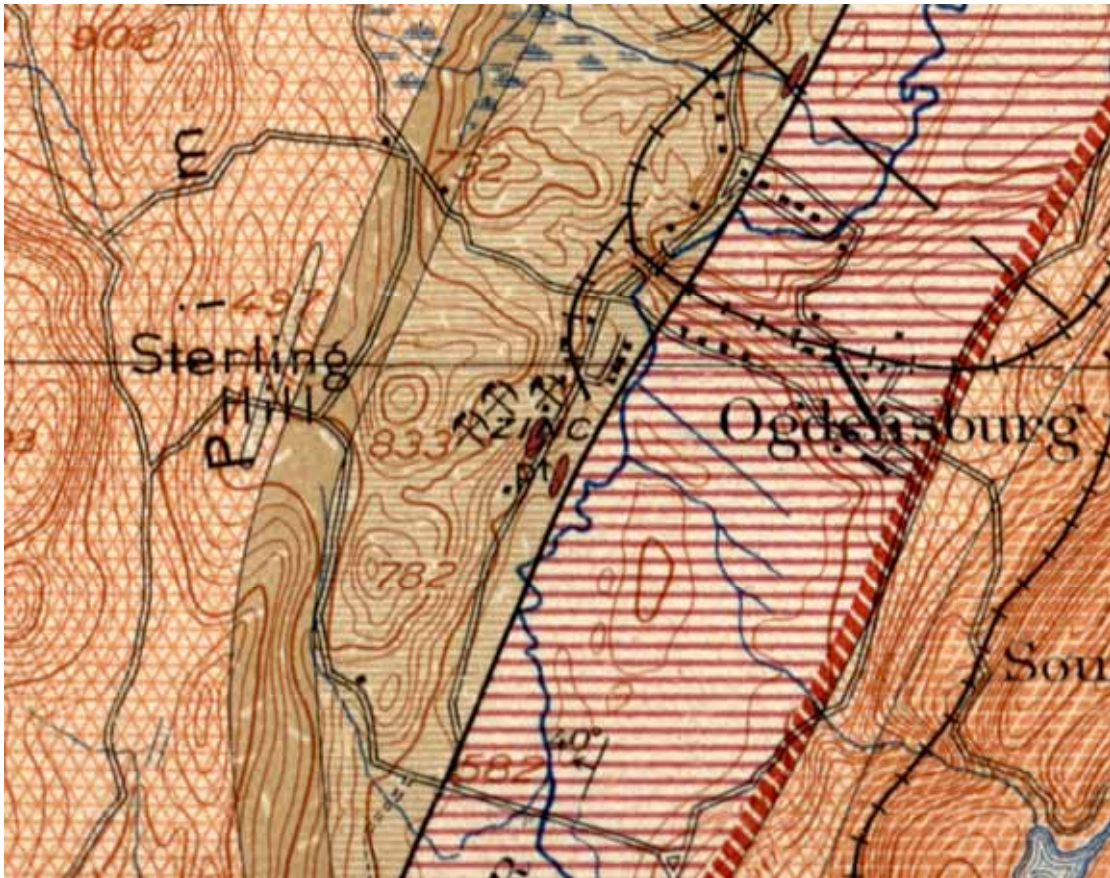


Geology Club Field Trip

New Jersey Zinc Mine and Vicinity Ogdensburg, NJ

3-4 May 2008



Bedrock map of the area surrounding the New Jersey Zinc Mine in Ogdensburg, New Jersey. The mines are found in the Franklin Marble (tan unit in center). See figure 1 for description of units. (From Spencer et al., 1908.)

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INTRODUCTION

Ore petrology is a unique application of the techniques we have developed in our experiences this semester in Geology 133. The main difference is that ore petrology utilizes reflected, rather than transmitted light to identify opaque mineral phases. Yet, the study of ore phases, textures, and the geochemical secrets of ore formation offer important insights into former tectonic regimes for card-carrying fans of orogenic studies. On today's trip we visit one of northwestern New Jersey's unique mineral deposits in the Franklin-Sterling Hill area, Sussex County. In the words of Robert W. Jones (1982, p. 194): "The next time you are stuck in turnpike traffic or have had it with the moribund world, head for the rolling hills of northwest New Jersey and revel in the history and beauty of America's unique zinc mines and minerals." *Jones neglects to add how you get unstuck from the traffic to **get** to northwestern New Jersey from Long Island, but,* back to Jones (1982, p. 190): "Franklin and Ogdensburg (Sterling Hill mine) are neighboring towns nestled in the rolling hills of northwest New Jersey. Each is situated next to a zinc-iron-manganese ore deposit the likes of which exist nowhere else in the world. The deposits have yielded nearly 300 different minerals, a number vastly greater than from any other known source in the world. Amazingly, nearly 60 of these minerals exhibit luminescence, in the form of instantaneous fluorescence or as persistent phosphorescence."

Four minerals constitute the primary ore group:

- (1) **franklinite** (a spinel-type oxide mineral of zinc, divalent- and trivalent manganese and -iron, identified in 1820);
- (2) **willemite** (a zinc silicate, first reported in 1824);
- (3) **zincite** (a zinc-manganese oxide, first discovered in 1810); and
- (4) **calcite**, (much of which contains manganese [rhodochrosite solid solution]).

Franklinite and zincite, abundant in the Franklin area, are known only in trace amounts elsewhere in the world. Manganiferous calcite, one of the so-called gangue minerals, fluoresces bright red. By contrast, willemite, a valuable ore mineral, fluoresces bright green. Thus, sorting of the mined material was aided by using ultraviolet light. We shall visit the zinc mine at Ogdensburg in the afternoon, take a tour through a mine drift and the museum, visit a few locations before dinner, then after dinner revisit the zinc mine to collect fluorescent minerals with black lights at night, a first for our Geology department.

Today's trip will enable participants not only to revel in the minerals but also to study some of the general geologic features of the bedrock. This guidebook, an offshoot and upgrade of a trip guide by Merguerian and Sanders (1995), summarizes some of the current research results on the geology and origin of the Franklin-Sterling Hill orebodies. If time permits in the afternoon, we will be able to visit some new exposures of the bedrock that include the Proterozoic gneisses, the Sauk carbonates (Cambro-Ordovician; protoliths of the Inwood Marble of New York City and vicinity), and the remarkable Proterozoic Y Franklin Marble. Past geologic interest in these rocks has been stimulated by interpretations that proved to be controversial. To mention only a few of these controversies: (1) the origin and age of the mineral deposits; (2) the age of the Franklin marble; (3) the extent of Paleozoic deformation and metamorphism, and (4) stratigraphic relationships of the Proterozoic rocks.

The debates over the Franklin Marble involved its age. The critical questions were: Is it merely an extreme altered facies of the Cambro-Ordovician carbonates, thus of Paleozoic age? Or is it an older formation, thus of Proterozoic age? The first idea was suggested by early workers on the New Jersey Geological Survey (summarized by F. L. Nason, 1891; also J. F. Kemp, 1893a). The case for Proterozoic ("Pre-Cambrian" of the older usage) age was first made by L. G. Westgate (1894) and settled for once and all by Wolff and Brooks (1898).

Various ideas have been prompted by studies of the other Proterozoic rocks. These rocks contain magnetite deposits as well as the unique zinc-iron-manganese ores of Franklin and Sterling Hill. A few of the authors of papers on the magnetite deposits include Baker and Buddington (1970); Bayley (1910, 1941); Buddington (1957, 1966); Collins (1969); Hager, Collins, and Clemency, 1963; Hotz (1953); Sims (1953, 1956); and Sims and Leonard (1952). The zinc deposits associated with the Franklin Marble have been studied by many generations of geologists, mineralogists, and geochemists. Figure 1 shows the result of a comprehensive regional survey carried out by the combined staffs of the United States Geological Survey and Geological Survey of New Jersey and published as part of the United States Geological Survey folio series by Spencer, Kümmel, Wolff, Salisbury, and Palache (1908). Suffice it to note here that the burning issue of their origin centered over whether the chief mineral growth had resulted from the emplacement of one- or more granitic plutons and associated pegmatites (the popular early view of how all metallic ore deposits formed) or from a two-stage development starting with some conditions associated with the history of deposition of the calcite precursor of the marble and including metamorphism under great depths of burial and temperatures in the range of 750 to 800° C. The current thinking on this question favors the high-temperature metamorphism of distinctive minerals of depositional origin [but agreement on the specific depositional-mineral precursor(s) of the ore minerals has not been reached].

The general relationships among the Proterozoic rocks have been studied from several points of view. One viewpoint has been particular rock types (for example, Fenner, 1914; Hinds, 1921; Drake, Aleinikoff and Volkert, 1991a, b; Drake and Volkert, 1991; Puffer, 1980; B. L. Smith, 1957, 1969). Much effort by some of these investigators comes under the heading of "lithology" or detailed descriptions of individual specimens. In some cases, no corresponding effort has been devoted to aggregating individual rock types into mappable formations. By contrast, formation recognition and mapping (for example, by Offield, 1967; and Drake, 1969, 1990) has shown that the geologic history has been complex. The concept that the Proterozoic rocks of the Reading Prong are part of a vast low-angle thrust sheet, or allochthon, proposed in 1964 by Isachsen (Figure 2), has been supported by geophysical research.

Both of the famous zinc mines have been exhausted. The last ore was lifted from the Franklin mine at 1530 (3:30 PM) on 28 September 1954 (Kozykowski, 1982, p. 189) and at Sterling Hill in early 1987 (FrondeL, 1990, p. 3; but Robbins, 1990, p. 2 stated 1988), much effort has been devoted by the local residents to keeping the two towns from becoming "ghost towns" of the kind found in Nevada, for example. Notable efforts have been made by the Kiwanis Club of Franklin and Steve Sanford to establish the Franklin Mineral Museum; by the Franklin-Ogdensburg Mineralogical Society in promoting various mineral-related activities such as the annual Franklin-Sterling Hill Mineral Show; and by Richard and Elna Houck, who have organized the Sterling Hill Mining Company which has purchased the Sterling Hill property and

is operating the Sterling Hill Mine and Museum as a tourist attraction. These fine people are our hosts. Many documents related to the long history of the mining operations are housed in the Sussex County Historical Society's building in Newton.

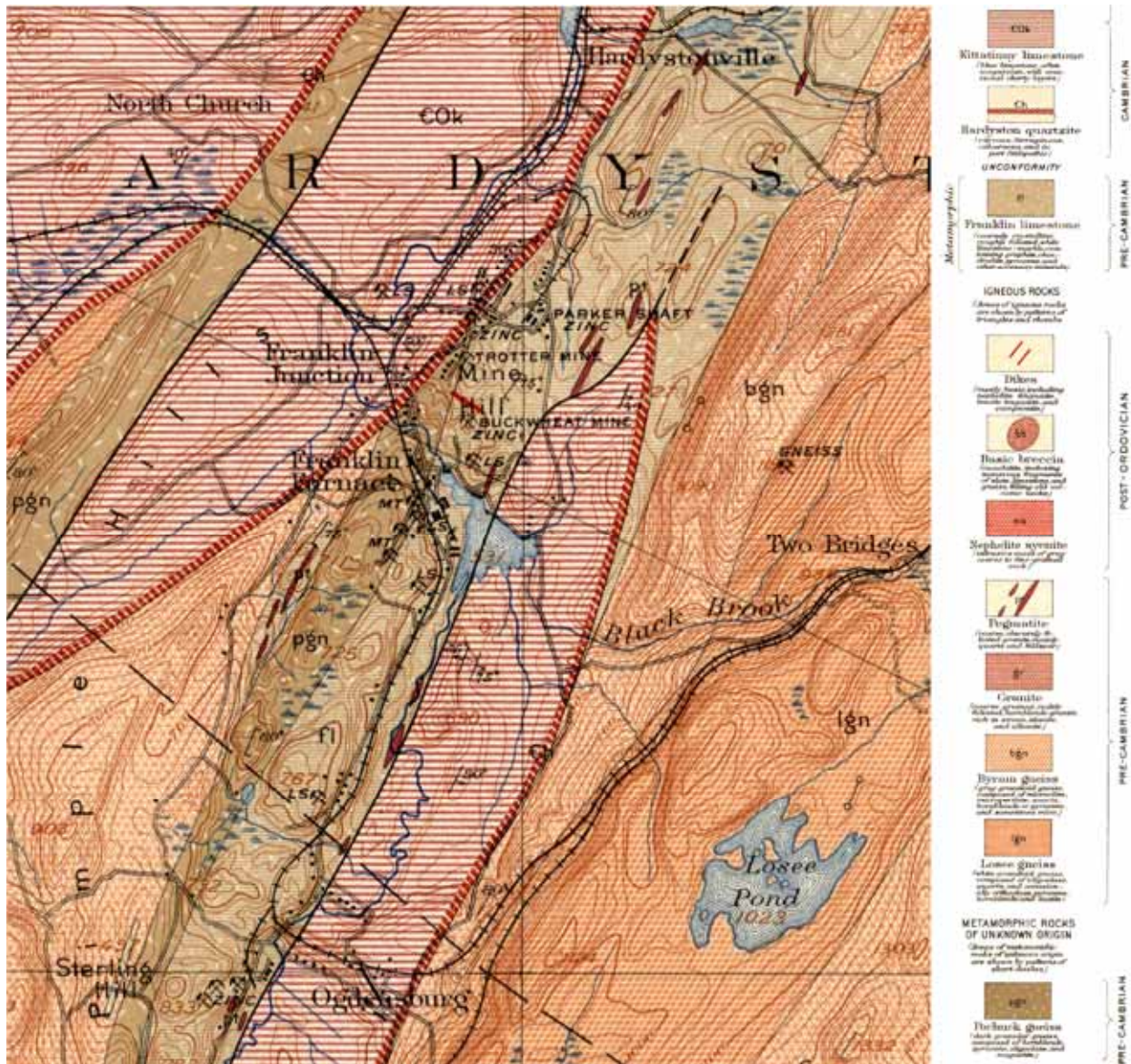


Figure 1. Geologic map of the Franklin-Sterling Hill mining district. (Spencer et al., 1908.)

