonite and strong gneissic banding, generally suggest NW-directed shortening throughout this event. In the Adirondack region, high-grade metamorphism and shortening structures are found, but there is no evidence of andesitic volcanism, suggesting collision similar to that of the Himalayan orogeny with the subduction zone outboard of the Adirondacks and with a SE polarity [3]. The continent that collided has not yet been identified, but the Amazonian shield is a good candidate [6].

The termination of the collision is identified by the emplacement of A-type (anorogenic) granites beginning at 1.07 Ga (Figure 6*g*). A-type granitoids have a high silica and halogen content, which results from the melting of granulite facies rocks as well as dehydrated tonalite and granodiorites [8]. Widespread collapse and denudation is supported by numerous data, including P-T-t paths [5], garnet zoning [7], and low-angle detachment faults [3]. The largest detachment fault in the Adirondacks is the Carthage-Colton mylonite zone that juxtaposes the amphibolite facies of the NW lowlands from the granulite facies in the SE highlands [9]. Such a rapid exhumation requires a cooling of the Adirondack highlands of ~15˚C/Myr, which is not unreasonable from the few studies attempted [3].

Beginning around 750 Ma, Rodinia began to rift apart. The Iapetus Ocean (predecessor to the Atlantic Ocean) formed to the east of the Adirondacks and a sequence of Cambrian passive margin sediments was deposited unconformably above the Grenville rocks.

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Mining in New York and New Jersey

Historical Overview

By Jesse Farmer

Though not normally considered stalwarts of American mining, New York and New Jersey both have rich mining traditions dating back to pre-colonial times. Mineral extraction has been a constant feature of the area since the first arrival of humans after the end of the last glacial period. Native tribes were known to exploit chert, clay, and iron- and manganese-rich mineral deposits for projectiles, pottery, and pigments, respectively [1].

With the arrival of European settlers to New Amsterdam around 1626, mineral exploration began in earnest in the southeastern New York and northern New Jersey. These early quests, though searching primarily (and unsuccessfully) for gold and silver, discovered iron ores in bog deposits and, later, from magnetite deposits along the Hudson River. Both became important iron sources for local refineries. Clay deposits in the Hudson Valley were also utilized for brick and pottery. Isolated galena and chalcopyrite deposits became sources of lead and copper, respectively, with copper ore mining operations established around Port Jervis early in the colonial period. As settlers migrated up the Hudson Valley, mining activities followed, though most were of local scale [2].

Prospectors reached the Franklin-Sterling Hill region in northern New Jersey around 1640, but mistook the abundant zincite and franklinite for suitable ores for copper and iron smelting, respectively. Thus began over two centuries of fruitless attempts to isolate iron from franklinite, a highly refractory iron ore. An iron forge constructed in Franklin, NJ around 1770 fell into disrepair by 1820. It was only by the start of the 19th century that chemists discovered the composition of the minerals at Franklin and Sterling Hill: zincite was described in 1810, franklinite in 1819, and willemite in 1824. Around 1835, a smelter in Washington, D.C. reduced the first metallic zinc in the United States from zincite mined in Franklin. In 1850, commercial zinc mining operations finally began in Franklin by the New Jersey Zinc Company, 210 years after the first discovery of the Franklin ores. The Sterling Hill franklinite mine opened for commercial production shortly thereafter, in 1877 [2].

The later 19th and early 20th century marked the apex of mining operations in New York State. Iron mines in the Adirondacks were critical to the Union's supplies during the Civil War, accounting for quarter of all U.S. iron ore production at the time. Bolstered by the Adirondack mines, New York State produced twenty-three million tons of iron ore between 1880 and the end of World War I [1]. Lead, sulfur, and graphite mining operations also began in the Adirondacks in this period. The original Barton garnet mine opened on Gore Mountain in 1878; Barton continues garnet mining operations in this area today.

For ore mining in New York and New Jersey, the twentieth century was largely a story of decline. The interwar period between 1919 and 1939 was marked by many mine closures, including repeated closure and reopening of the Franklin and Sterling Hill mines in New Jersey [2], and closures of graphite, stone quarry, and most iron and garnet mines in New York State. With surging demand for domestic raw materials during World War II, however, many mining operations recommenced. The large Adirondack iron mines reopened in 1938, with mines in Essex County, NY producing eight million tons of iron ore through 1945 [1].

Following World War II, the Franklin Mine in New Jersey shuttered due to ore depletion in 1954 [2]. The Sterling Hill zinc mine closed in 1986 due to low zinc prices and a local property-tax dispute [3]. In New York State, iron and titanium mining, both recommenced during World War II, continued until 1982. Industrial talc and sphalerite mines in St. Lawerence County, opened in the interwar period, finally shuttered in 2008 during the most recent recession. Wollastonite mining, initiated by NYCO in 1953, continues to this day, with the Adirondack mines accounting for about third of the present-day global supply of wollastonite [1].

Present day ore mining operations in New York and New Jersey have declined significantly since the 19th and early 20th century. Nonetheless, almost 2000 permitted mines exist today in New York State [4], with 264 active [5], and 75 additional active mines in New Jersey [6]. In 2009, mining operations accounted for $1.64 billion in non-fuel production from both states combined (*Tables 1 and 2*) [7,8]. Salt mining in western New York, and sand, gravel, and crushed stone mining from both states account for the majority of production and revenues. Approximately one million tons of extractable zinc ore is still present within the Sterling Hill Mine, but will remain in the ground for the foreseeable future in due to the high costs for pumping and testing mine water to comply with environmental regulations [9].

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2009 Minerals Yearbook

NONFUEL RAW MINERAL PRODUCTION IN NEW YORK[1, 2]

(Thousand metric tons and thousand dollars)

Mineral	2007 Quantity	2007 Value	2008 Quantity	2008 Value	2009 Quantity	2009 Value
Clays, common	699	28,500	745	28,200	605	30,200
Gemstones, natural	NA	96	NA	96	NA	97
Salt	7,990	400,000	7,660	431,000	6,240	426,000
Sand and gravel, construction	34,300 r	286,000 r	34,400 r	260,000 r	31,100	266,000
Stone:						
Crushed	47,300	432,000	41,000 r	384,000 r	37,200	410,000
Dimension	70	12,000	57	16,000	97	28,200
Combined values of cadmium [byproduct from zinc concentrates (2007–08)], cement, garnet (industrial), peat, sand and gravel (industrial), talc [crude (2007–08)], wollastonite, zinc (2007–08)	XX	393,000	XX	354,000	XX	207,000
Total	XX	1,550,000	XX	1,470,000 r	XX	1,370,000

r Revised. NA Not available. XX Not applicable.
1 Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
2 Data are rounded to no more than three significant digits; may not add to totals shown.

Table 1. Quantities and values of non-fuel mineral production in New York for 2007, 2008, and 2009. Source: [7]

NONFUEL RAW MINERAL PRODUCTION IN NEW JERSEY[1, 2]

(Thousand metric tons and thousand dollars unless otherwise specified)

Mineral	2007 Quantity	2007 Value	2008 Quantity	2008 Value	2009 Quantity	2009 Value
Clays, common	65	(3)	--	--	--	--
Gemstones, natural	NA	1	NA	1	NA	1
Sand and gravel:						
Construction	15,700 r	145,000	13,600 r	153,000 r	11,100	116,000
Industrial	1,090	33,200	1,010	31,800	906	30,200
Stone, crushed	20,000	162,000	17,900	155,000	14,500	124,000
Combined values of greensand marl, peat, and value indicated by footnote 3	XX	3,220	XX	W	XX	W
Total	XX	343,000	XX	339,000 r	XX	270,000

[r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; excluded from "Total." XX Not applicable. -- Zero.
[1]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[2]Data are rounded to no more than three significant digits; may not add to totals shown.
[3]Withheld value included in "Combined values" data.

Table 2. Quantities and values of non-fuel mineral production in New Jersey for 2007, 2008, and 2009. Source: [8]

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Barton Garnet Mine

By Alexander Lloyd

The Barton Mines Corporation open pit mine is located at an elevation of about 2600 ft on the north side of Gore Mountain. For 105 years, this was the site of the world's oldest continuously operating garnet mine, and the country's second oldest continuous operating mine under one management. The community at the mine site is the highest self-sufficient community in New York State. It is 10 miles from North Creek and 5 miles from State Route 28 over a Company-built road that rises 300 feet per mile.

The mined garnet is used in coated abrasives, glass grinding, metal and glass polishing, and most recently as the abrasive component in water jet cutting techniques. Garnet has been designated as the official New York State gemstone; however, Barton produces no gem material but collectors are still able to find rough gems. Stones cut from Gore Mountain rough material generally fall into a one to five carat range. Garnets from this locality are a dark red color. Special cutting schemes have been devised for this material in order to allow sufficient light into the stone.

As for the history of the mine, Mr. Henry Hudson Barton came to Boston from England in 1846 and worked as an apprentice to a Boston jeweler. While working there in the 1850's, Barton learned of a large supply of garnet located in the Adirondack Mountains. Subsequently, he moved to Philadelphia and married the daughter of a sandpaper manufacturer. Combining his knowledge of gem minerals and abrasives, he concluded that garnet would produce better quality sandpaper than that currently available. He was able to locate the source of the Adirondack garnet stones displayed at the Boston jewelry store years before. Barton procured samples of this garnet, which he pulverized and graded. He then produced his first garnet- coated abrasive by hand. The sandpaper was tested in several woodworking shops near Philadelphia. It proved to be a superior product and Barton soon sold all he could produce.