BEDROCK UNITS ENCOUNTERED ON TRIP ROUTE

Layer I: "Basement Complex" (Proterozoic Z, Y and X)

The basement complex of northwestern New Jersey is part of a major tectonostratigraphic unit known as the Reading Prong massif (Figure 2). Paralleling the main trend of the core zone of the Appalachians, the Reading Prong trends northeasterly from Reading, Pennsylvania

through New Jersey and on into New York as the Hudson Highlands. We have examined parts of this belt on many of our trips in the past (Bear Mountain Gneisses, Fordham Gneiss, Hudson Highlands Gneiss, etc.). Paleozoic sedimentary rocks occur in fault-bounded basins and interrupt the across-strike continuity of the Proterozoic rocks. Most interpretations of these occurrences would put the Paleozoic in fault-bounded grabens (down-faulted basins with normal faults at the boundaries). Modern views (including Merguerian and Sanders, 1989f; 1995) offer the suggestion that some of the Paleozoic strata are parts of upfaulted horsts in contact with downdropped remnants of one- or more formerly continuous low-angle thrust sheets.

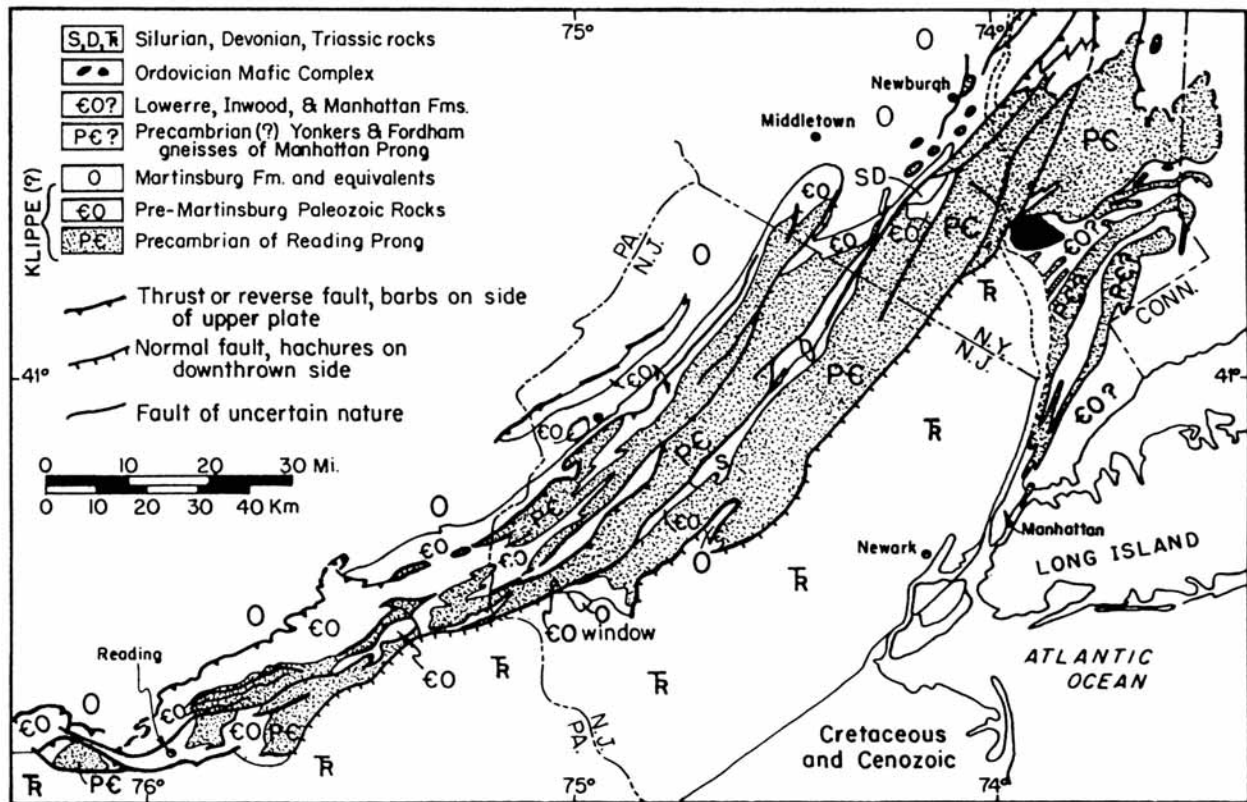


Figure 2. Sketch map showing extent of Reading Prong klippe [stippled areas]. (Isachsen, 1964, fig. 5, p. 821.)

The Proterozoic rocks of the Reading Prong and the Hudson Highlands, long considered to indicate greatly elevated parts of the "basement complex" underlying all the Paleozoic strata (and thus continuing indefinitely downward through the felsic-crust part of the continental lithosphere), are now thought to be parts of a vast allochthon or overthrust belt. According to the allochthon interpretation, as first proposed by Isachsen in 1964, the Proterozoic rocks do not extend indefinitely downward into the "ewige Tiefe," but rather end abruptly downward against a low-angle overthrust, beneath which are Paleozoic strata (and, of course, beneath them, the lower plate "basement complex"). The extent and date(s) of the overthrusting of Proterozoic rocks over Paleozoic rocks are topics now engaging the efforts of some of the current generation of Appalachian structural geologists.

The first proof of such overthrusting came to light about 100 years ago when the Lehigh Railroad excavated a tunnel through Musconetcong Mountain, New Jersey. Isachsen (1964, p. 822) cites Kümmel (1940) as his source for what the tunnel revealed, but Kümmel (1940) does not mention the tunnel. Instead, the correct citation should be Lewis and Kümmel (1915), not included among Isachsen's list of references, but listed in the reference section, of course (Figure 3). Isachsen (1964) thought that the age of overthrusting had been Taconian (late Ordovician), but the current preference of A. A. Drake and associates, of the United States Geological Survey, based on extensive detailed mapping in eastern Pennsylvania and NW New Jersey, is Late Paleozoic ("Alleghanian," a term we prefer to cease using in favor of the prior term "Appalachian"). Thus, we keep open the idea that significant continentward overthrusting of basement occurred during the Late Ordovician Taconic orogeny, as demonstrated in southern New England along the fronts of the Berkshire and Green Mountains massifs, but suggest that another episode of cratonward basement and cover displacement may have happened late in the Paleozoic Era.

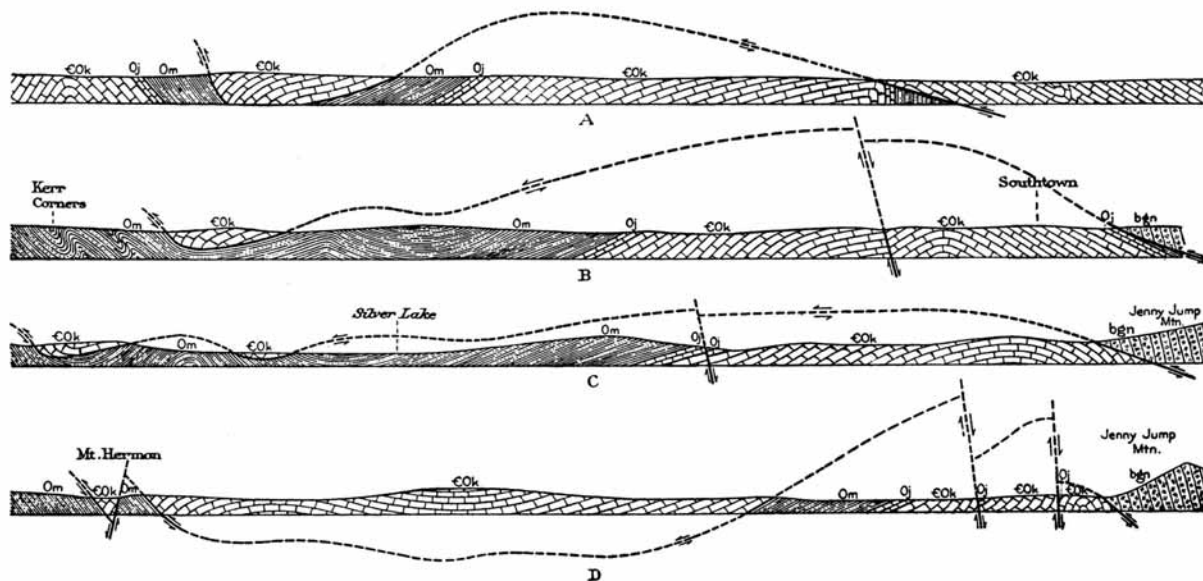


Figure 3. Geologic sections illustrating the vast thrust sheets of Cambro-Ordovician strata in the Kittatinny Valley and klippe composed of Proterozoic rocks at Jenny Jump Mountain. (J. V. Lewis and H. B. Kümmel, 1915, fig. 3, p. 58.)

The Proterozoic rocks of the Reading Prong in the vicinity of Franklin, New Jersey consist of a wide variety of granitoid igneous rocks, metaigneous-, and metasedimentary rocks as described by Spencer and others (1908), Hague and others (1956), and more recently by Puffer (1980); Drake (1984, 1990); Drake, Hall, and A. E. Nelson (1988); and Drake, Aleinikoff, and Volkert (1991a, b). Figure 4 displays a generalized section for the Proterozoic rocks. The oldest part of this sequence crops out in Pennsylvania as the Hexenkopf Complex (Drake, 1984) an ancient (Proterozoic X), highly metamorphosed oceanic suite consisting of mafic- and ultramafic rocks and chert. These rocks are overlain by the Losee Metamorphic Suite of New Jersey which is, in turn, overlain by Proterozoic Y metamorphosed quartzofeldspathic and calcareous rocks,

known as the "Grenvillian" terrane farther north in the Adirondack Mountains of New York State. The Proterozoic Y rocks have been intruded by numerous syntectonic and post-tectonic granitoid- and syenitic intrusives.

<u>Column</u>	<u>Units</u>	<u>Remarks</u>	<u>Thickness</u>
P R E C A M B R I A N	POCHUCK MOUNTAIN GNEISS SERIES <i>(Lake Lenape, Pimple Hills, Pochuck Mtn., and Glenwood synclines)</i>	<i>A thick series of inter-layered hornblende gneiss, microcline gneiss, and biotite gneiss with thin bands of garnet gneiss, graphitic gneiss, pyroxene gneiss, and local quartzite. Intrusive(?) oligoclase gneiss in Pimple Hills.</i>	<i>unconformity</i> <i>Over 2000'</i>
	WILDCAT MARBLE	<i>Indistinguishable from Franklin marble.</i>	<i>300' at Franklin</i>
	CORK HILL GNEISS ZONE	<i>Similar to gneisses above. Graphitic gneiss, garnet gneiss and pyroxene gneiss at Mt. Eve. Light pyroxene gneiss north of McAfee.</i>	<i>500' at Glenwood 1000' at Franklin 800' at Sterling 1900' at Limecrest</i>
	FRANKLIN MARBLE	<i>Coarsely crystalline limestone with local banding of mica, tremolite, chondrodite, norbergite and other silicates. Abundant graphite. Franklin (1) and Sterling(2) ore horizons.</i>	<i>1100'-1500'</i>
	MEDIAN GNEISS	<i>Very few outcrops. Mostly biotite gneiss and quartz gneiss with local hornblende and microcline gneisses.</i>	<i>50'-300'</i>
	FRANKLIN MARBLE		<i>Thickness unknown because of probable duplication by folding in the Walkill Valley</i>
	HAMBURGH MOUNTAIN GNEISS SERIES	<i>A series of gneisses similar to the Pochuck Mountain series. Local quartzite and local graphitic gneiss. Byram gneiss intrusive into this series.</i>	<i>Thickness unknown because of intrusion by the Byram gneiss probably over 2000'</i>

Figure 4. Generalized columnar section of the Proterozoic metasedimentary and metavolcanic rocks of the Franklin-Sterling Hill area (Hague and others, 1956, fig. 18, p. 468.)

Locally, the Chestnut Hill Formation of Drake (1984), lies unconformably above the Proterozoic Y gneisses and granitoids, and consists of less-metamorphosed Proterozoic Z arkose, ferruginous quartzite, quartzite conglomerate, possible metarhyolite, and metasaprolite (Drake, 1990). The Proterozoic basement complex is unconformably overlain by deformed sedimentary rocks of the Kittitiny Supergroup, including the Hardyston sandstone (locally quartzite), Kittitiny limestone, and overlying black shales and turbidites of the Martinsburg formation. (See Table 2.) These are direct lithostratigraphic equivalents of the lower Paleozoic Sauk and Tippecanoe sequences, as examined on our previous trips in southern New England.

The Proterozoic rocks surrounding the Franklin-Ogdensburg area consist of the Losee Metamorphic Suite whose type locality is the Beaver Lake Antiform near Losee Pond. The Losee, which also crops out to the west of Sterling Hill in the Pimple Hills, is interpreted as a metamorphosed volcano-plutonic pile consisting originally of dacite, splitic basalt, tonalite, and trondhjemite. Associated with the Losee are orthopyroxene-bearing granitoids known as charnockites. These unusual rocks were first identified and named from the tombstone of Job Charnock, the British founder of Calcutta, who died in 1693. Charnockites are felsic rocks consisting of 10 to 60% quartz; the proportion of alkali feldspar to total feldspar ranges from 35 to 90%. Charnockites form under conditions of high temperature and -pressure and may be either igneous- and/or metamorphic rocks.

Similar sequences of Proterozoic Y rocks are present in the Green Mountains of Vermont and in the Adirondacks of New York State. Most of the Proterozoic rocks we will examine today are part of the "Grenvillian" metasedimentary sequence developed unconformably above the Losee sequence. The most- distinctive Proterozoic unit we will examine today is the Franklin Marble, host for the Franklin and Sterling Hill ore bodies. Below we discuss the geology and deformational history of the Proterozoic rocks in the Franklin-Ogdensburg area. The Proterozoic basement complex formed a unique cratonic substrate atop which Paleozoic sediments accumulated by Cambrian times as discussed below.

Layers IIA and IIB: Cambro-Ordovician Strata of the Sauk and Tippecanoe Sequences

Early in the Paleozoic Era, this part of the Appalachian region became the trailing edge of a continental plate, a passive continental margin. This tectonic setting persisted until the Taconian orogeny late in the Ordovician Period (Tables 1, 2). Interestingly, the current plate-tectonic passive-continental-margin setting of eastern North America [deformed Paleozoic and older basement covered by essentially nondeformed Mesozoic and younger sediments that were (and continue to be) deposited as the margin subsides toward an ocean basin to the east] more or less duplicates that of Early Paleozoic time (Figure 5).

The Cambrian and Ordovician bedrock units (Layer II) underlying the Manhattan Prong and adjacent parts of central New Jersey consist of sedimentary rocks that formed near the Earth's surface. They began their geologic "lives" approximately 550 million years ago as thick accumulations of both shallow- and deep-water sediments adjacent to the Early Paleozoic shores of proto-North America. The **Sauk Sequence** is represented by the area denoted Limy Coastal Plain on Figure 5. Elsewhere in NJ, strata of the **Tippecanoe Sequence** overlie the Sauk.



Figure 5. Paleogeographic reconstruction of North America as it is inferred to have existed during the Cambrian Period. Not shown are paleolatitudes and position of the Early Paleozoic equator, which extended across what is now North America passing through Oklahoma, Kansas, and the Dakotas such that what is now east in the Early Paleozoic was south. (G. M. Kay, 1951, plate 1, facing p. 1.)

Layer II can be divided into two sub-layers, IIA and IIB. The older of these, IIA or the **Sauk Sequence**, represents the ancient passive-margin sequence of the proto-Atlantic ocean. In turn, these rocks can be subdivided into two facies that differ in their original geographic positions with respect to the shoreline and shelf. A nearshore-shelf facies [Layer IIA(W)] was deposited in shallow water and is now represented by the Cambrian Hardyston Quartzite and Cambro-Ordovician Kittatinny "Blue" Limestone in New Jersey (Stops 1, 4, and 5), the Lowerre Quartzite and Cambro-Ordovician Inwood Marble in New York City, and the coeval Cheshire Quartzite and Stockbridge Marble sequence in western Connecticut and Massachusetts. These strata were deposited first as sandy and then as limey sediments in an environment closely

resembling that of the present-day Bahama Banks. The chief difference is that the salinity of the Paleozoic seas exceeded that of normal seawater (inferred from the features of the dolostones).

Farther offshore, fine-grained terrigenous time-stratigraphic equivalents of the shallow-water strata (shelf sequence) were evidently deposited under deep water on oceanic crust [Layer IIA(E)]. This sequence, not a focus of today's trip, is also of Cambrian to Ordovician age and is known as the **Taconic Sequence** in upstate New York, as units €-Om and €-Oh of the Manhattan Schist(s) in New York City and vicinity. Layer IIB consists of younger, mostly terrigenous strata that were deposited unconformably above the products of the western shallow-water platform [Layer IIA(W)]. In eastern New York State, the metamorphosed equivalents of these terrigenous rocks are mapped as the Walloomsac Schist and Manhattan Formation. In Pennsylvania and New Jersey the rocks are known as the Martinsburg Formation.

In the region of our field trip, these rocks were folded and eroded several times. Initially, the Cambro-Ordovician dolomitic carbonates were elevated and gently folded. The overlying limestone filled local sinkholes and rests on various units. During the Taconic orogeny, the folding was more intense and, the erosion cut more formations than during the Medial Ordovician. Accordingly, the basal unit of Layer III (Lower Silurian Green Pond or Shawangunk Conglomerate) rests on any of these units, even on the Proterozoic "basement" (Finks and Raffoni, 1989).

On our trip we will visit (Stop 1), a new roadcut (near Sparta, New Jersey, where part of the Cambro-Ordovician carbonate succession displays numerous features made by a peritidal environment. Present are dolomitic rocks that formed from what were originally calcium-carbonate muds and -sands. Chert is locally abundant. Finally, as a result of deep burial, some layers have been subjected to pressure solution, as is evidenced by the numerous stylolites on several scales.

In the region of New Jersey that we shall visit, two vastly different belts of carbonate rocks are found. In the area of the Sterling Hill Mine, they are in direct fault contact along the Zero Fault (Figure 1). The older of these, the Franklin Marble is host for unusual mineralization. The Sauk carbonates (here known as the Kittatinny or "Blue" Limestone), have been mined for industrial uses.

GEOLOGY OF THE FRANKLIN FURNACE DISTRICT, NEW JERSEY

Ask any mineral collector where the most-phenomenal assemblage of minerals can be found in a small area and the response will undoubtedly be: "Franklin Furnace, New Jersey" (unless the mineral collector is a wisecrack and names the Smithsonian where George Roebling deposited his vast collection to start them off!). Surely, with roughly 300 reported species, more minerals have been recorded from the Franklin area than any place in the world with at least 20 minerals unique to the deposit. If hosting roughly 20% of all known minerals in one place were not enough, Franklin also boasts the world's most-spectacular fluorescent mineral assemblages with more than 60 varieties known and described, largely by amateur mineral collectors. Tables

3 and 4 list by name and fluorescent coloring these unique mineral species and, for reference, the most useful and comprehensive work on the subject is by Gleason (1972).

Short-wave (2537 nanometers) radiation yields the best results from the Franklin-Sterling Hill suite although long-wave (3660 nanometers) radiation produces an effect on some species. The dominant minerals that show spectacular color are the **manganoan calcite** (white, cream, yellow, orange, red, green, and pink fluorescence), **smithsonite** (yellow), and **willemite** (green, yellow-orange, and yellow fluorescence) although many, many more fluoresce (Tables 3 and 4).

Fluorescence, and its allied physical property phosphorescence, result from the presence of loosely held electrons in the outer electron shells of elements such as, but not limited to, manganese. In the presence of an energy source, a UV lamp producing short- or long-wave radiation, electrons become over excited and leap, upon absorption of energy, to higher electron energy levels. After a number of electrons make the jump an equilibrium is established between jumpers and those that choose to return back to their former (lower-energy) electron sites. This "jump back" results in the production of visible light with the color corresponding to the rate and degree of jumping.

Phosphorescence is the ability of some minerals to give off visible light even after the energy source has been removed. Thus, if a delay in "electron jump shut-off" by procrastinating electrons occurs, the mineral will continue to glow in the dark. You will marvel at these phenomena at the NJ Zinc Mine Museum display and in the dark of the night as we collect.

Let us now draw our attention to the history of the Franklin Furnace Mining District and a discussion on the geology and genesis of the ores, the latter a controversial, unsettled subject. The following draws heavily, if not bordering on plagiarism, from the following sources which can be looked up and hunted down from the reference list: Spencer and others (1908), Palache (1935), Frondel (1972), Metsger (1990), Drake (1990), Leavens and Nelen (1990), and Johnson and others (1990).

The east limb of the orebody at Sterling Hill cropped out boldly on a hillside west of the Wallkill Valley (present site of Sterling Hill Mine headframe) and the Franklin orebody originally cropped out on Mine Hill. (See figure 1.) Thus, discovery of these ores was not difficult by modern standards. The oldest reported workings of the district, from tree-ring studies, indicate that ore was mined prior to 1739, probably by Dutch settlers who operated a copper mine near the Delaware Water Gap, Pennsylvania, in the interval from 1640 to 1657.

Pinger (1950) suggested that the Dutch mined hemimorphite (zinc-rich saprolite) from the top of the orebody at Sterling Hill for use in the production of brass. The Reading-Hudson Highland Prong is well known for its iron deposits and the earliest mining in the region (near Sparta, NJ) was directed toward that end (Figure 6). The first iron smelter (or furnace) was built before 1787 in Sparta by Robert Ogden, after whom Ogdensburg is named. An iron forge was built in Franklin, named incidentally after William Franklin, son of Benjamin Franklin, in about 1765 and a smelting furnace was added in 1770. The forge and furnace were located west of the dam on Mine Pond but was covered in the 1930's to build a small park (Figure 7). These early miners worked the magnetite vein (Pikes Peak and Longshore Mines) that cropped out to the

west of the Franklin orebody. Thus, the name Franklin Furnace was founded on the presence of iron ore in the region. A large, modern blast furnace was built in the area in 1874 and continued operation until 1906.

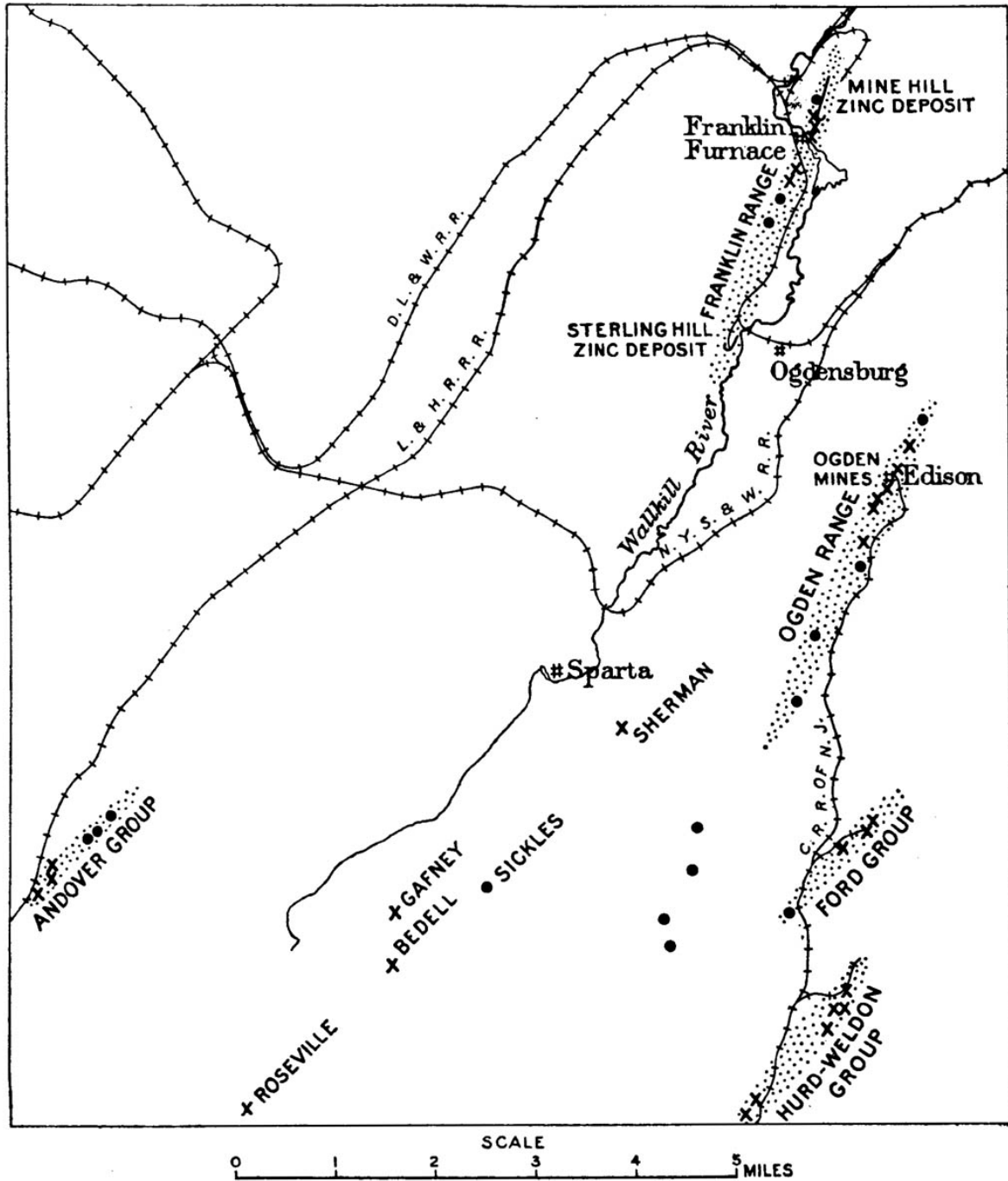


Figure 6. Sketch map showing the distribution of ore ranges south of Franklin Furnace. (A. C. Spencer, H. B. Kümmel, J. E. Wolff, R. D. Salisbury, and C. Palache, 1908, fig. 8.)

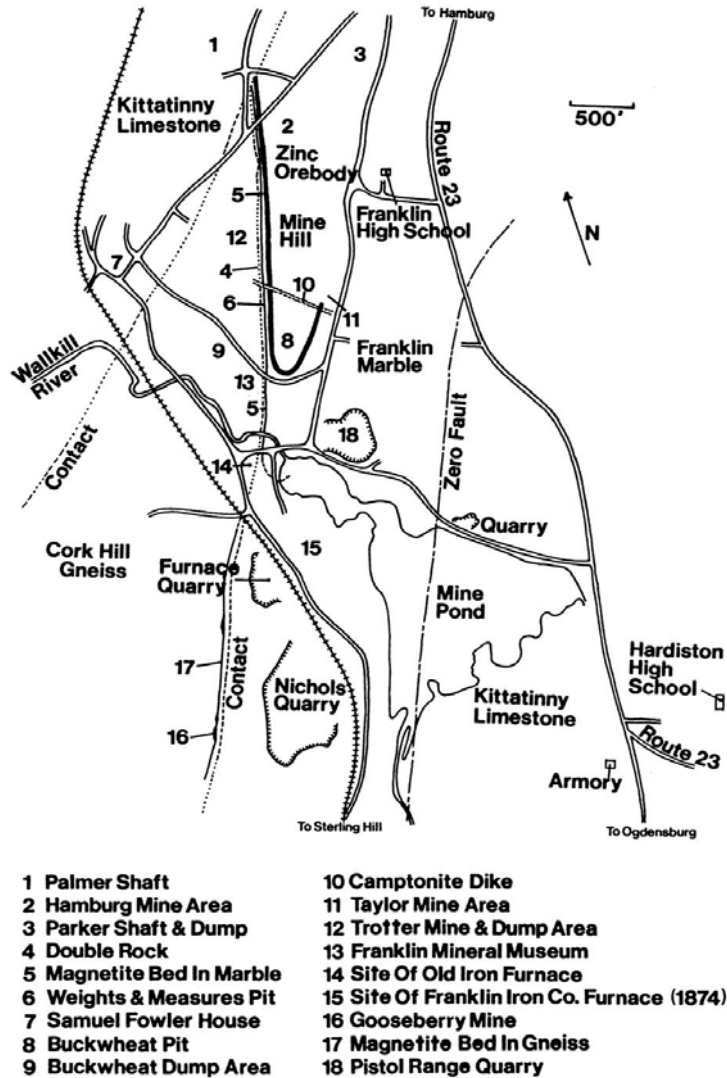


Figure 7. Location map of the Franklin Furnace mining district, New Jersey (Frondele, 1972).