H.H. Barton began mining at Gore Mountain in 1878, and in 1887, he bought the entire mountain from New York State. Early mining operations were entirely manual. The garnet was hand cobbled (i.e. separated from the waste rock) by small picking hammers and chisels. Due to the obstacles in moving the ore, the garnet was mined during the summer and stored on the mountain until winter. It was then taken by sleds down to the railroad siding at North Creek whence it was shipped to the Barton Sandpaper plant in Philadelphia for processing. The "modern" plant at Gore Mountain was constructed in 1924. Crushing, milling, and coarse grading was done at the mine site. In 1983, the Gore Mountain operation was closed down and mining was relocated to the Ruby Mountain site (Figure 8), approximately four miles northeast, where it continues at present.

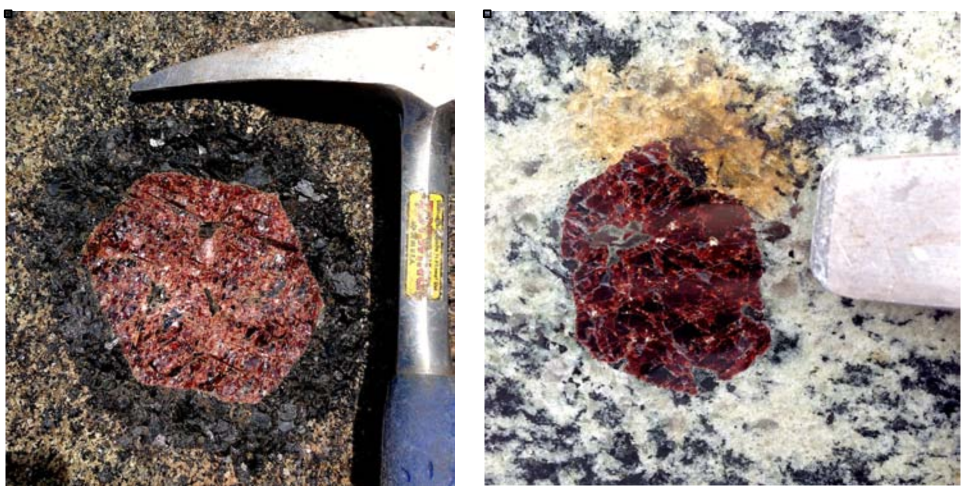

Figure 8. Gore Mountain (GM) Garnet (left) in comparison to Ruby Mountain (RM) Garnet (right).

Gore Mountain (GM) garnet had been mined for close to 100 years before the mine was moved to Ruby Mountain (RM). The garnets at GM tend to be much larger and form thick hornblendite borders between the garnet and host rock. This is a great example of the dodecahedral crystal habit of garnet (6-sided in cross section) and the tectonic parting that created the angular edges seen throughout the megacryst. On the other hand, the RM garnets tend to be much smaller and in a matrix that is primarily composed of plagioclase (consistent with the lack of H_2O to enhance growth and hornblende formation during garnet crystallization).

The now historic Barton Mine at Gore Mountain is approximately one mile in length in an ENE-WSW direction. The ore body varies from 50 to 400 feet and is roughly vertical. Mining was conducted in benches of 30 feet using standard drilling and blasting techniques. The ore was processed through jaw and gyratory crushers to liberate the garnet and then concentrated in the mill on Gore Mountain. Garnet concentrate was further processed in a separate mill in North River at the base of the mountain. Separation of garnet is accomplished by a combination of concentrating methods including heavy media, magnetic, flotation, screening, tabling, and air and water separation. Processes are interconnected and continuous or semi-continuous until a concentrate of 98% minimum garnet for all grades is achieved. Finished product ranged from 1/4 inch to 1/4 micron in size.

The garnet mined at Gore Mountain is a very high quality abrasive. The garnets display a well developed tectonic parting that, in hand specimen, looks like a very good cleavage. This parting is present at the micron scale. Consequently, the garnets fracture with chisel-like edges yielding superior cutting qualities. The garnet crystals are commonly twelve inches in diameter and rarely up to thirty-six inches with an average diameter of 4 inches. The composition of the garnet is approximately 37-43% pyrope, 40-49% almandine, 13-16% grossular and 1-2% spessartine. Chemical zoning in this garnet, where present, is very weak and variable. The garnet has hardness between eight and nine, and an average density of 3.95 g/cm^3.

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2. Smith-Amherst Mineralogy Field Trip to the Adirondack Mountains, 2008 (http://www.science.smith.edu/geosciences/min_jb/AdirondackTrip.pdf).

Franklin & Sterling Hill Mines

By Gary Mesko and Helen Janiszewski

The Franklin-Ogdensburg area in Sussex County is home to the world-famous Franklin and Sterling Hill mines that have unique zinc ore deposits and a wide variety of associated minerals. Over 300 types of minerals are known to occur there, approximately 10% of all known minerals in the world. Of those, 35 have not been found anywhere else, and 91 fluoresce [1]. Furthermore, the ore is mostly composed of zinc and manganese, with iron is a minor component, which is a very rare combination. The three most common ore minerals are franklinite, willemite, and zincite. These ore bodies lie within the Reading Prong massif and are part of the Franklin Marble formation. This marble was originally deposited as limestone on a Precambrian passive margin, and subsequently metamorphosed during the Grenville Orogeny. Although some metamorphism likely occurred during the Elzevirian Orogeny, most of the metamorphic ages (to amphibolite grade) are younger than 1.1 Ga, suggesting a closer relationship to the Ottawan Orogeny (*see p.12-14 for details*).

Mining in the Sterling Hill Mine began in 1730, but early attempts to produce economic products from these deposits failed due to a lack of understanding of the character of the ore minerals [2]. The ore was mistakenly thought to be a copper deposit. Indeed, zincite (ZnO) was likely early mistaken for cuprite (Cu_2O), and franklinite ($ZnFe_2O_4$) was long mistaken for magnetite (Fe_3O_4) that was early recognized in numerous other local deposits as an important source of iron ore. Continuous commercial production commenced in approximately 1848 as markets for zinc oxide as a white pigment were developed, with minor byproduct ferromanganese (spiegeleisen or spiegel) sold as demand warranted. Commencing in the 1880's, the demand for spiegel – with widespread adoption of the Bessemer steel process – increased to the point it became an important byproduct. Production was primarily from the Franklin Mine until it was depleted and closed in 1954; the Sterling Hill Mine, less economical to mine than Franklin, was the sole producer following 1954 and closed in 1986 due to economic conditions [3, 4]. The Sterling Mine achieved a depth of about 2,670 feet at the sump of the North ore body, under the center of the Wallkill River Valley [2]. The western side of the belt has many quarries that have been worked for blast furnace flux, lime, and cement [5]. At the time of its closing in 1986, the Sterling Hill Mine was the last working underground mine in New Jersey. It became a museum in 1989.

Many of the minerals present in the Sterling Hill Mine and nearby locations exhibit the property of fluorescence and phosphorescence. Fluorescence is an emission of light by a substance that absorbs electromagnetic radiation due to the energy released as an excited electron returns to its ground state. Typically, the emitted light is of a lower wavelength than the absorbed light due to energy lost to heat radiation. Phosphorescence is the after-glow present after the electromagnetic radiation source has been removed from the object and is due to intermediate reactions slowing the return of the electron to the ground state (Figure 9). The Sterling Hill mine minerals absorb UV radiation and emit visible light, making them very striking to the human eye (Figure 10). For a mineral to fluoresce several conditions must be met. Either it must be an inherently fluorescent substance (e.g., the mineral scheelite) or it must contain an impurity known as an activator. Manganese, a large component of this New Jersey ore body, is a known activator and at Sterling Hill its presence causes willemite to fluoresce. Furthermore, the mineral cannot contain a quencher, or a chemical that disrupts fluorescence by changing the path of the electron after it is excited. Iron, cobalt, copper, and nickel are known quenchers and these are not found in large amounts in the mine [1]. Fluorescence played an important role while mining of the ore was active. Within the mine it would be used to search for ore, as it was usually associated with the glowing calcite or willemite minerals, and it was used to determine the ore/gangue dividing line.