Sterling Hill was named after Lord Stirling, originally known as William Alexander (1726-1783), an American patriot born in New York City. He adopted the title Lord in 1756 having laid claim to the Earldom of Stirling, in Scotland, to which his father was heir. He was an officer in Washington's army, and found himself in possession of extensive estates in New York and New Jersey and was active in developing iron mines in Sussex County. He owned the Sterling Hill mine from 1761 to 1776, and made numerous attempts at developing and smelting the ores. Early mining efforts at the Franklin and Sterling Hill mines were hampered by the difficulty in smelting the Mn, Zn, Fe ores as the combination produced a refractory ore that was difficult to purify.

The Franklin-Sterling Hill orebodies are situated in the Franklin Marble belt which is located on the northwest edge of the Reading Prong roughly 50 miles from New York City. The

Franklin Marble, as discussed earlier, is part of a diverse sequence of metamorphic- and igneous rocks of Proterozoic Y age that were subjected to intense regional metamorphism of sillimanite grade and intruded by a host of synkinematic and post-tectonic intrusive rocks. The Proterozoic (or "white") marble is faulted against the Cambro-Ordovician (or "blue") marble of the Kittatinny Supergroup along the Zero Fault and the Rutherford Cross Fault (Stop 4) on the west side of the Wallkill valley. The Spencer et al. (1908) folio map (See also Figure 1) shows the mines of the Franklin district following the NE trend of the Franklin marble belt (Figure 8) and the close association with pods of pegmatite.

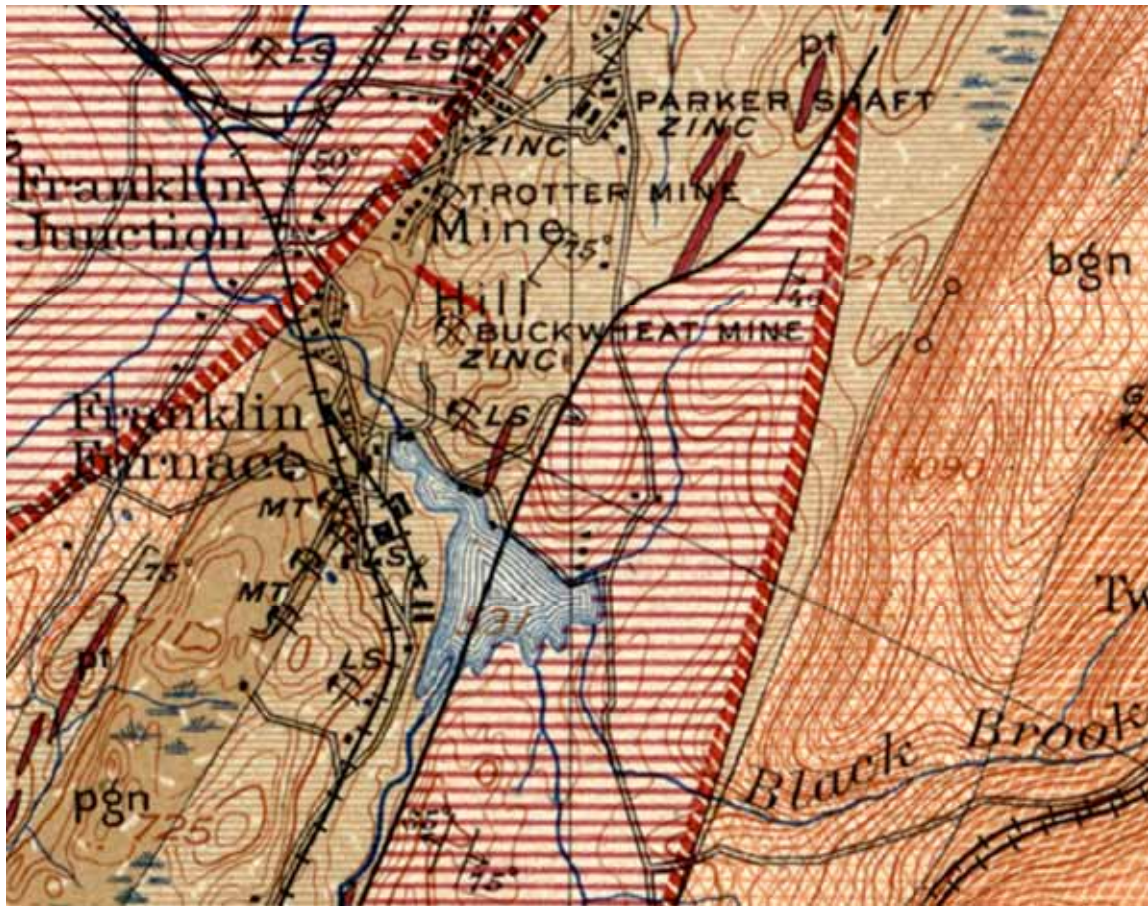


Figure 8. Geologic map of the Franklin Furnace area showing mines and prospects. See figure 1 for explanation of units. (Spencer et al., 1908.)

Palache's (1935) map and geologic sections of the Franklin orebody (redrafted from Spencer et al., 1908) are reproduced in Figure 9. Note the northeast trend of the geologic units and their fault-bounded relationships. The overall synformal shape of the ore-bearing zone at Mine Hill is shown as a stereogram in Figure 10. Figure 11 shows the complex shape of the Wildcat marble horizon along strike from the Glenwood syncline southward to Franklin, Ogdensburg, and beyond Sparta. The Proterozoic rocks consist of interlayered mafic and felsic gneiss and the Franklin Limestone (marble). The Paleozoic units are the Kittatinny Supergroup and underlying Hardyston Quartzite. All of these metamorphic rocks are cut by numerous intrusives ranging in composition from felsic pegmatites to mafic- and alkalic dikes.

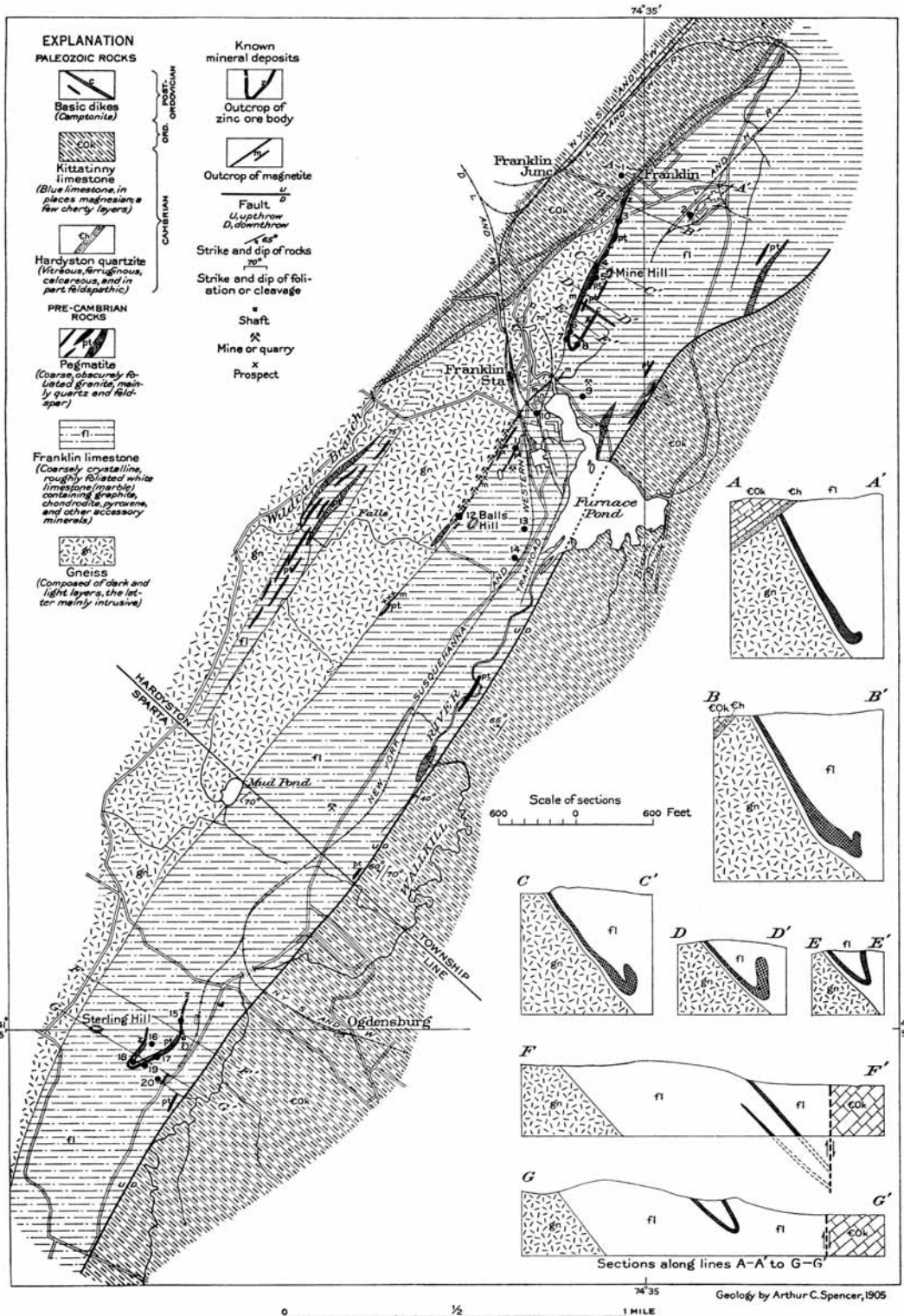


Figure 9. Geologic map of the Franklin mining district showing sites of principal mineral localities. (Palache, 1935, plate 1, p. 18.)

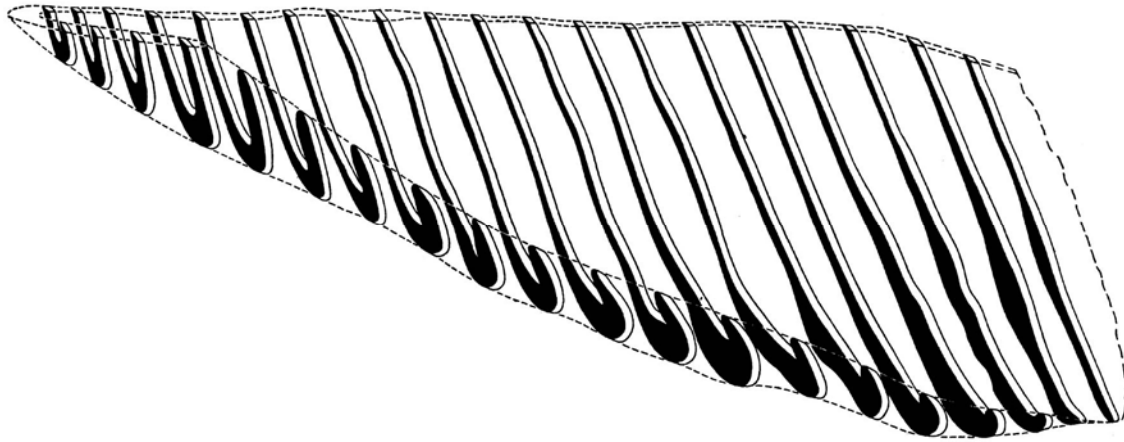


Figure 10. Stereogram the synformal nature of the zinc orebody at Mine Hill in the Franklin district. (Spencer et al., 1908, fig. 11.)

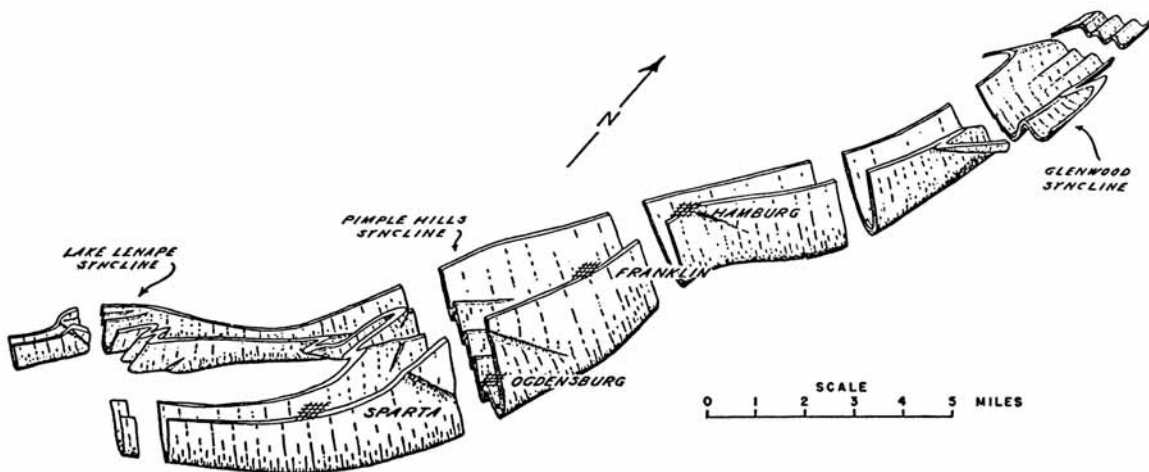


Figure 11. Stereogram illustrating pre-faulting structural interpretation of the Wildcat marble horizon in the Franklin-Ogdensburg mining district. (J. M. Hague, J. L. Baum, L. A. Hermann, and R. J. Pickering, 1956, fig. 17, p. 466.)

The structure of the Franklin orebody is one of a synformal fold that plunges northeast at an angle of roughly 25° (Figure 12). The trough of the plunging synform crops out at Mine Hill (See sections C-C', D-D', and E-E' in Figure 9 for down-plunge projections of synformal structure). The overall shape has, in the view of Metsger, resulted from negative diapirism. That is, downward sinking of the dense, metalliferous ores into a lower-density marble during plastic deformation that resulted in flow in the Franklin Marble. One question that remains to be answered is whether the Franklin Marble simply acted as a ductile material or whether it actually became a fluid and moved as a liquid carbonate "magma".

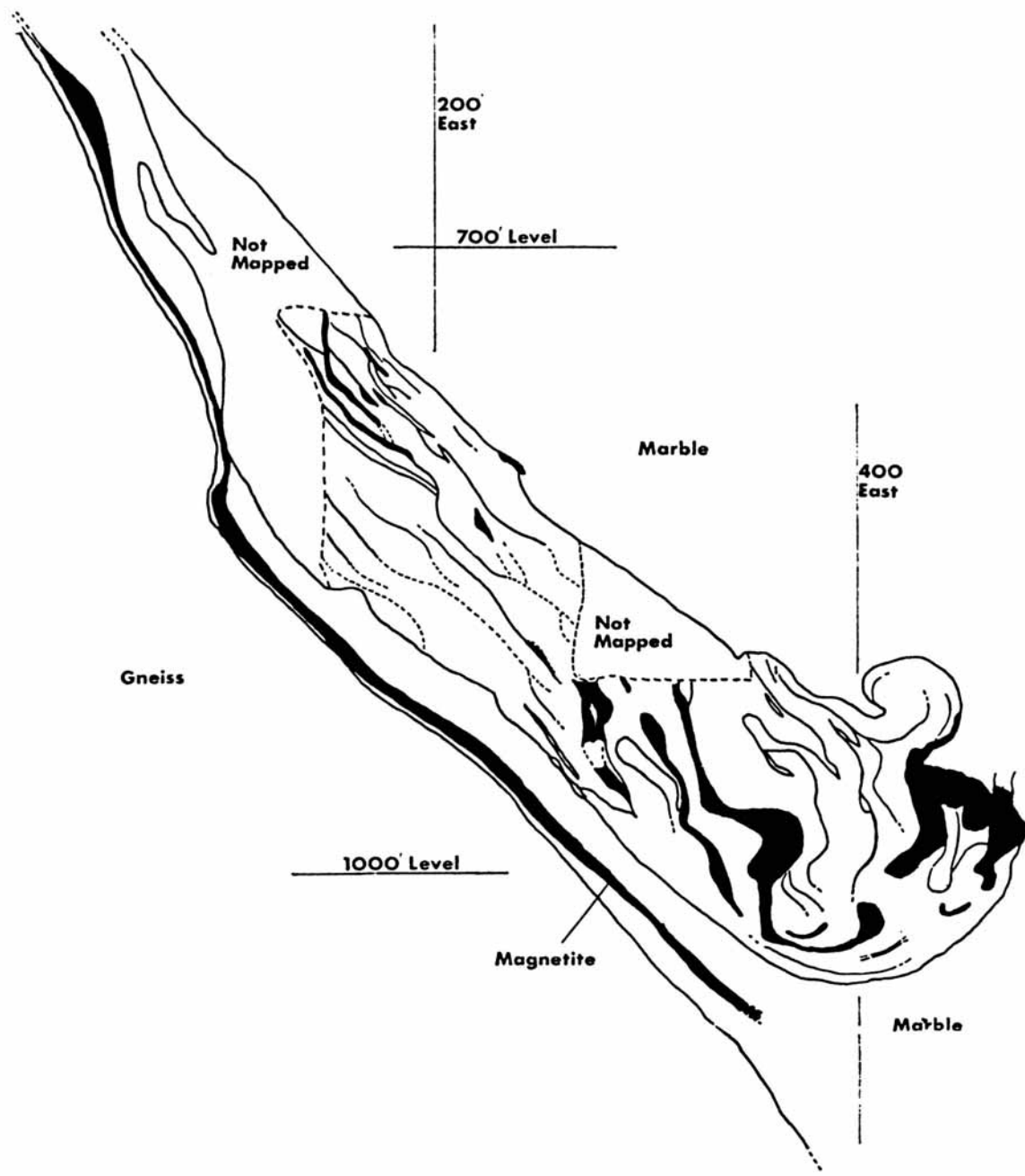


Figure 12. Vertical cross section of the Franklin ore body. Calcisilicate rocks are shown in black and only the boundaries of the ore are indicated. (C. Frondel and J. L. Baum, 1974, fig. 3, p. 162.)

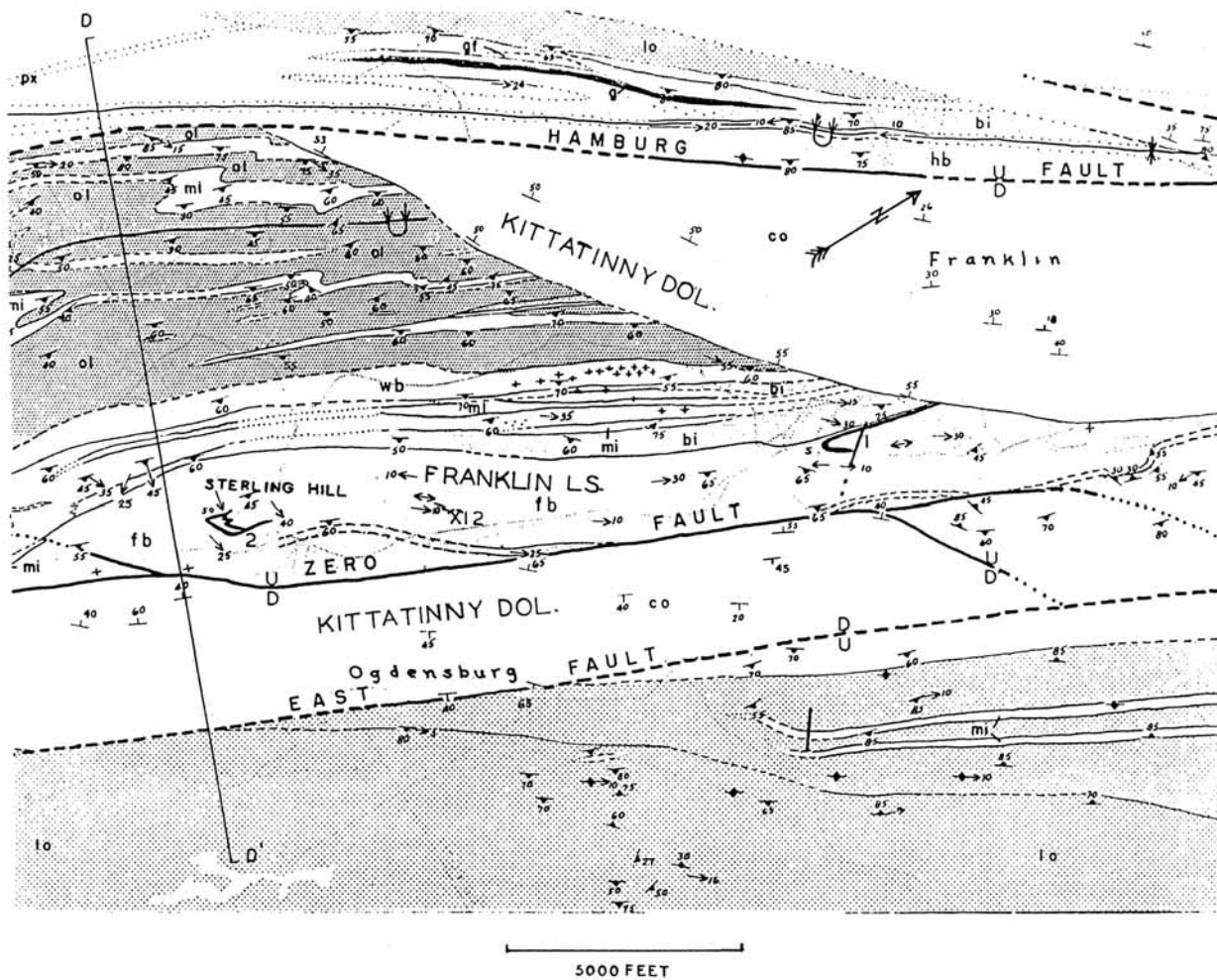


Figure 13. Detailed geologic map showing the distribution of major rock units in the Franklin-Sterling Hill area. (Adapted from J. M. Hague, J. L. Baum, L. A. Hermann, and R. J. Pickering, (1956) by R. W. Metsger, 1990, fig. 2, p. 44.)

The structure of the Sterling Hill orebody is much more complex than the body at Franklin and occurs as a delicately folded synform that plunges steeply toward the ENE at 45°. Figure 13 is a detailed geologic map of the regional geologic relationships of the Franklin Sterling Hill area and shows that both orebodies lie west of the Zero Fault and are developed in the Franklin Marble. An early detailed geologic map of the ore body (Figure 14) and a stereogram of the ore horizon (Figure 15) show the overall synformal structure. Subsequent detailed mapping depicts the intricate details of the ore zone of Sterling Hill (Figure 16) and the subsurface distribution of units and their relationship to the Zero Fault (Figure 17). The mineral composition of the ores are in accordance with the high degree of regional metamorphism of the area (sillimanite grade). The degree of ore remobilization during Paleozoic orogenesis and the nature of ore genesis are questions that still prevail today. In the following section, we briefly discuss these problems.

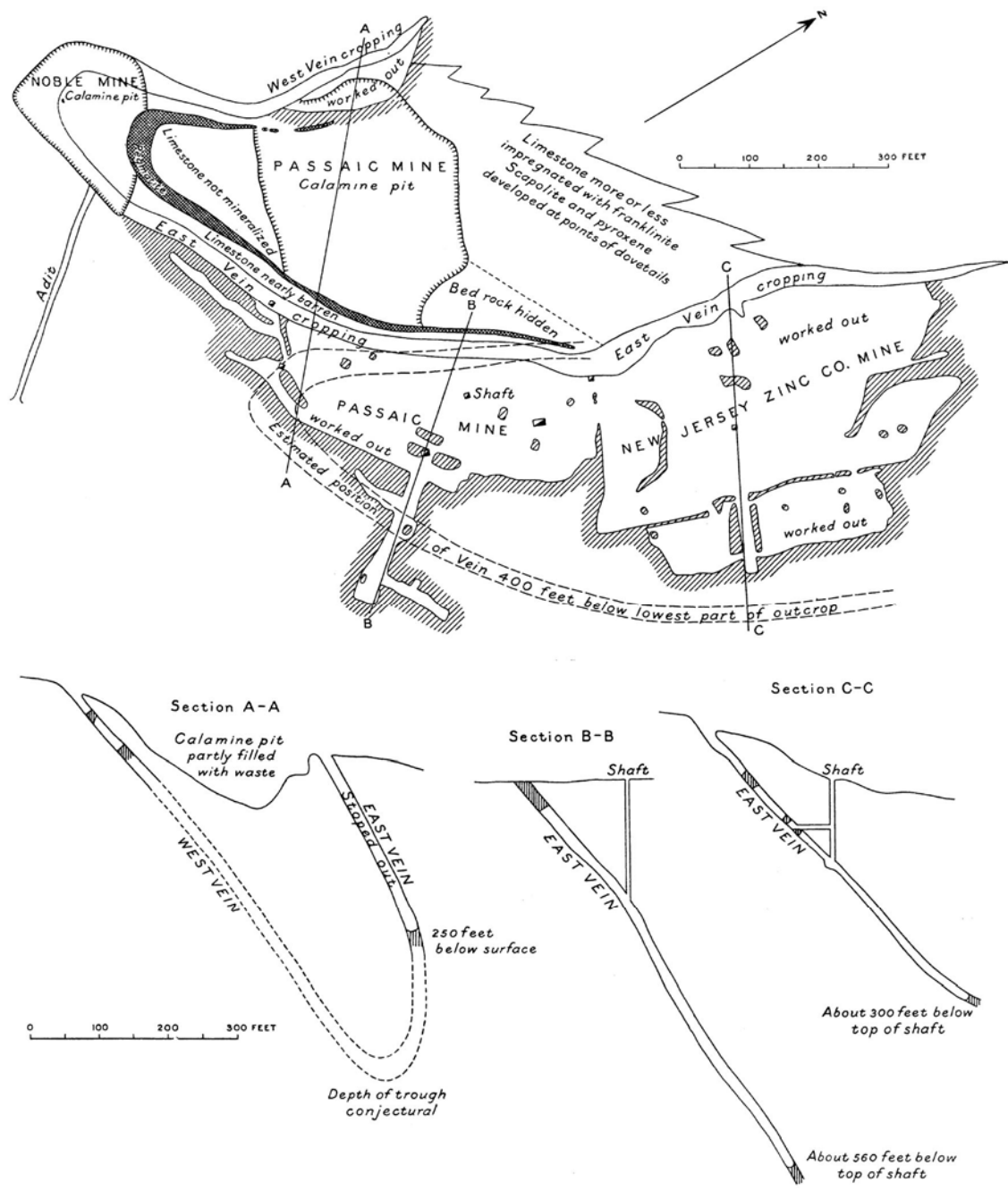


Figure 14. Composite diagram showing plan view (top map) and sections of the Sterling Hill orebody. (Spencer et al, 1908, figs. 14 and 15.)

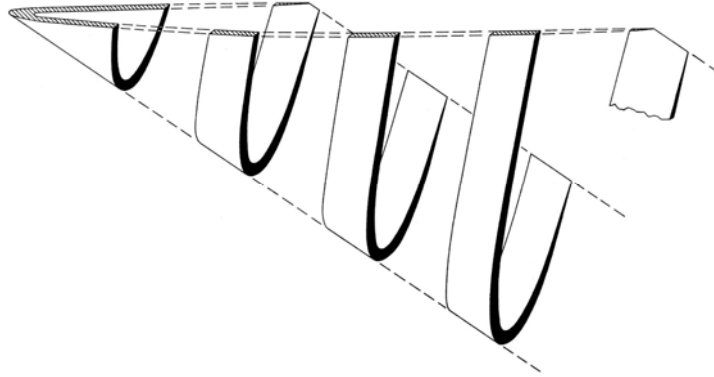


Figure 15. Stereogram showing the overall synformal shape of the Sterling Hill orebody. (Spencer et al., 1908, fig. 13.)