References:

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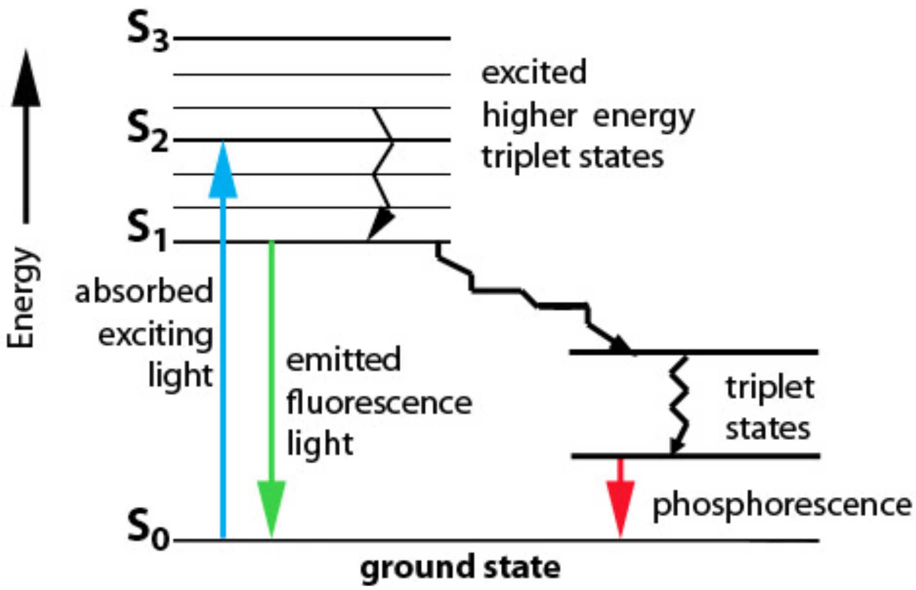

Figure 9. Jablonski diagram illustrating fluorescence and phosphorescence. http://web.uvic.ca/ail/techniques/epi-fluorescence.html

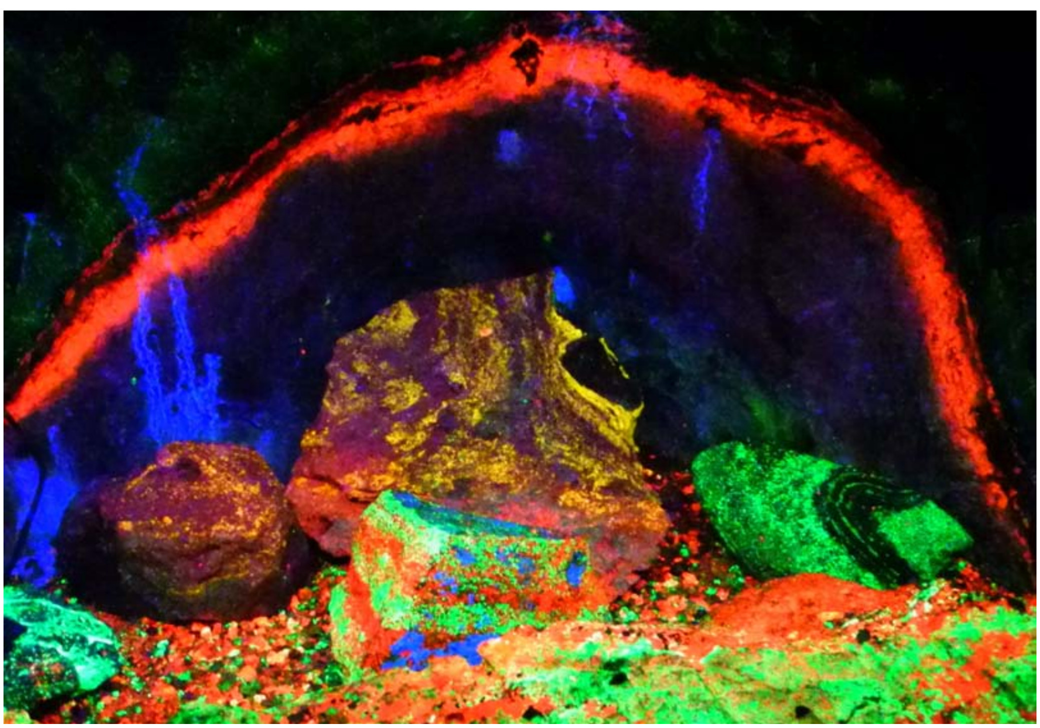

Figure 10. The "Rainbow Room" in Sterling Hill Mine. An example of the many fluorescent minerals that can be found in the mine

Trip Itinerary

By Jonathan Gale & Hannah Rabinowitz

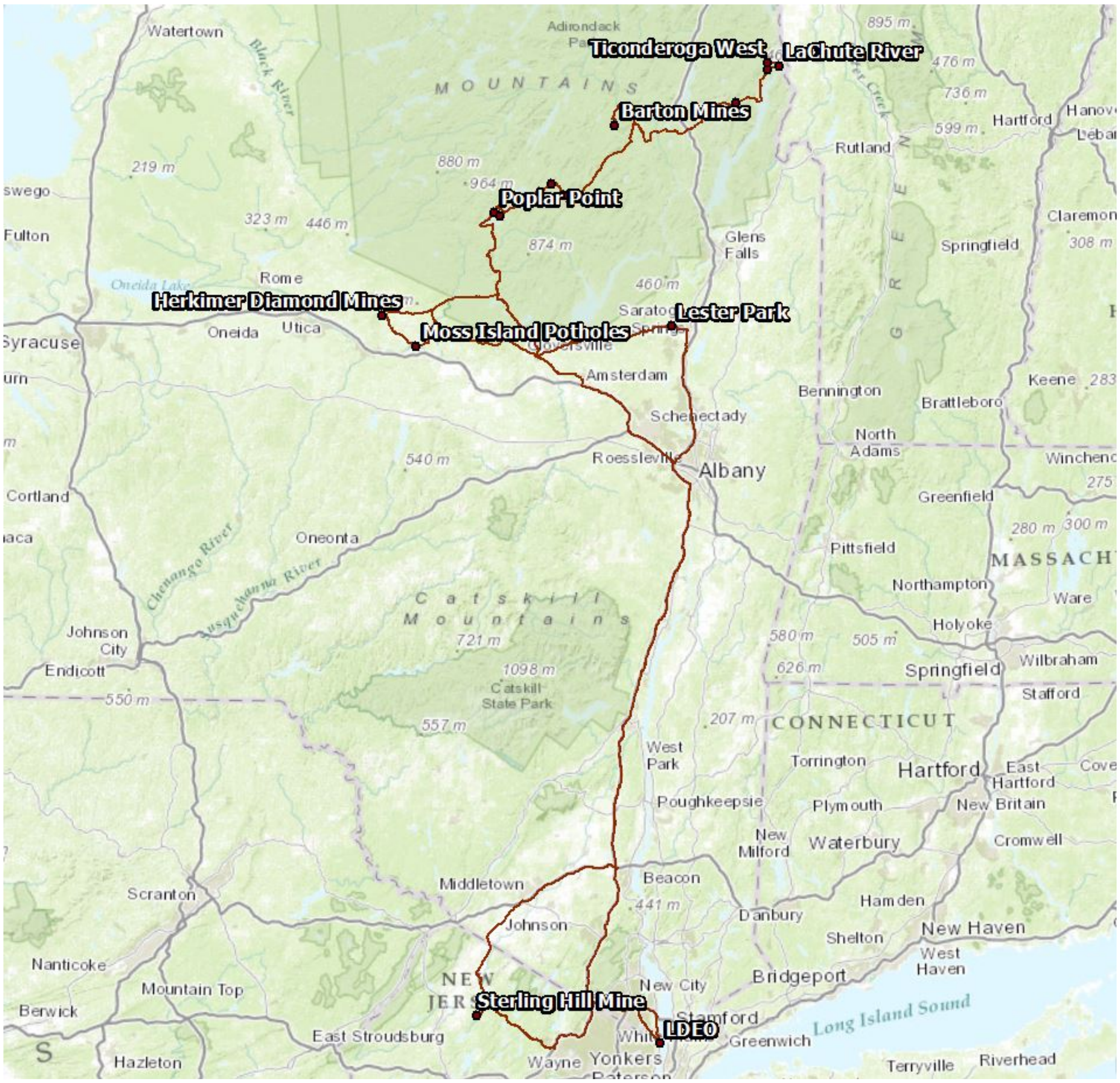

Figure 11. Map of the route and major sites visited during the trip.

Day 1 – August 2, 2013

9:20 am	Left Lamont-Doherty Earth Observatory (LDEO)
12:15pm	Arrived to Lester Park: observed stromatolites and had lunch
1:00 pm	Left Lester Park
2:30 pm	Arrived to Herkimer Mine for mineral collecting
5:10 pm	Left Herkimer Mine (closed at 5 pm)
5:40 pm	Arrived to Moss Island to look at glacial potholes
7:00 pm	Set up camp, cooked fajitas for dinner

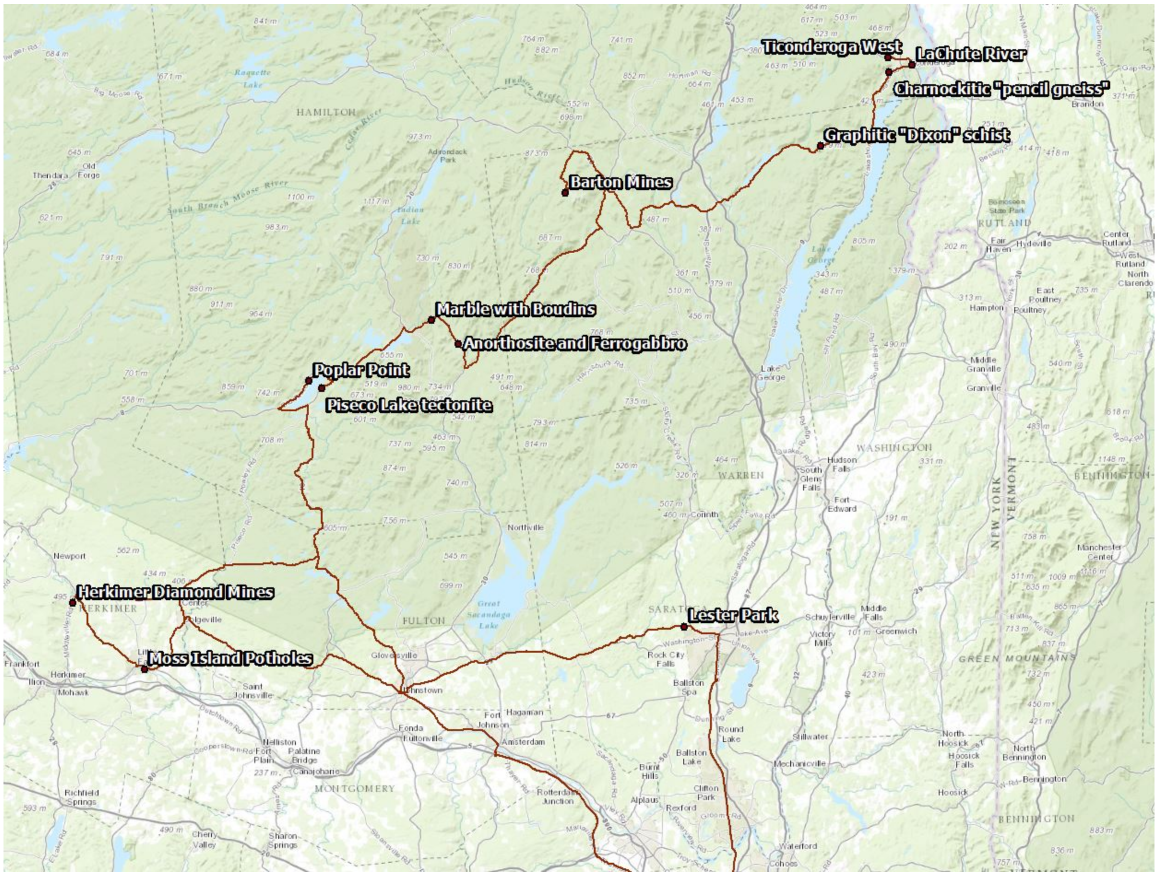

Figure 12. Detailed map for Day 2 of the trip.

Day 2 – August 3, 2013

7:30 am	Woke up and had breakfast
8:45 am	Left the campsite
8:50 am	Piseco Lake Tectonite
9:50 am	Marble with amphibolite and charnockite boudins
10:30 am	Anorthosite and ferrogabbro
12:00 pm	Gore Mountain, mineral collecting, lunch
3:50 pm	Graphite Schist
5:00 pm	Pencil Quartz Gneiss
5:30 pm	Potsdam Sandstone
7:00 pm	Returned to camp and cooked kebabs for dinner

Day 3 – August 4, 2013

7:00 am	Woke up and had breakfast
8:30 am	Packed up and left camp
1:30 pm	Arrived to the Sterling Hill Mine, had a quick lunch
2:00 pm	Tour of the Sterling Hill Mine and Museum of Fluorescence
5:30 pm	Left the Sterling Hill Mine and retuned to LDEO

Description of Visited Sites

Lester Park Stromatolites (43.094188°, -73.848251°)

By Jonathan Gale

Lester Park near Saratoga Springs (Figure 13) is the site of one of the finest examples of domal stromatolites to be seen anywhere in ancient rocks, and is significant in the history of geology as the area where stromatolites were first described and interpreted [1]. A stromatolite is a structure formed by cyanobacteria in shallow waters. Often, the resulting rock undergoes dolomitization due to high levels of salinity in peritidal environments where stromatolites are found. The microbial mat is the result of outward growth of the mat's domal surface. These dome structures that develop can fuse together if they grow large enough to interact. The particular stromatolites found at Lester Park (Figure 13) are *Cryptozoon proliferum* from the Cambrian Hoyt Limestone [1]. They are found planed off by glacial activity, and their 3D structure can be observed.

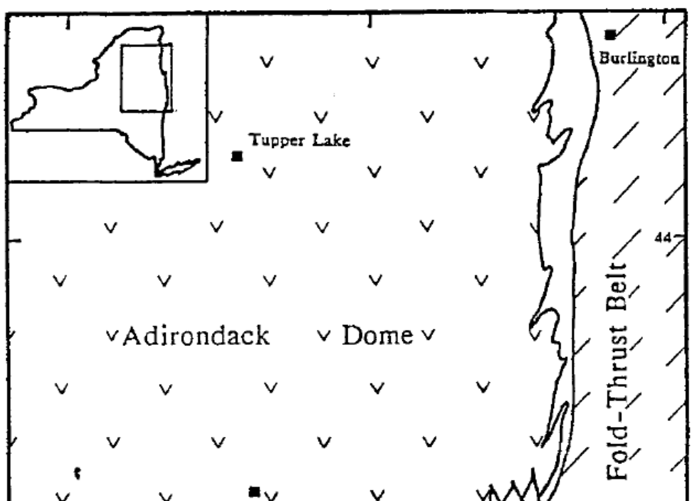

Figure 13. Sketch map (lakes and rivers omitted) showing the location of stromatolite exposure at Saratoga Springs site (Lester park) [1].

The Hoyt Formation of Late Precambrian (~490-505 Ma) was deposited on the shelf of the Iapetus Ocean after the Grenville Orogeny. It is a part of the transgressive sedimentary sequence beginning with the Potsdam Sandstone and becoming deeper and progressively more carbonate-rich throughout the Cambrian and into the Ordovician. The outcrop occurs in a thin exposure of Cambro-Ordovician units that are bordered on the east by the frontal thrusts of the Taconic Orogeny.

The outcrop has a limited exposure, and is marked by a sign of Skidmore University Geology Club. Across the street and down a footpath, an outcrop shows the stromatolites in a sequence of calcareous beds. Similar Cambrian stromatolites are found further west in the Little Falls Dolomite in Herkimer, NY [2,3].

Figure 14. Exposure of domal stromatolites in Lester Park.

References

1. Friedman, G. M. (2000). Late Cambrian cabbage-head stromatolites from Saratoga Springs, New York, USA. Carbonates and Evaporites, 15(1), 37-48.
2. Slater, B. E., & Smith, L. B. (2012). Outcrop analog for Trenton–Black River hydrothermal dolomite reservoirs, Mohawk Valley, New York. AAPG bulletin, 96(7), 1369-1388.
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Herkimer Diamond Mines (43.127047°, -74.975852°)

By Hannah Rabinowitz

Herkimer diamonds are double-terminated quartz crystals that grew (decoupled) in the 500-Ma-old Little Falls dolomite, a part of the shelf deposits of the Iapetus Ocean. These quartz crystals are often gem-quality (Figure 15) though many have small inclusions, which can be any of a wide range of materials (organic matter, pyrite, earlier-forming quartz crystals, etc.). Herkimer diamonds are popular with mineral collectors and among people looking for minerals with supposed healing and cleansing properties.

Herkimer diamonds are closely linked to the presence of organic material, locally known as anthraxolite. This link can be inferred through observation: these quartz crystals are most frequently found in vugs that also contain anthraxolite. However, this juxtaposition is likely more causational than circumstantial. Anthraxolite began as a liquid and percolated through the Little Falls dolomite, concentrating in areas of high porosity. This liquid organic matter began to solidify after this percolation phase yielding the crumbly black form visible at Herkimer (Figure 16) [1].

Figure 15. A Herkimer diamond in Little Falls Dolomite. The quartz crystal in this image is about ¾ " in length.

At this time, quartz probably also started precipitating out in the form of druzy quartz crystals that line the edges of the vugs. The range of inclusions found in these euhedral quartz crystals (e.g., both oil and more solid bitumen have been found included in Herkimer diamonds) hints at a long-term crystallization. This would indicate a crystallization time that also strongly overlaps with the solidification of the anthraxolite [2].

In our visit to Herkimer, we found that the most efficient approach to finding Herkimer diamonds was to smash large pieces of dolomite with a heavy sledgehammer and then break it into even smaller pieces using smaller sledgehammers and chisels. Darker dolomite that contains more anthraxolite tends to have more euhedral quartz crystals, but this is not always reliable. Small Herkimer diamonds can be found by simply sifting through mud (particularly in areas near active official mining sites.)

References

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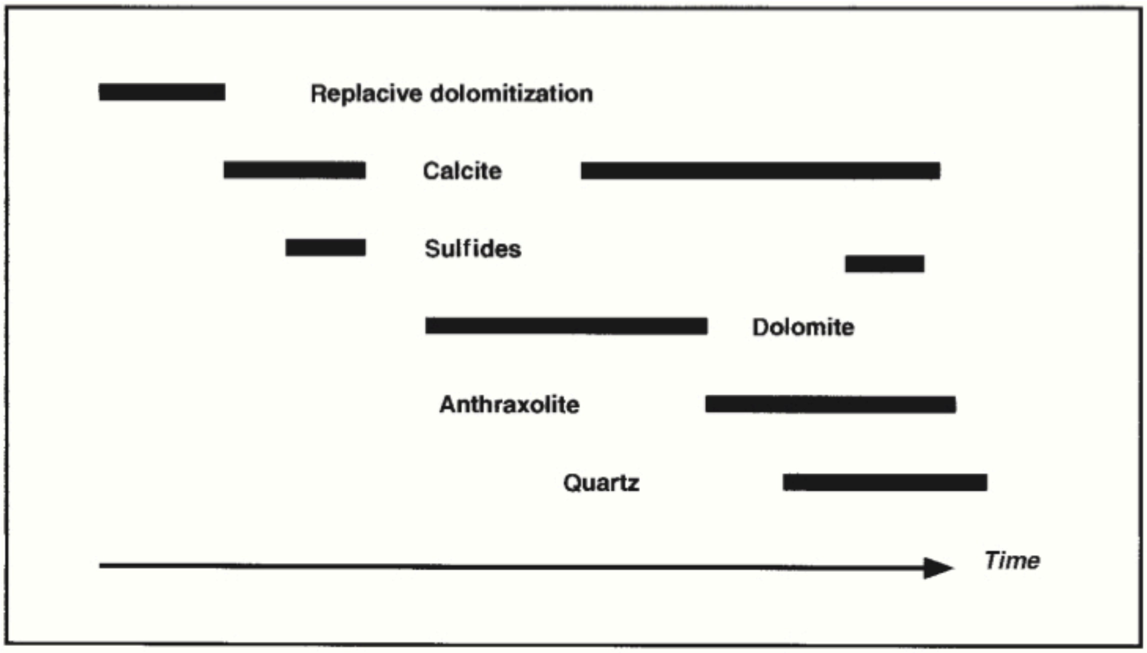

Figure 16. General timeline in the Little Falls Dolomite. Formation of anthraxolite and crystallization of quartz overlap in time quite significantly [2].