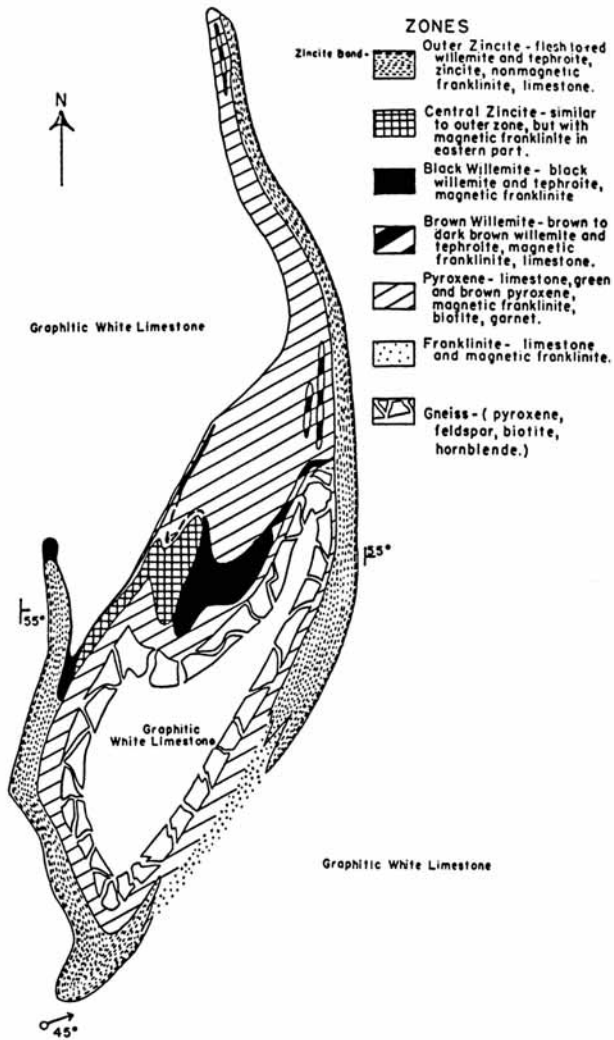


Figure 16. Geologic map of the Sterling Hill orebody. (R. W. Metsger, C. B. Tennant, and J. L. Rodda, 1958, fig. 1, p. 779.)

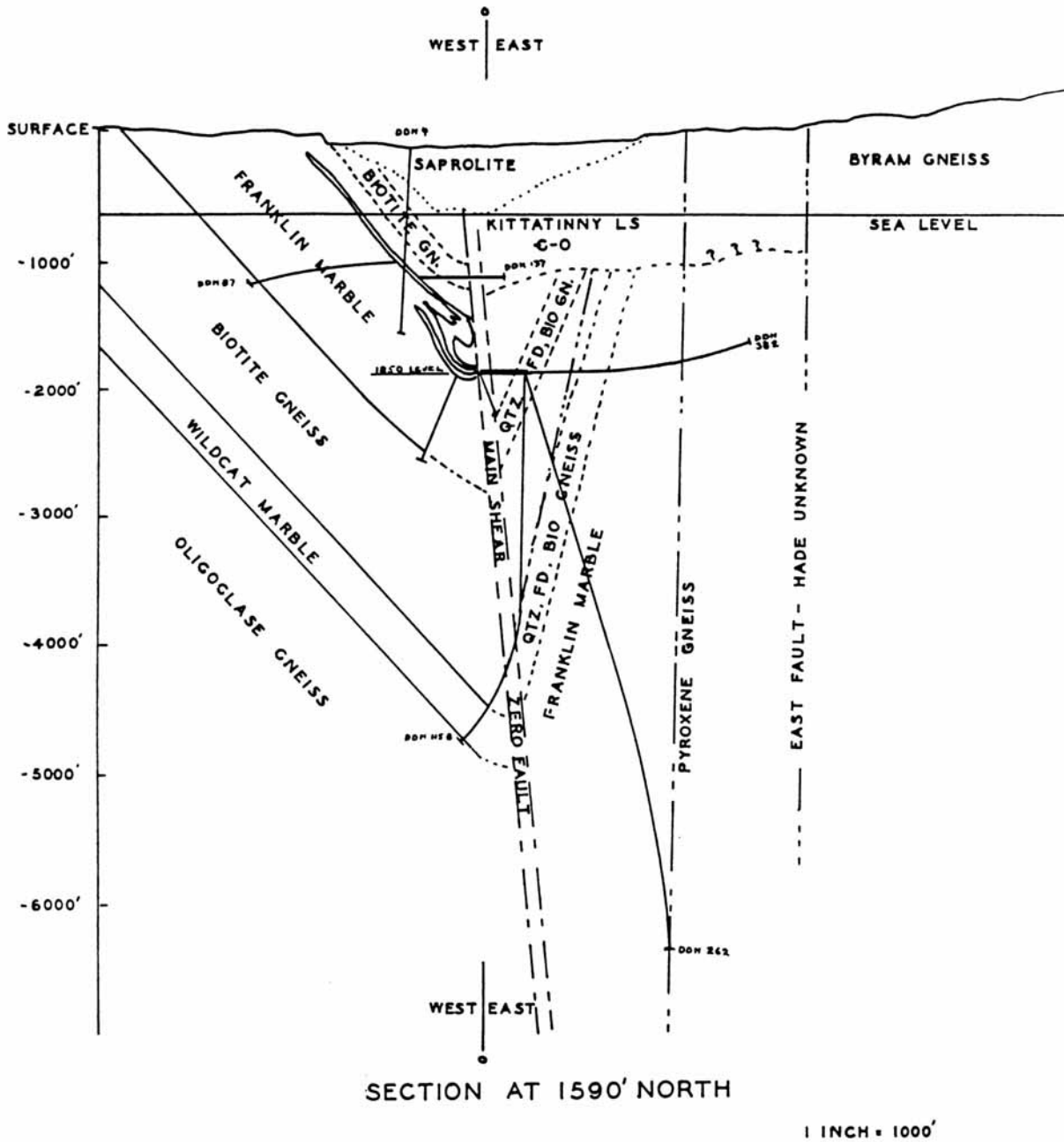


Figure 17. Vertical geologic section of the Sterling Hill Mine showing the location of the Zero Fault and bounding units. (R. W. Metsger, 1990, fig. 3, p. 45.)

Under the heading of Layer I - The Proterozoic X, Y, and Z, we discussed the regional framework of the Proterozoic units exposed in the vicinity of northwestern New Jersey. In the vicinity of Franklin and Sterling Hill, these rocks consist of quartz-feldspar-epidote gneiss, amphibolite, and massive carbonate rocks. Separated by an interval of biotite-quartz-plagioclase gneiss, the massive carbonate layers of the Franklin area form two outcrop belts to the west of

the Zero Fault. (See Figure 13.) They have been formally named, from west to east, the Wildcat and Franklin Marbles by Drake and others (1991). Drake (1990) suggests that the Franklin Marble, host for the Franklin and Sterling Hill ore bodies, is a locally massive, but discontinuous unit that may have originated not on a passive margin but as a local carbonate buildup on the flanks of an ancient rift zone. Drake cites the Everonia Limestone of the Virginia Piedmont as a type example.

CM disagrees with this model, but appreciates the potential "need" for an active rift zone to concentrate the ore-bearing sediments. CM argues that the carbonates are not discontinuous and thin, but significant in thickness and areal extent to warrant embracing a passive margin interpretation. Similar zinc- and magnetite-bearing carbonate deposits are found to the north in the Adirondacks, for example. Perhaps much of the Proterozoic Y carbonate sequence is structurally buried by basement overthrusts as suggested by the distribution of basement-involved thrust faults as shown in figures 2 and 3.

One fact is clear and undisputed, however. The Franklin Marble, which shows evidence of intense brecciation and perhaps Paleozoic dissolution collapse (Metsger 1990), was a highly reactive host for development of the unique, world-renowned Zn-Mn-Fe deposits found within it. Further, as discussed below and at Stop 5, 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 Proterozoic Y Grenville orogeny, roughly 1.1 Ga. We expect that Paleozoic orogenesis and intrusive activity strongly modified and amplified the type and numbers of minerals to their present outstanding variety, but maintain, along with most modern workers, that the major-element mineralogic framework was in place before the close of the Proterozoic Era as indicated by the presence of detrital franklinite and graphite in the basal Cambrian Hardyston Quartzite (Stop 5).

The genesis of the ores in the Franklin Marble remains a sticking point in the geologic history of the district. Moving far afield from earlier models involving mineralization from hot solutions related to intrusive igneous activity, most modern studies support the idea that the metalliferous deposits are syngenetic, meaning that they were deposited at the same time as their Proterozoic Y host rocks. Not a surprising interpretation as they are stratabound deposits, conformable with layering in the Franklin Marble. According to Drake (1990) and Metsger (1990), minerals grew as a consequence of rift-related volcanism at a spreading-ridge crest during the Proterozoic. At first glance, this explanation seems reasonable as Proterozoic X rocks stratigraphically beneath the Franklin Marble are volcanic and volcanoclastic, but the host rocks for the Franklin-Sterling Hill ores are massive (perhaps remobilized in a fluidal state?) carbonates that, for reasons mentioned earlier, may be a part of an extensive carbonate-platform sequence. What is more, oceanic rift-related metalliferous deposits, such as those found in the Ordovician of western New England (Abu-Moustafa and Skehan, 1976; Merguerian, 1980, 1981) and elsewhere in the world (Binstock, 1977; Kramm, 1976) are characterized by stratabound manganese-quartz granofels (coticles) and disseminated iron-oxide (typically hematite-rich, itabirite) deposits, together with podiform and disseminated Cu-Fe-Zn sulfide deposits, all intercalated with mafic rocks and dismembered ophiolitic material (Bonatti, 1975; Bonatti et al., 1976a,b; Corliss, 1971; Dumont, 1847; Merguerian, 1979, 1983; Renard, 1878; and Schiller and Taylor, 1965).

These lithologies are not found association with the oxide- and silicate ores of the Franklin-Sterling Hill area. For one thing, the Franklin-Sterling Hill deposits are unique in terms of chemical composition with no known terrestrial counterpart (although the mineral deposits at Langban, Sweden are closest). They do not contain Cu-rich rocks, Fe-Zn sulfides are rare, and laminated itabirites and/or coticles are absent. Based on this negative evidence, CM argues that 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. Thus, the ocean-rift model is probably "dead in the water". Rather, aspects of the Franklin-Sterling Hill deposits are reminiscent of the massive Proterozoic metalliferous carbonates of India (the "Gondites" and "Kodurites" of Mitra, 1965; Mookherjee, 1961; Prasada Rao and Murty, 1956; and Roy, 1956, 1965).

ROAD LOG AND DESCRIPTIONS OF LOCALITIES ("STOPS")

Today's road log begins at the northeast corner of Fort Washington Avenue and 179 Street, Manhattan, by the Holy Rood Episcopal Church. For locations of the trip Stops, refer to Figure 18.

- [0.0] Bear L for ramp to George Washington Bridge, upper level.
- [1.5] Passing tollgate on L; keep L for I-80 and I-95.
- [2.1] Bear R for I-80 local.
- [2.3] Take ramp on L to I-80 local.
- [2.7] Jones Road overpass; upper contact of Palisades sheet exposed on R.
- [2.9] Top of intrusive sheet at road level. Note contact-metamorphosed Lockatong Formation. Ahead is the strike ridge underlain by a sandstone in the Passaic Formation.
- [4.8] Bear R for Exit 69 to I-80 local (Paterson).
- [5.8] Red sandstones and shales of Passaic Formation on R.
- [6.2] More Passaic sandstones exposed on R.
- [7.6] Pass Exit 65 on R.
- [8.0] Pass Exit 64B on R.
- [8.5-8.6] More Passaic strata dipping NW exposed on R.
- [9.4] Pass ramp on R for Exit 63.
- [9.7] More Passaic strata exposed on R.
- [11.0] Pass ramp on R for Exit 52, Garden State Parkway.
- [11.6] MP 62 on R.
- [13.4] Passing ramp on R for Exit 59 to US Route 46 and NJ Route 20.
- [13.7] MP 60 on R.
- [14.4] View ahead to contact between top of red Passaic Formation and base of overlying Orange Mountain basalt (=First Watchung of pre-Paul Olsen terminology).
- [15.9] Large cut on L of Orange Mountain basalt showing columnar joints cut by five sub-vertical faults.
- [16.5] Passing Exit 56 ramp on R to Paterson.

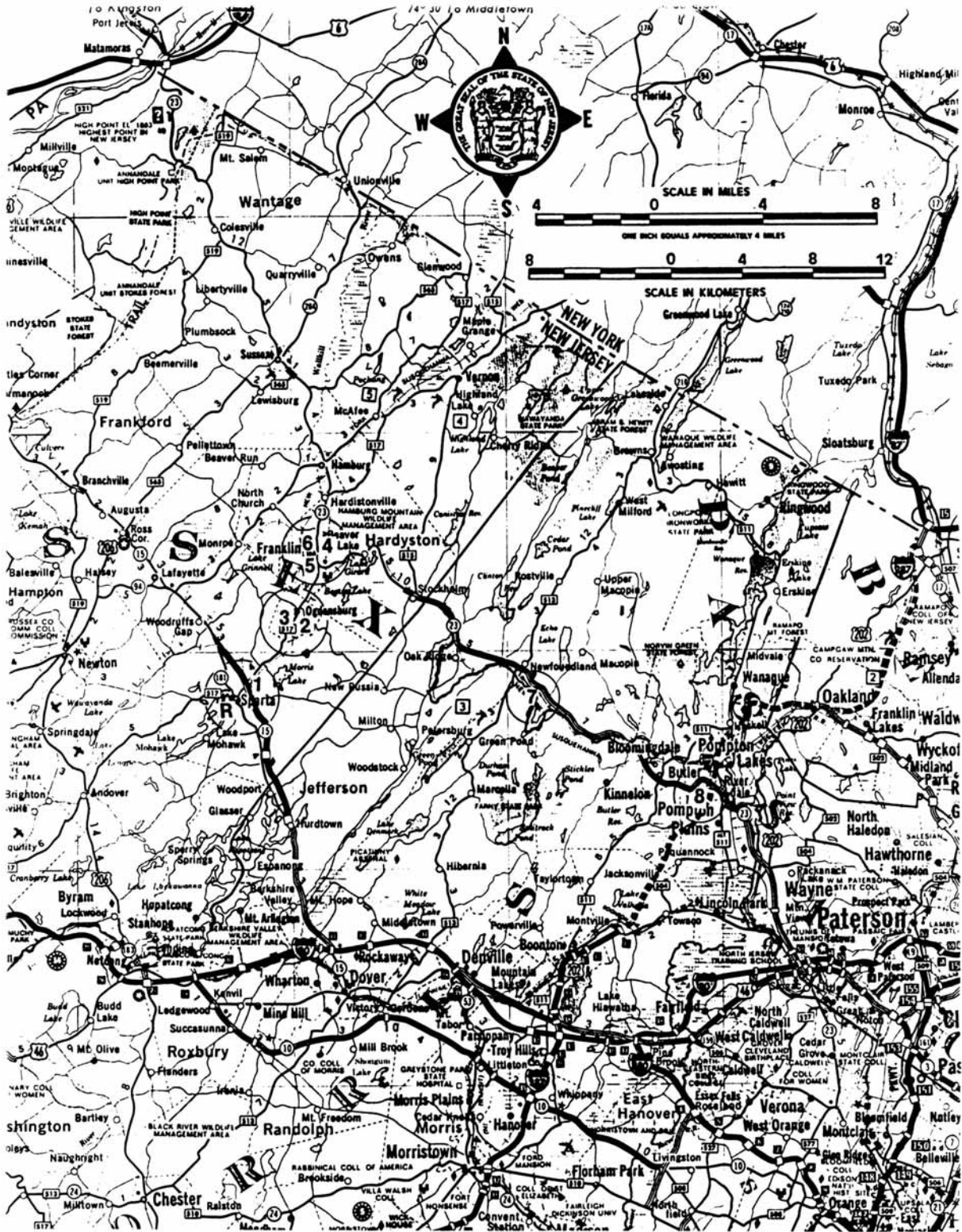


Figure 18. Road map showing numbered trip stops 1 through 6 (circled). (State of New Jersey, 1993-1994 Official Transportation Map and Guide.)