Moss Island Potholes (43.037290°, -74.843572°)

By Natalia Zakharova

Moss Island, located on the Mohawk River in Little Falls, NY, has a large number of spectacular potholes, some of which reach 40-50 ft in diameter (Figure 17). The potholes were created by huge volumes of water falling over a prehistoric cataract once located here, much like modern day Niagara Falls [1, 2]. At that time, ~20,000-80,000 years ago (i.e., prior and during the last glaciation) the Great Lakes drained through the Mohawk Valley/ Hudson River because the St. Lawrence River was blocked by a glacier. As the glaciers retreated and glacial melt waters drained, they flooded the present river valley, at times deviating from the main current and swirling to form small whirlpools or eddies. Sand, gravel, and rocks became trapped in the spinning whirlpools and spiraling eddies, and over time, the grinding action of these abrasive materials drilled circular or cylindrical holes known as potholes into the underlying bedrock. The specific abrading materials that carve the potholes during their formation are called grinders and are frequently found in the bottom of the pothole. With the continued downward spiraling action of the grinder, the pothole becomes deeper and the once angular surface of the grinder is smoothed.

To reach Moss Island, one needs to cross the Mohawk River at Lock 17 of the Erie Canal (now part of the State Barge Canal system). Notably, it is the highest lift lock in New York State, with the elevation change of 40.5 ft [3].

Figure 17. Potholes on Moss Island near Lock 17 of the State Barge Canal.

References:

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Piseco Lake Tectonite (43.418362°, -74.517566°)

By Hannah Rabinowitz

The Piseco Lake Tectonite is a metamorphic rock sequence that preserves tectonic deformation in the form of mineral preferred orientations. The outcrop we visited (Figure 18) also demonstrated this deformation in a more macroscopic form: that of a plunging anticline. The tectonite consists of two main gneiss layers: a reddish gneiss and a bluish gneiss. The reddish gneiss was largely potassium feldspar and pyroxene and was created through the deformation of a granitic protolith. The bluish gneiss was composed of hornblende, plagioclase, and light green amphiboles and recorded the presence of a gabbroic protolith and is more foliated than the reddish gneiss. The outcrop is characterized by quartz and feldspar pencils that are oriented parallel to the major fold axis. To the NE end of the outcrop, we observed recumbent folding with the axis parallel to the main lineations in the outcrop, suggesting multiple generations of deformational features. The folding and lineations at this outcrop were developed during the Ottawan Orogeny. The trend of the folds and the mineral lineations are ~100-110˚, consistent with the generally E-W trend to Ottawan deformation in the Adirondacks.

Figure 18. Piseco Lake Tectonite anticline, and specimens of the two main gneiss types from the outcrop.

References:

Whitney, P.R., S.R. Bohlen, J.D. Carl, W. deLorraine, Y.W. Isachsen, J.M. McLelland, J.F. Olmsted, J.W. Valley, I. Cartwright, J. Morrison, P.W. Ollila, B. Selleck, 1989. The Adirondack Mountains—A Section of Deep Proterozoic Crust: Montreal, Canada to Albany, New York June 30-July 8, 1989. 1st ed., American Geophysical Union.

Marble with Amphibolitic and Charnockitic Boudins

(43.510567°, -74.313799°)

By Gary Mesko

This outcrop illustrates a localized effect of CO_2-infiltration on granulite facies metamorphism, which appears to be locally present but not prevalent in the Adirondacks [1]. Carbonic metamorphism has been described as a pervasive regional process in other granulite facies terrains but here in the Adirondacks it appears to have been a very restricted process [2]. Its manifestation, however, can be observed in a number of marble-rich outcrops, best exposed along Route 8-30E near the town of Speculator. The marbles in the outcrop we visited (Figure 19) consist of calcite, diopside, graphite, tourmaline and sulfides and contain numerous interlayers of calc-silicate rock containing phlogopite, diopside, tremolite, grossularitic garnet, and, at one locality, wollastonite [1]. Garnetiferous amphibolite layers are common, and numerous boudins of charnockite and garnetiferous amphibolite are present. A charnockitic boudin at the west end of the road cut has been intensively studied by McLelland et al. [2] and appears to record locally elevated partial pressure of CO_2 during metamorphism. The bulk composition of the boudin is similar to that of pink granitic gneiss exposed along Route 30 about 1 km to the west. The unusual association of charnockitic rocks and marble can be explained if decarbonation reactions in the marble served as a source of CO_2-rich fluid that infiltrated in the surrounding gneisses promoting dehydration reactions and giving rise to local small amounts of granulite facies rocks [2]. Rotated boudins and "tectonic fish" consisting of dismembered isoclines manifest the extreme ductility of these marbles during deformation [3]. Since it is associated with amphibolite and the outcrop is located near the amphibolite-granulite facies transition, the marble is likely to be associated with the Ottawan Orogeny.

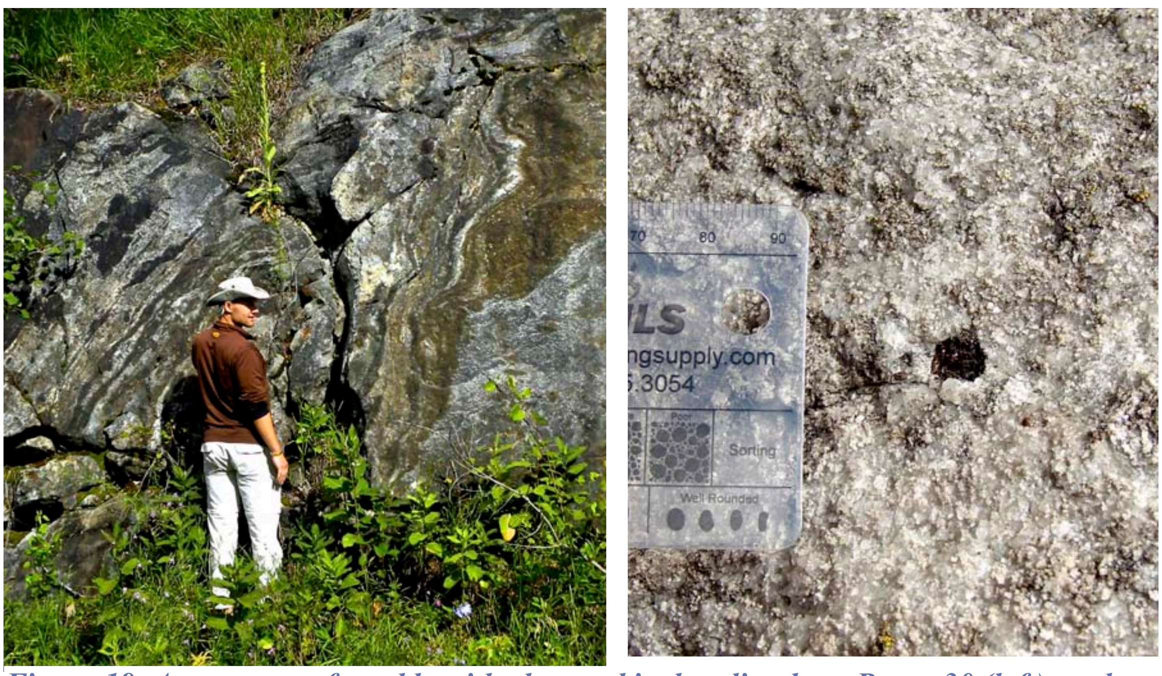

Figure 19. An outcrop of marble with charnockite boudin along Route 30 (left), and a large tourmaline crystal (right).

References:

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Anorthosite & Ferrogabbro (43.478190°, -74.263549°)

By Gary Mesko

A small road cut on the west side of the highway (Route 8/30) exposes anorthosite typical of the Oregon Dome [1, 2]. This outcrop is a classic example of the anorthosites that underlie much of the central and northern Adirondacks, and was formed during the delamination that followed the Ottawan. Megacrysts of andesine are set in a fine-grained groundmass of andesine and pyroxene. The groundmass plagioclase may have been derived from original megacrysts by grain size reduction, or by crystallization of an interstitial liquid. Subophitic textures (feldspar crystals partly enclosed by pyroxene crystals of the same size) are still preserved in some minimally deformed areas. Coronas of garnet around pyroxenes and Fe-Ti oxides [3] are locally well developed. The anorthosite is intruded by a pyroxene-rich ferrogabbro that carries xenoliths of the host anorthosite as well as of calc-silicates. The ferrogabbro is probably a late differentiate of the anorthosite, although a remobilized cumulate cannot be ruled out. Zircons from the ferrogabbro yield ages >1070 Ma of the later Ottawan Orogeny [4]. These dates may be metamorphic in origin as a complex belt of arcs and orogens with Pb-isotopic crystallization ages of 1.8-1.3Ga had already been emplaced [1,5,6].

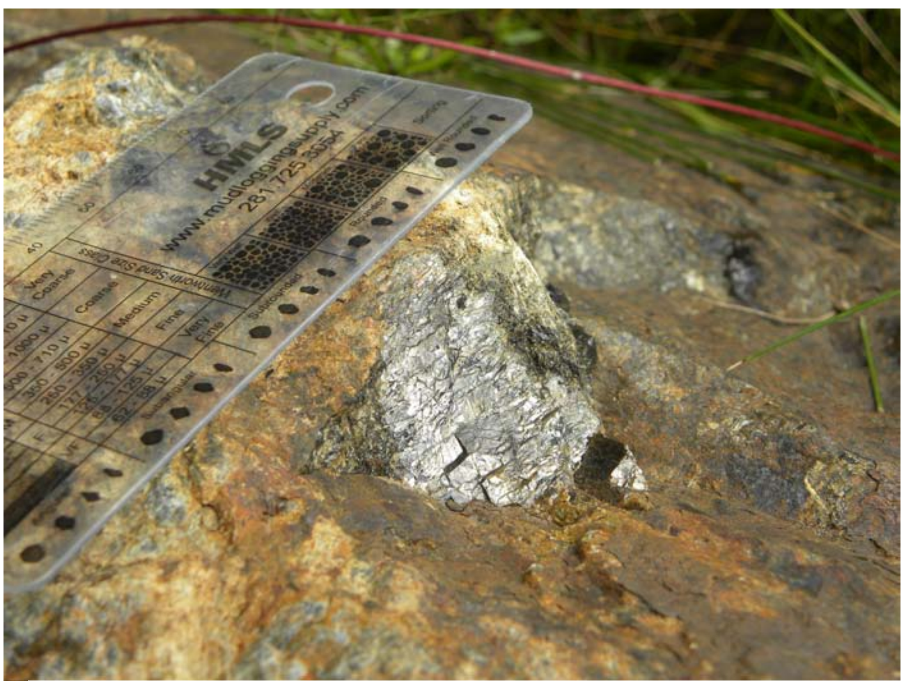

Figure 20. Anorthite megacryst showing labradorescense.

References:

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5. Emslie, R.F. (1985) "Proterozoic Anorthosite Massifs." The Deep Proterozoic Crust in the North Atlantic Provinces. NATO ASI Series, Vol. 158. p.39-60.
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Barton Garnet Mine (43.681584°, -74.063424°)

By Alexander Lloyd

This stop at Gore Mountain was one of the three major destinations on our Adirondack field trip. Gore Mountain is famous for its megacrystic garnet that has been mined as an abrasive since the 1870s. For any potential field trip planners who read this field guide, I highly recommend calling the mine tour operators ahead of time. If you explain that you are visiting Gore Mountain for academic purposes, the tour operator (Bonnie Barton) will allow you to explore other sections of the mine typically closed to visitors. On the standard tour, the tour guides lead you down to the lowest point of the now inactive mine, Pit #1, and present a short ten-minute lecture followed by 40 minutes of exploring and collecting. Tour participants are limited to walking around the mine floor and cannot approach the unstable walls or use rock hammers to take samples and expose fresh surfaces. There are excellent examples of the garnet available to take pictures though (Figure 8). Once finished in Pit #1, the tour guide led our group to Pit #9 where he allowed our group to approach the walls (Figure 21) and use rocks hammers. This ability to access and see the garnet in situ was very helpful in understanding uniqueness of the garnet crystallization that occurred at this locality.

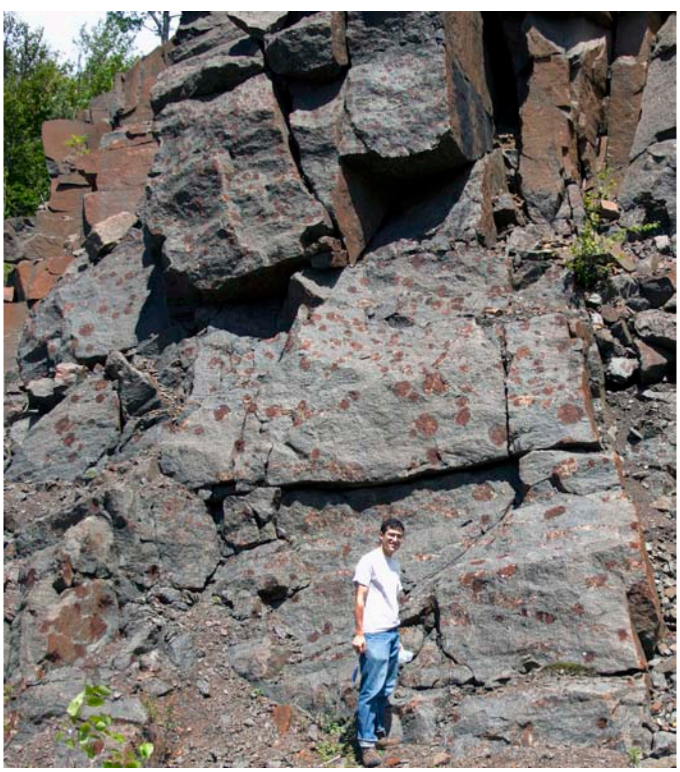

Figure 21. The mine wall at Pit #9. Though the size of the garnets at this location are smaller in comparison to those we observed in Pit #1, the total abundance of garnet in the host metagabbro is similar. The color of this photo was edited to increase the visibility of the garnets in the outcrop.

The garnet mine is entirely hosted by a hornblende-rich garnet amphibolite unit sandwiched between a small olivine meta-gabbro body which contacts meta-anorthosite to the north and is in fault contact with meta-syenite to the south (Figure 22). Originally a gabbro, likely intruded during the Elzevirian Orogeny (or the post-Elzevirian collapse) this unit was metamorphosed to amphibolite grade during the Ottawan Orogeny. Prior to metamorphism, the rock was composed of plagioclase, olivine, clinopyroxene, and ilmenite. During metamorphism, coronas of orthopyroxene, clinopyroxene, and garnet formed between the olivine and the plagioclase and coronas of biotite, hornblende and ilmenite formed between plagioclase and ilmenite. During the crustal delamination that followed the Ottawan Orogeny, excess heat from emplacement of granitic plutons generated granulite facies metamorphism that led to garnet growth. This, coupled with intense fluid flow through the metagabbro, led to the megacrysts found today.

The contact between the olivine meta-gabbro and the garnet amphibolite is gradational through a transition zone 2-3 meters wide. Garnet size increases dramatically across the transition zone, from <1 mm in the olivine metagabbro, to 3 mm in the transition zone, to 50 to 350 mm in the amphibolite. Crossing the transition zone, the increase in garnet size is paralleled by a ten-fold increase in the size of hornblende and biotite, olivine disappears, modal clinopyroxene decreases as it is replaced by hornblende, and spinel-included plagioclase grades to inclusion-free plagioclase. The modal percent garnet varies from 5 to 20 percent but averages 13 percent in both the olivine metagabbro and the amphibolite. At the west end of the mine, a garnet hornblendite with little or no feldspar is locally present. This rock probably represents original ultramafic layers in the gabbro. In the more mafic portions of the ore body, the garnets are rimmed by hornblende up to several inches thick (Figure 8). Elsewhere, the ore is less mafic, and the rims contain plagioclase and orthopyroxene.

A strong, consistent lineation and a weak planar fabric coincide with the zone of large garnets and are important characteristics of the ore zone. The lineation is defined by parallel alignment of prismatic hornblende grains, elongate segregations of felsic and mafic minerals, plagioclase pressure shadows and occasional elongate garnet. The foliation is defined by a slight flattening of the felsic and mafic aggregates. Chemical analyses of the olivine metagabbro and garnet amphibolite show that the garnet ore was derived by retrograde isochemical metamorphism, accompanied by an increase in H_2O and fO_2.

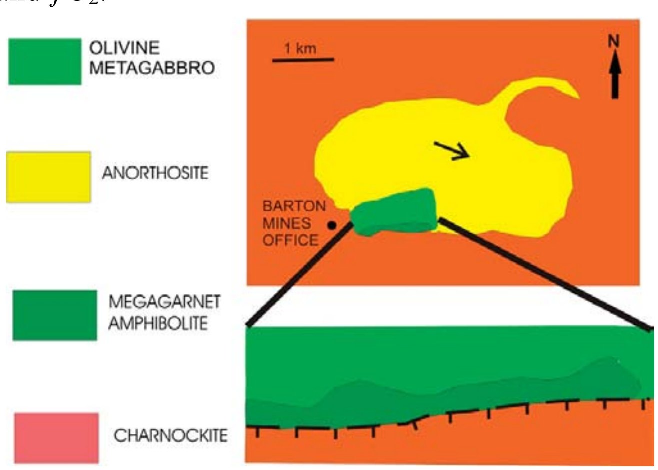

Figure 22. Simplified geologic map of the Gore Mountain area [3].