- [17.4] Bridge over Passaic River.
- [18.4] Pass ramp on R for Exit 55B.
- [18.7] Pass ramp on R for Exit 55A.
- [20.1] Pass ramp on R for Exit 53, US Route 46 and NJ Route 23.
- [21.1] Bridge over Passaic River (again).
- [21.5] Pass ramp on R for Exit 52, Lincoln Park. View ahead to Second Watchung Basalt Ridge (Preakness Mountain basalt).
- [23.0] MP 51.
- [25.7] Bridge, entering Montville Township.
- [26.2] MP 48; pass ramp on R for Exit 48.
- [26.4] Cuts of Preakness (2nd Watchung) Basalt.
- [27.7] Pass ramp for Exit 47 on R to US Route 46 (Westbound) toward Parsippany.
- [28.0] Road divides. Keep L for I-80, do not veer R to I-287 (Morristown).
- [31.3] MP 43.
- [31.4] Pass ramp on R for US Route 202.
- [33.1] Exposures on L of subvertical Proterozoic gneiss.
- [33.4] Interlayered mafic and felsic gneisses.
- [34.4] MP 40.
- [35.0] Passing Exit 39 on R (Denville) to US Route 46 and NJ Route 59.
- [36.5] MP 38.
- [36.8] Entering Rockaway Township.
- [36.9] Pass ramp on R for Exit 37.
- [37.5] Proterozoic gneiss on R.
- [39.0] Pass Exit 35B ramp on R. (to Mt. Hope).
- [39.3] Pass Exit 35A ramp on R.
- [40.2] Take Exit 34B ramp on R for NJ Route 15 (North) to Sparta.
- [41.0] Traffic light. Road for trucks to Picatinny Arsenal.
- [42.1] Entering Jefferson Township.
- [42.4] Traffic light by powerline parallel to road.
- [42.6] MP 4 on R.
- [43.0] Pass road junction with Taylor Road (no light).
- [44.0] Proterozoic pyroxene-bearing mafic gneiss in cut on R.
- [44.1-44.2] Felsic quartz-oligoclase Proterozoic gneisses.
- [44.55] Traffic light.
- [44.6] MP 6 on R.
- [45.6] Take exit on R for 181 N.
- [45.8] Coming from NJ 15, take 1st R turn onto 181 N.
- [46.7] Proterozoic pyroxene-bearing granite gneiss in cut on R.
- [46.9] MP 1. Lake on L ahead.
- [47.2] Crossing bridge between lakes on L and R.
- [47.6] Entrance on L to Hopatcong Crushed Stone Co.
- [47.8] Proterozoic felsic gneisses on L.
- [48.0-48.1] Iron-stained, mafic Proterozoic gneiss.
- [49.0] MP 3 on R.
- [49.1-49.3] Proterozoic gneisses on R.
- [49.3] Sawmill Road on L followed by more gneisses.

- [49.5] Junction with NJ 15 (Should have exited here). Lots of Proterozoic quartz-oligoclase gneiss and amphibolite around cloverleaf.
- [50.1] Hunters Lane on L.
- [50.9] Pull into Sparta Diner on L. Time for a driving break and Rest Stop.
- [51.0] Leave parking lot by turning L.
- [51.1] Stop sign at Stanhope Road, turn R.
- [51.2] Traffic light; merge with NJ 181 N.
- [51.3] Turn R on 181.
- [51.4] Bear L on 181 toward Lafayette and Newton.
- [51.5] Traffic signal; go straight toward Newton.
- [51.9] Blinking light, bear R toward Lafayette.
- [52.1] MP 6 on R.
- [52.4] Proterozoic gneisses on L.
- [52.6-52.8] More Proterozoic gneisses on L in long exposure. Scenic views of countryside ahead.
- [53.6] U-turn onto NJ 15 (South).
- [54.0] Proterozoic gneisses on R.
- [54.7] Grenville (Proterozoic) marble and gneisses on R.
- [54.8] MP 13 on R.
- [55.2] Big exposure on R before and beneath overpass. Pull over for Stop 1.

STOP 1 - Folded and Faulted Sauk Sequence Carbonates (Cambro-Ordovician) in new cuts on NJ Route 15. [UTM Coordinates: 530.7E / 4544.5N, Newton East quadrangle.]

New road cuts are the stuff geologist's dreams are made of. Here, in freshly opened roadcuts for new ramps on NJ 15, Paleozoic carbonate rocks (the blue limestone of the older literature or Kittatinny Dolostone and Limestone of modern usage) of Layer IIA(W) (See Table 2.) are exposed. At the extreme south end of the exposure note the well-bedded nearly vertical layers oriented N47°E, 75°NW with discontinuous black chert seams 3- to 4 cm thick. The bedding is subparallel to subvertical dissolution cleavage (stylolites) that indicate, along with the steep orientation, that some degree of deformation has affected these strata. These features are cut by subhorizontal cross fractures filled with calcite.

Grading northward, underneath the overpass, the carbonates are more massive. Here, crenulate folds with subhorizontal axial surfaces deform the dissolution cleavage and sedimentary layering. These second-generation (F_2) folds are geometrically, and possibly temporally, related to the calcite-filled fractures noted above. North of the overpass significant zones of breccia are present; clast sizes range from 1 cm to 1 m and many show significant internal cracking suggesting high pore pressures during brecciation of consolidated rock. In addition, some of the boulders are breccias within themselves! We interpret that most of the brecciation was stratigraphic (sinkhole- and collapse breccias) and compare them to the breccia zones found within the Pine Plains Formation of the Wappinger Group of New York State (Guo, Sanders, and Friedman, 1994). The possibility exists that some breccias are of tectonic origin, however, as northward-dipping low-angle faults are obvious above- and through the breccia

zone. Channels cut into the bedding indicate that tops are to the south and thus the beds that dip 75° NW are overturned.

Above the breccias, north of the overpass, note how the carbonates take on a laminated appearance which is similar to, and thus in our view, correlative with, the Pine Plains Formation of New York. Just beyond the laminated rocks, the bedding begins to swing wildly in the axis of an isoclinal F₁ synform with axial surface parallel to bedding (and to dissolution cleavage at S end of outcrop). At the extreme N end, bedding is N28°E, 20°NW. As such, a possible broad-wavelength anticlinal F₃ (or younger) fold is suggested, with a structural break in the outcrop at the axial surface. Such superposed folds are reminiscent of the Inwood Marble of New York City which is a direct lithostratigraphic correlative of these rocks.

[55.2] Continue S on NJ 15.

[55.5] Bridge over local road, Sparta.

[55.8] MP 12 on R. Sign for exit coming up to Sparta, Lake Mohawk.

[56.5] Proterozoic rocks exposed on L; steep foliation.

[56.8] More but with interlayered mafic gneiss and felsic dikes.

[56.9] Mostly granitic Proterozoic.

[57.4] Exit on R. for NJ 181; Sparta business district. Back to cloverleaf of earlier part of log. Bear R on NJ 181 N. Note that we duplicate earlier log for a little bit here as we try to see who is actually paying attention. Round in circles we go!.

[58.1] Saginaws Drive on R.

[58.3] Hunters Lane on L.

[58.4] Turn R on East Mountain Road.

[58.6] Pond on R; Proterozoic rocks exposed on L.

[58.9] Crossing above NJ 15.

[59.1] Morning Star Drive on R.

[59.4] Proterozoic rocks exposed in driveway on R.

[59.7] Stop at T-intersection; turn L on Sussex County Route 620, toward Ogdensburg.

[59.8] Highly jointed Proterozoic rocks.

[60.6] Traffic light. Junction with Sussex County Route 517 (Main Street) entering from Glen Road. Turn R onto 517.

[61.1] Crossing RR line.

[61.2] Station Road on L.

[61.6] West Mountain Road on L.

[62.9] Gravel pit on R.

[63.0] Village of Ogdensburg. The elongate valley on the L is the Wallkill Valley which is underlain primarily by the easily eroded Cambro-Ordovician Kittitiny dolostone (as seen at Stop 1). The lack of relief also results from the fact that the limestone belt here has been downdropped in a graben structure. Here, drill-core data disclose that the thickness of the Paleozoic strata exceeds 1,100 feet (Metsger, oral communication).

[63.5] Brooks Flat Road enters on L.

[63.7] MP 38 on R.

[63.8] Glenbrook Road on L.

[64.0] View on L of headframe, Sterling Hill Mine.

[64.25] Turn L on Passaic Avenue.

[64.8] Pull over to R onto shoulder leading into old gravel pit for Stop 2.

STOP 2 - Pleistocene Till and Gravel Body of Ogdensburg Moraine. [UTM Coordinates: 533.4E / 4548.0N, Franklin quadrangle.]

The Ogdensburg Moraine of Cotter and others (1985) occurs in a lowland east of the Sterling Hill Mine, New Jersey. This is an old gravel pit from which extensive amounts of outwash sand and gravel have been removed. Till forms the west wall. This locality has furnished erratics from the Franklin ore deposit to the north. As noted on a foregoing page, such erratics are easily to identify because of their fluorescence in ultraviolet light. Mineral collectors are well aware of this and use it to look for specimens at night among the stones. A considerable hole has been excavated in the gravel in search of Franklin erratics. According to Bob Metsger, part of the Sterling Mine lies 2000 feet beneath the small hole dug in the gravel.

Another feature of interest here is the precipitation by circulating ground water of a white calcite cement. Evidence of this cement consists of coarse sand-size particles attached to larger cobbles and of a thin, discontinuous white coating on the surfaces of cobbles and -boulders. If conditions are conducive to digging, we might scrape away at the face of till with the idea of exposing some fluorescent erratics that have not been spotted by zealous collectors.

[64.8] Continue ahead.

[64.9] Cork Hill Road on R; Plant Street on L. Go straight on Passaic Avenue, uphill, under old trestle.

[65.0] Turn L into Sterling Hill Mining Company entrance.

[65.1] Park in lot by office for Stop 3.

STOP 3 - Sterling Hill Mine, Ogdensburg. [UTM Coordinates: 532.9E / 4547.9N, Franklin quadrangle.]

Mr. Richard Houck, owner of the Sterling Hill Mining Company and tour guide/lecturer, re-opened the mine as a tourist attraction on 01 July 1990, about two years after it was closed in September of 1988. Of further benefit, Dr. Bob Metsger, former Chief Geologist (in the years 1949 to 1988) for the New Jersey Zinc Company at Sterling Hill and currently geologist for the New Jersey Geological Survey, has agreed to meet us at the mine and provide a guided tour of the mine area. As such, we will allow the area experts to provide the details. This is a great place for an outing with family and friends where a world-class mineral deposit is on display!

[65.1] Retrace route out of former mine area back to street.

[65.3] Turn R onto Passaic Avenue.

[65.3] Turn L onto Corkhill Road and pass through tunnel.

[65.5] At Y-intersection, bear L.

- [65.7] Kennedy Avenue on R.
- [65.9] Old RR grade crossing; track has gone bye bye.
- [66.8] Another crossing for vanished RR.
- [66.9] Large boulders of Franklin marble on R.
- [67.1] Exposures of Franklin marble on L.
- [67.4] Maple Road on L.
- [67.5] Stop sign at T-intersection. Turn R on Sussex County Road 631 (Franklin Avenue).
- [67.6] Road on L to Franklin Mineral Museum opposite dam to water supply on R.
- [67.7] Grenville Marble exposed on L.
- [68.1] Traffic light at intersection of NJ 23 and County Road 517. New shopping center ahead (Franklin Shopping Center). Turn L toward Sussex.
- [68.4] Paleozoic carbonates on L with low dip to NW. At top of hill note Dunkin Donuts (a culinary marvel even without the hairs) on R.
- [68.75] Turn R on gravel road just before McDonald's (a fine, world-class Scottish Restaurant).
- [68.8] Drive through gate. Do Not Pass Go. Do not pay \$200.
- [68.9] Turn L toward rockface beyond big boulders ahead for Stop 4.

STOP 4 - Rutherford Cross Fault, Franklin. [UTM Coordinates: 535.5E / 4551.4N, Franklin quadrangle.]

In the large rock face in front of you, massive Cambro-Ordovician carbonates (to the right - SE) are in fault contact with mylonitic Grenville Marble (to the left - NW) along the Rutherford cross fault of Metsger. This area is actively being cleared by developers and as such the rock face may be unstable and may not last forever. The Paleozoic rocks are massive dark gray dolostones with black chert stringers on the SE side of the fault. According to Metsger (oral communication) drill-core data show that the thickness of the Paleozoic rocks exceeds 1300 ft. The Rutherford fault is sharp and strikes N57°E and dips 81°SE. Slickensides in the fault zone are marked by graphite smears in the Grenville Marble and indicate dominantly dip-slip normal motion (hanging wall down to SE) with some component of oblique slip. The fault zone is extremely sharp and marked by a clay- rich gouge zone 10 cm thick. Weathering of the clay gouge creates a recess that makes the fault all the more visible.

Even without the marked gouge zone, the difference in lithology across the fault is striking. Here, the footwall is composed of highly laminated graphitic marble with tight isoclinal and rootless folds of a well-developed mylonitic foliation in the marble defined by smeared graphitic lamellae. The folds of the mylonitic foliation (which may be related to faulting) plunge steeply toward the NE. The Grenvillian marble grades into iron-stained quartzofeldspathic gneiss and a massive quartz-feldspar alaskitic intrusive away from the fault.