The formation of the garnets is not completely understood. Whereas the Gore Mountain deposit is the largest known, it is not unique in the Adirondacks. Elsewhere, there are occurrences of garnet amphibolite that are texturally and mineralogically similar. These are usually located on the margins of gabbroic rock bodies. Although the garnets at Gore Mountain are atypical in size, the modal amount of garnet is not unusually high for Adirondack garnet amphibolites. The ore at the currently operating Barton Corporation mine at Ruby Mountain, for example, is of the same tenor but the garnets rarely are larger than several centimeters in diameter (Figure 8). Petrologic studies have agreed that the growth of the large garnets is related to a localized influx of water at the margin of a competent metagabbro body during amphibolite facies metamorphism. Southward across the transition zone, increased ductile deformation resulted in grain size reduction of plagioclase and clinopyroxene. The presence of deformation lamellae, undulose extinction, deformation twins, bent twins, and subgrain boundaries in plagioclase are evidence for plastic deformation and high strain, and abundant hornblende is a testament to the large amount of fluid that has permeated the rocks. Recognition that the ore body, retrograde metamorphism, and L-S deformation fabric all coincide with the southern margin of the olivine metagabbro led to the hypothesis that the high fluid flow required for growth of large garnets was the result of a high temperature shear zone that crossed the contact of lithologies with contrasting rheologies (Figure 22). It was proposed that ductility contrasts at this lithologic contact were responsible for localizing garnet growth, retrograde metamorphism and fabric development. Grain size reduction by cataclasis was replaced by recrystallization as the hydrated ore body replaced the olivine meta-gabbro during ductile deformation.

The Gore Mountain garnets are chemically homogeneous indicating that the garnets grew under conditions in which all chemical components were continuously available, and that temperature and pressure conditions must have been uniform during the period of garnet formation. If the garnet amphibolite zone within the original gabbro represents a zone wherein fH_2O was higher than elsewhere during the granulite facies metamorphism, this may have facilitated diffusion and favored growth of very large garnets and thick hornblende rims at the expense of plagioclase and pyroxene. The physical and chemical conditions necessary for the nucleation of a mineral may be different from the conditions necessary for the growth of that mineral. But in this case, the presence of volatile components, particularly H_2O, promoted the growth of the megacrystic garnets that are present at Gore Mountain.

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Graphitic 'Dixon' Schist (43.742486°, -73.588194°)

By Helen Janiszewski

The 'Dixon' schist is a Pre-Cambrian aged (Grenville) graphitic schist found in several locations in the Adirondacks in New York. It likely formed as a part of the passive margin sequence prior to the Elzevirian Orogeny, later overprinted by metamorphism during the Ottawan Orogeny. Harold Alling mapped many of the graphite deposits in upstate New York during the early 20th century [1]. The term 'Dixon' schist is unofficial for this geologic unit, and names it after the Dixon Company that mined the unit extensively for graphite. Alling describes it as a feldspar quartz schist with 5-7 percent graphite, and lesser amounts of biotite and pyrite. There may also be chlorite, apatite, titanite, zircon, and garnet. It is typically around 15 ft thick. The Faxon limestone overlies the Dixon schist, and a quartzite, known as the Swede Pond quartzite, overlies that. The graphite, which was very important for the Adirondack mining industry, appears to have a common, organic origin throughout the region demonstrated by carbon isotopes [2, 3]. In our visit to the outcrop, we observed that the graphitic schist also includes large quartz veins and that portions of the overlying limestone contain large clasts.

Figure 23. A roadside outcrop and a close-up image of the 'Dixon' schist.

References:

1. Alling, H. L., 1917, The Adirondack graphite deposits: New York State Mus. Bull. 199, p.150.
2. Valley, J. W., James R O'Neil, 13C12C exchange between calcite and graphite: A possible thermometer in Grenville marbles, Geochimica et Cosmochimica Acta, Volume 45, Issue 3, March 1981, Pages 411-419.
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Charnockite "Pencil" Gneiss (43.841193°, -73.458745°)

By Alexander Lloyd

This stop is located adjacent to a red barn that sells fresh produce. It consists of glacially eroded bedrock that crops out from the surface in a few locations. The outcrop overlooks a few farms to the northwest, which are part of the Lake George graben system that is floored by the Cambrian Potsdam sandstone in this particular location. The rock at this location is described as a 'pencil gneiss', with the defining texture resulting from intersections between metamorphic foliations. Most commonly these are due to intersections between compositional layering (felsic/mafic), the earliest foliation (gneiss emplacement), and foliation axial planar to the earliest folding event. These intersections result in pencil gneisses (Figure 24). They are named as such because the minerals appear to be elongated (but still segmented) along the foliation, but in cross section have a round or square shape.

This gneiss, with a U/Pb age of 1.11 Ga, was likely intruded during the first delamination event, after the Elzevirian Orogeny, but before the "main" Grenville event (the Ottawan). The lineation of the quartz and pyroxene grains are oriented 10-20˚, nearly perpendicular to the lineations and fold trends at the Piseco Lake Tectonite (*see p.29*). This is the dominant orientation of the northeast Adirondacks, while the Piseco Lake Tectonite orientation is the common orientation in the southern Adirondacks.

We were surprised to find discernible glacial features on this outcrop as well. The surface was smoothed during the last glacial event and striations on the surface of the rock were observed as well (Figure 25). Some students proposed the possibility that the shape of the outcrop resembled a *roche moutoneé* that Columbia students have observed in Central Park, NYC. The plucked face coincided with the road cut, so we were unable to confirm this observation.

Figure 24. Representative rock face from Charnockite "Pencil" Gneiss (scale bar is 10 cm). The sheared felsic (white) minerals are primarily quartz with secondary feldspar. The mafic (black) minerals are pyroxene. Take note of the non-elongated cross sections of the lineated quartz crystals on the dark rock face perpendicular to the main rock face, highlighting the square or round cross section that gives the "pencil gneiss" its name.

Reference:

McLelland, James M, 1984, The origin of ribbon lineation within the southern Adirondacks, U.S.A., Journal of Structural Geology. Vol. 6, No 1/2, pp. 147-157.

Figure 25. Photo of the glacially smoothed surface of a subsection of the outcrop, forming a small wave. The glacial striations are difficult to see in this picture, but can be felt when the observer runs his or her hand over the surface of the rock.

Potsdam Sandstone at LaChute River

(43.850034°, -73.415162°)

By Natalia Zakharova

The Potsdam Sandstone was deposited in the late Cambrian during a sea-level highstand that flooded much of the interior of North America after the break up of Rodinia (*see p. 8 for more details*). The Potsdam is age-equivalent to the Tapeats Sandstone, in the Grand Canyon of Arizona. Deposited in a shallow marine environment by waves and tidal currents, it lies unconformably above the Grenville-age rocks, and contains trace fossils of large crawling invertebrates, including a trace fossil called Protoichnites. Throughout the 19th century, the Potsdam sandstone was highly regarded as a building material. Today one can observe some great specimens of the Potsdam Sandstone in slabs used to decorate the exterior of the Lower LaChute hydroelectric plant building in the Village of Ticonderoga (Figure 26).

Located immediately below the Falls of Carillon, the Lower LaChute plant functions as a 'run-of-the-river' hydroelectric facility (i.e., it only uses the natural flow of the river without any water storage). The La Chute River is the outlet of Lake George, and was an important travel route during the 17th and 18th century conflicts between France and England, and during the Revolutionary War. The LaChute flows into Lake Champlain near Fort Ticonderoga. Ticonderoga Village lies within a down faulted block of lower Paleozoic sedimentary rocks, including the Potsdam Sandstone. The sandstone was used as millstones in grain mills and graphite mills along the LaChute River.

Figure 26. Hydroelectric plan on the LaChute River (left), and an example of spectacular ripple marks in the Potsdam Sandstone on the plant building's exterior (right).

Reference:

Field Trip Stops in the southern Adirondacks and Champlain Valley, by Bruce Selleck, Colgate University (http://departments.colgate.edu/geology/faculty/selleck.html).

Ticonderoga West (43.860958°, -73.459416°)

By Helen Janiszewski

At the road cut, several rock formations are observed including granitic gneiss, granite pegmatite, amphibolite, and a calc-silicate gneiss and quartzite. The pegmatite contains quartz, feldspar, and biotite. Large flaky grains of graphite are also present, mainly along the boundary between the pegmatite and gneiss [1]. The outcrop is near the unconformity with the Cambrian platform sediments. The amphibolite and gneisses exposed here are assumed to be an expression of the Ottawan Orogeny, but experienced a lower grade metamorphism than the granulite facies we saw further west.

Figure 27. Ticonderoga West at outcrop and sample scale. Large grains of graphite can be seen in the hand sample

This stop also offers some views that summarize the regional tectonics. This includes the Green Mountain-Berkshire Massif to the east and the Champlain Valley in the foreland. The Green Mountain-Berkshire Massif is part of the Grenville Orogeny (same age as the Adirondacks). The later Taconic Orogeny deformed this massif as well as deposits of Paleozoic rocks (sandstones and limestones). Evidence for this can be seen from the faulting in these regions. The Taconic Orogeny was also responsible for the creation of several hills in the region, which are primarily formed of slate and schist [1]. The Champlain Valley overlays the Paleozoic rocks, which are themselves covered by glacial sedimentary deposits [2]. Several large faults run through the area separating the Champlain Valley from the Adirondacks, including those that form the graben known as Lake George Valley [1].

Reference:

1. Selleck, Bruce, 2008, Field Trip Stops in the Southeastern Adirondacks and Champlain Valley, Colgate University: http://offices.colgate.edu/bselleck/Publication%20PDF/Field%20Trip%20Stops%20in%20the%20SE%20Adirondacks%20and%20Champlain%20Vallley.pdf
2. Peet, Charles E., Glacial and Post-Glacial History of the Hudson and Champlain Valleys. The Journal of Geology, Vol. 12, No. 5 (Jul. - Aug., 1904), pp. 415-469 http://www.jstor.org/stable/30062519

Figure 28. View from Ticonderoga West outcrop looking eastwards. The Green Mountain-Berkshire Massif is visible in the background.

Sterling Mine (41.083522°, -74.604566°)

By Gary Mesko

The Franklin district lies at the border between the two physiographic provinces known as the Archean Highlands and the Great Valley, and is about 50 miles northwest of New York City in the Hudson/NJ Highlands or Reading Prong. The Franklin Marble, which shows evidence of intense brecciation and perhaps Paleozoic dissolution collapse [1], was a highly reactive host for development of the unique, world-renowned Zn-Mn-Fe deposits found within it. The development of franklinite ore in the Franklin- Sterling Hill Mining District was accomplished under conditions of high oxygen fugacity during the Proterozoic Era and probably during the Grenville orogeny, roughly 1.1 Ga.

Franklin-Sterling Hill deposits are unique in terms of chemical composition with no known terrestrial counterpart. Fe-Zn sulfides are rare, Cu-rich rocks are absent, and laminated itabirites and/or coticules are also absent. The absence of such distinctive deposits dismisses an oceanic rift environment as the genetic source of ore-bearing fluids. Because of the thermally induced leaching of these elements from fractured ocean crust by rising volcanic fluids adjacent to the rift, ocean-floor mineral deposits and associated rocks typically are rich in Cu-Fe-Zn sulfides.

The zinc ores are found in the Franklin marble, of pre-Cambrian age. The outcrop of this formation ranges in width from one-half mile to nearly two miles in this area, and extends for about twenty miles from Ogdensburg, NJ, to Big Island, New York. The southern end of the Franklin marble lies in a syncline, which is faulted close to the axis. This fault brings the Kittatinny limestone, adjacent to the Franklin Marble in the valley east of the two mines. The Kittatinny limestone has an anticlinal structure, and is again faulted along its contact with the Byram gneiss of Hamburg Mountain on the east side of the valley. From Franklin to McAfee, the Franklin marble is bordered on the west by a thin basal Cambrian quartzite and the Kittatinny limestone that dips uniformly to the northwest, and lies unconformably upon the Franklin marble. From Franklin to the end of the belt south of Sterling, the Franklin Marble is bordered on the west by the Pochuck gneiss, which dips uniformly to the east.

Figure 29. Generalized columnar section of the Proterozoic metasedimentary and metavolcanic rocks of the Franklin-Sterling area [2].

The Franklin Marble

The Franklin marble is a highly metamorphosed, coarsely crystalline marble. The color is generally white to light gray with occasional gray to dark gray dolomitic areas. The rock is low in magnesia content except for these local dolomitic areas that appear to be secondary, following zones of fracture, which cut across the banding of the Franklin marble. The stratigraphic sequence is obscure, and because of the lack of recognizable marker horizons, accurate measurement of the thickness of the strata is difficult. The main minerals are graphite, chondrodite, mica, and amphibole, with considerable variations in crystal size and in color. The banding, likely inherited from original bedding, is generally parallel to the contact of the Pochuck gneiss, and to gneissic and quartzitic beds in the marble.

Pegmatite intrusion into the Franklin marble is common through the marble body. The pegmatites related to the zinc-bearing ore bodies are notably different than those outside these very localized zones. In the Franklin mine, in close proximity to the ore, the pegmatites are marked by the development of abundant garnet, pyroxene, and mica in locally broad skarn zones. Elsewhere in the district the pegmatites are bordered by very narrow reaction rims of pyroxene, mica, and rarely garnet. The pegmatites are generally granitic to syenitic in composition.

Related Facies

The **Pochuck gneiss** (Figure 29) is presumably metamorphosed sediment, since it contains lenticular beds of crystalline white limestone rather widely but irregularly distributed along its strike. Locally it contains abundant pegmatites. The **Byram gneiss**, bordering the limestone to the East in Hamburg Mountain, is generally a dark colored syenitic rock of igneous origin. It contains local granitic pegmatite and occasional veins of magnetite as at the Ogden mines east of Ogdensburg. The **Losee gneiss** (Figure 30) is generally light colored, foliated, and also of igneous origin. The Losee seems to intrude into the Byram gneiss, the contact between them is marked by a narrow band of amphibolite. The **Kittatinny limestone** is a thick series of early Paleozoic dolomitic limestone, probably of overlapping late Cambrian and Ordovician age. The base is marked by a thin bed, rarely twenty feet thick, of Hardyston quartzite of Lower Cambrian age.

Reference:

1. Metsger, R. W., 1990, Geology of the Sterling Hill Zn, Fe, Mn, deposit, p. 32-48 in Sclar, C. B., ed., Character (sic) and origin of the Franklin- Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.
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4. Pinger, A.W. (1948): Excursion No.1 – Geology of the Franklin/Sterling Area, Sussex County, NJ. Guidebook of excursions: the Geological Society of America, 61st annual meeting. New York, NY.

Figure 30. Losee Gneiss from Hamburg Quarry, Hamburg, NJ.

Lists of Minerals in the Franklin District, New Jersey

1. Franklin Mining District - Mindat (http://www.mindat.org/loc-3947.html)
2. Franklin Mineral Museum (http://www.franklinmineralmuseum.com/list.htm)
3. Sterling Hill Mining Museum (http://sterlinghillminingmuseum.org/aboutus/minerals.php)

Acknowledgements

The participants of the 2013 Arthur D. Storke Memorial expedition would like to thank:

- The Storke Endowment Fund, for making this trip possible;
- The Department of Earth and Environmental Sciences, and the chair Prof. Peter DeMenocal, for continued support of graduate student field trips;
- Alexander Lloyd, for coming up with the brilliant idea of a local mineral-collecting trip, and taking the lead in putting it to life;
- Jonathan Gale and Jesse Farmer, for joining Alex in organizing the trip, and covering all related logistics, planning, seminar scheduling, background material, etc.;
- Prof. Philipp Ruprecht, for leading insightful discussions during the preparatory seminars and in the field;
- And all members of the group for making it successful and fun experience!

Participant of the trip, from left to right: Margaret Reitz, Gary Mesko, Alexander Lloyd, Helen Janiszewski, Philipp Ruprecht, Jonathan Gale, Natalia Zakharova, Jesse Farmer, and Hannah Rabinowitz, at Lock 17 on the Erie Canal.

Appendix 1. Campsite Information

New York State DEC Campground - Poplar Point

Address: County Route 24, Old Piseco Road, Piseco, NY 12139
Campground Phone: (518) 548-8031

- Online Reservation Strongly Recommended – (http://www.dec.ny.gov/outdoor/24491.html).
- 3 campsites were required to accommodate all field trip participants (10 people).
- Outhouses and potable water were available at the campsite; firewood and showers were located one mile south at the Little Sand Campground.
- DEC campgrounds require different people to reserve each individual campsite.
- It was generally agreed that it was convenient to camp at the same location both nights, but moving camp on Saturday night may have allowed more outcrops to be visited.

Poplar Point

Address: County Route 24, Old Piseco Road, Piseco, NY 12139
GPS Info. (Latitude,Longitude): 43d25'43.13"N, 74d32'29.33"W
Campground Phone: (518) 548-8031
Regional Office Phone: (518) 863-4545
Camping Fee: $20

Campground Map PDF File (218 KB)

Make a reservation at this campground with ReserveAmerica.

Firewood Restriction Map II (PDF file, 1.2 MB) View map showing 50-mile radius from which untreated firewood may be moved to this campground. For more information see firewood restrictions.

This campground on Piseco Lake offers fine fishing, canoeing, sailing and all water sport opportunities. Concrete boat launch. Numerous hiking trails to challenge the day hiker to the 133 mile long Northville-Lake Placid Trail are located just minutes away. A natural sand beach offers a swimming area from mid-June to Labor Day.

Directions: From NYS Thruway (I-90), Exit 27 at Amsterdam follow Route 30 north approximately 50 miles to the Village of Speculator. Turn left on Route 8, west about 11 miles to Old Piseco Road, turn right, campground is located 4 to 7 miles from that point on the left side of the road.

Appendix 2. Trip Budget

Item	Quantity	Price	Explanation
DEES Van Rental	927 miles	$695.25	75 cents per mile rental cost
Gas	70 gallons	$242.07	Approx. $3.65/gal
Gore Mountain	10	$119.50	Admission for 10 to Gore Mountain Garnet Mine plus collecting fees
Herkimer Mines	10	$210.31	Admission for 10 to Herkimer Mines (discount rate)
Sterling Hill Mine	10	$100.00	Admission for 10 to Sterling Hill Mines and collecting area (discount rate)
Camping Sites	3 (2 nights)	$147.00	Two nights of camping, 3 sites, $22 per site per night plus reservation fee
Food		$312.58	
Total:		**$1,826.71**	