- [68.9] Turn around and head back toward NJ 23.
- [69.1] Turn R onto NJ 23 and then make immediate L onto Washington Avenue.
- [69.2] Pass Franklin Elementary School.
- [69.3] At Stop sign, turn L.
- [69.35] Franklin marble exposed on R.

[69.65] Evans Street on R; the street leading to the Franklin Mineral Museum.

[69.7] Exposure of Franklin marble on R.

[69.8] Sharp turn to L into driveway of Franklin Rod & Rifle Club and bear L on gravel road.

[69.85] Park by shooting points at end of driveway for Stop 5.

STOP 5 - Proterozoic-Cambrian surface of nonconformity and camptonite dike in Franklin Marble. [UTM Coordinates: 534.65E / 4551.0N, Franklin quadrangle.]

Climb up on steep slope to R beside Franklin Revolver and Rifle Club building and note, where the rock was not quarried, the presence of a 1.5-m-thick camptonite dike oriented N40°E, 60°SE. The dike, which is an alkalic igneous rock similar to the Beemerville intrusives to the west, is intruded into the Franklin Marble and contains a thin vein of quartz along its SE side. The quarrying removed marble for lime.

Of further interest here, note the crack filling of quartzite of overlying Lower Cambrian Hardyston Formation. Look closely at the iron-stained quartzite and note the presence of detrital franklinite and graphite. This simple observation proves the Proterozoic age of ore formation and you've just sampled across the Proterozoic-Cambrian nonconformity at no extra charge. CM notes that the thin veneer of iron-stained quartzite here may be older than Cambrian as the lithology fits descriptions presented earlier for the Proterozoic Z Chestnut Hill Formation (Drake, 1984) which rests nonconformably above the Grenvillian Franklin Marble. More work needs to be done here to prove or disprove this idea.

TABLES

Table 01 - GEOLOGIC TIME CHART

(with selected major geologic events from southeastern New York and vicinity)

<u>ERA</u>		
Periods (Epochs)	Years (Ma)	Selected Major Events
<u>CENOZOIC</u>		
(Holocene)	0.1	Rising sea forms Hudson Estuary, Long Island Sound, and other bays. Barrier islands form and migrate.
(Pleistocene)	1.6	Melting of last glaciers forms large lakes. Drainage from Great Lakes overflows into Hudson Valley. Dam at The Narrows suddenly breached and flood waters erode Hudson shelf valley. Repeated continental glaciation with five? glaciers flowing from NW and NE form moraine ridges on Long Island.
(Pliocene)	6.2	Regional uplift, tilting and erosion of coastal-plain strata; sea level drops. Depression eroded that later becomes Long Island Sound.
(Miocene)	26.2	Fans spread E and SE from Appalachians and push back sea. Last widespread marine unit in coastal-plain strata.
<u>MESOZOIC</u>		
(Cretaceous)	96	Passive eastern margin of North American plate subsides and sediments (the coastal-plain strata) accumulate.
	131	(Passive-margin sequence II).
(Jurassic)		Baltimore Canyon Trough forms and fills with 8,000 feet of pre-Cretaceous sediments.
(Triassic)	190	Atlantic Ocean starts to open. Newark basins deformed, arched, eroded. Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive. Newark basins form and fill with non-marine sediments.

PALEOZOIC 245

- (Permian) Pre-Newark erosion surface formed.
- 260 **Appalachian orogeny.** (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
- (Carboniferous) Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
- (Devonian) 365 **Acadian orogeny.** Deep burial of sedimentary strata. Faulting, folding, and metamorphism in New York City area. Peekskill Granite and Acadian granites intruded.
- (Silurian) 440 **Taconic orogeny.** Intense deformation and metamorphism.
450 Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line). Arc-continent collision. Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata. Ultramafic rocks (oceanic lithosphere) sliced off and transported above deposits of continental shelf.
- (Ordovician) Shallow-water clastics and carbonates accumulate in west of basin (= Sauk Sequence; protoliths of the Lowerre Quartzite, Inwood Marble, part of Manhattan Schist Fm.). Deep-water terrigenous silts form to east. (= Taconic Sequence; protoliths of Hartland Formation, parts of Manhattan Schist Fm.). (Passive-margin sequence I).
- (Cambrian)

PROTEROZOIC

- 570 Period of uplift and erosion followed by subsidence of margin.
- (Z) 600 Rifting with rift sediments, volcanism, and intrusive activity. (Ned Mountain, Pound Ridge, and Yonkers gneiss protoliths).
- (Y) 1100 **Grenville orogeny.** Sediments and volcanics deposited, compressive deformation, intrusive activity, and granulite facies metamorphism. (Fordham Gneiss, Hudson Highlands and related rocks).

ARCHEOZOIC

- 2600 No record in New York.
- 4600 Solar system (including Earth) forms.

Table 02

Generalized Descriptions of Major Geologic "Layers", SE New York State and Vicinity

This geologic table is a tangible result of the On-The-Rocks Field Trip Program conducted by Drs. John E. Sanders and Charles Merguerian between 1988 and 1998. In Stenoan and Huttonian delight, we here present the seven layer cake model that has proved so effective in simplifying the complex geology of the region. Under continual scrutiny and improvement, we provide this updated web-based information as a public service to all students and educators of geology. We encourage any comments, additions, or corrections. References cited can be sought by following this link.

LAYER VII - QUATERNARY SEDIMENTS

A blanket of irregular thickness [up to 50 m or more] overlying and more or less covering all older bedrock units. Includes four or five tills of several ages each of which was deposited by a continental glacier that flowed across the region from one of two contrasting directions: (1) from N10°E to S10°W (direction from Labrador center and down the Hudson Valley), or (2) from N20°W to S20°E (direction from Keewatin center in Hudson's Bay region of Canada and across the Hudson Valley). The inferred relationship of the five tills is as follows from youngest [I] to oldest [V]. [I] - Yellow-brown to gray till from NNE to SSW, [II] - red-brown till from NW to SE, [III] - red-brown till from NW to SE, and [IV] - yellow-brown to gray till from NNE to SSW, and [V] - red-brown till from NW to SE containing decayed stones (Sanders and Merguerian, 1991a,b, 1992, 1994a, b; Sanders, Merguerian, and Mills, 1993; Sanders and others, 1997; Merguerian and Sanders, 1996). Quaternary sediments consist chiefly of till and outwash. On Long Island, outwash (sand and gravel) and glacial lake sediment predominates and till is minor and local. By contrast, on Staten Island, tills and interstratified lake sediments predominate and sandy outwash appears only locally, near Great Kills beach.

[Pliocene episode of extensive and rapid epeirogenic uplift of New England and deep erosion of major river valleys, including the excavation of the prominent inner lowland alongside the coastal-plain cuesta; a part of the modern landscape in New Jersey, but submerged in part to form Long Island Sound].

~~~~~**Surface of unconformity**~~~~~

**LAYER VI - COASTAL-PLAIN STRATA (L. Cretaceous to U. Miocene; products of Passive Continental Margin II - Atlantic).**

Marine- and nonmarine sands and clays, present beneath the Quaternary sediments on Long Island (but exposed locally in NW Long Island and on SW Staten Island) and forming a wide outcrop belt in NE New Jersey. These strata underlie the submerged continental terrace. The basal unit (L. Cretaceous from Maryland southward, but U. Cretaceous in vicinity of New York City) overlaps deformed- and eroded Newark strata and older formations. Also includes thick (2000 m) L. Cretaceous sands and shales filling the offshore Baltimore Canyon Trough. At the top are Miocene marine- and coastal units that are coarser than lower strata and in many

localities SW of New Jersey, overstep farther inland than older coastal-plain strata. Capping unit is a thin (<50 m) sheet of yellow gravel (U. Miocene or L. Pliocene?) that was prograded as SE-directed fans from the Appalachians pushed back the sea. Eroded Newark debris is present in L. Cretaceous sands, but in U. Cretaceous through Miocene units, Newark-age redbed debris is conspicuously absent. This relationship is considered to be proof that the coastal-plain formations previously buried the Newark basins so that no Newark-age debris was available until after the Pliocene period of great regional uplift and erosion. The presence of resistant heavy minerals derived from the Proterozoic highlands part of the Appalachians within all coastal-plain sands indicates that the coastal-plain strata did not cover the central highlands of the Appalachians.

[Mid-Jurassic to Late Jurassic episode of regional arching of Newark basin-filling strata and end of sediment accumulation in Newark basin; multiple episodes of deformation including oroclinal "bending" of entire Appalachian chain in NE Pennsylvania (Carey, 1955), and one or more episodes of intrusion of mafic igneous rocks, of folding, of normal faulting, and of strike-slip faulting (Merguerian and Sanders, 1994b). Great uplift and erosion, ending with formation of Fall-Zone planation surface].

~~~~~**Surface of unconformity**~~~~~

LAYER V - NEWARK BASIN-FILLING STRATA (Upper Triassic and Lower Jurassic)

Newark-age strata unconformably overlie folded- and metamorphosed Paleozoic strata of Layer II and some of the Proterozoic formations of Layer I; are in fault contact with other Proterozoic formations of the Highlands complex. Cobbles and boulders in basin-marginal rudites near Ramapo Fault include mostly rocks from Layers III, IIB, and IIA(W), which formerly blanketed the Proterozoic now at the surface on the much-elevated Ramapo Mountains block. The thick (possibly 8 or 9 km) strata filling the Newark basin are nonmarine.

In addition to the basin-marginal rudites, the sediments include fluvial- and varied deposits of large lakes whose levels shifted cyclically in response to climate cycles evidently related to astronomic forcing. A notable lake deposit includes the Lockatong Formation, with its analcime-rich black argillites, which attains a maximum thickness of about 450 m in the Delaware River valley area. Interbedded with the Jurassic part of the Newark strata are three extrusive complexes, each 100 to 300 m thick, whose resistant tilted edges now underlie the curvilinear ridges of the Watchung Mountains in north-central New Jersey. Boulders of vesicular basalt in basin-marginal rudites prove that locally, the lava flows extended northwestward across one or more of the basin-marginal faults and onto a block that was later elevated and eroded. The thick (ca. 300 m) Palisades intrusive sheet is concordant in its central parts, where it intrudes the Lockatong at a level about 400 m above the base of the Newark strata. To the NE and SW, however, the sheet is discordant and cuts higher strata (Merguerian and Sanders, 1995a). Contact relationships and the discovery of clastic dikes at the base of the Palisades in Fort Lee, New Jersey, suggest that the mafic magma responsible for the Palisades

was originally intruded at relatively shallow depths (roughly 3 to 4 km) according to Merguerian and Sanders (1995b).

Xenoliths and screens of both Stockton Arkose and Lockatong Argillite are present near the base of the sill. Locally, marginal zones of some xenoliths were melted to form granitic rocks (examples: the trondhjemite formed from the Lockatong Argillite at the Graniteville quarry, Staten Island, described by Benimoff and Sclar, 1984; and a "re-composed" augite granite associated with pieces of Stockton Arkose at Weehawken and Jersey City, described by J. V. Lewis, 1908, p. 135-137).

[**Appalachian terminal orogeny**; large-scale overthrusts of strata over strata (as in the bedding thrusts of the "Little Mountains east of the Catskills" and in the strata underlying the NW side of the Appalachian Great Valley), of basement over strata (in the outliers NW of the Hudson Highlands, and possibly also in many parts of the Highlands themselves), and presumably also of basement over basement (localities not yet identified). High-grade metamorphism of Coal Measures and intrusion of granites in Rhode Island dated at 270 Ma. Extensive uplift and erosion, ending with the formation of the pre-Newark peneplain].

~~~~~**Surface of unconformity**~~~~~

**LAYER IV - COAL MEASURES AND RELATED STRATA (Carboniferous)**

Mostly nonmarine coarse strata, about 6 km thick, including thick coals altered to anthracite grade, now preserved only in tight synclines in the Anthracite district, near Scranton, NE Pennsylvania; inferred to have formerly extended NE far enough to have buried the Catskills and vicinity in eastern New York State (Friedman and Sanders, 1982, 1983).

[**Acadian orogeny**; great thermal activity and folding, including metamorphism on a regional scale, ductile deformation, and intrusion of granites; dated at ~360 Ma].

**LAYER III - MOSTLY MARINE STRATA OF APPALACHIAN BASIN AND CATSKILLS (Carbonates and terrigenous strata of Devonian and Silurian age)**

**(Western Facies)**

Catskill Plateau, Delaware Valley monocline, and "Little Mountains" NW of Hudson-Great Valley lowland.  
Kaaterskill redbeds and cgl.  
Ashokan Flags (large cross strata)  
Mount Marion Fm. (graded layers,

**(Eastern Facies)**

SE of Hudson-Great Valley lowland in Schunnemunk-Bellvale graben.  
Schunnemunk Cgl.  
Bellvale Fm., upper unit  
Bellvale Fm., lower unit



|                                |                                |
|--------------------------------|--------------------------------|
| marine)                        | (graded layers, marine)        |
| Bakoven Black Shale            | Cornwall Black Shale           |
| Onondaga Limestone             |                                |
| Schoharie buff siltstone       | Pine Hill Formation            |
| Esopus Formation               | Esopus Formation               |
| Glenerie Chert                 |                                |
| Connelly Conglomerate          | Connelly Conglomerate          |
| Central Valley Sandstone       |                                |
| Carbonates of Helderberg Group | Carbonates of Helderberg Group |
| Manlius Limestone              |                                |
| Rondout Formation              | Rondout Formation              |
| Decker Formation               |                                |
| Binnewater Sandstone           | Poxono Island Formation        |
| High Falls Shale               | Longwood Red Shale             |
| Shawangunk Formation           | Green Pond Conglomerate        |

[**Taconic orogeny**; 480 Ma deep-seated folding, dynamothermal metamorphism and mafic- to ultramafic (alkalic) igneous intrusive activity (dated in the range of 470 to 430 Ma) across suture zone (Cameron's Line-St. Nicholas thrust zones). Underthrusting of shallow-water western carbonates of Sauk Sequence below supracrustal deep-water eastern Taconic strata and imbrication of former Sauk-Tippecanoe margin. Long-distance transport of strata over strata has been demonstrated; less certain locally is proof of basement thrust over strata and of basement shifted over basement. In Newfoundland, a full ophiolite sequence, 10 km thick, has been thrust over shelf-type sedimentary strata].

~~~~~**Surface of unconformity**~~~~~

LAYER II - CAMBRO-ORDOVICIAN CONTINENTAL-MARGIN COVER (Products of Passive Continental Margin I - Iapetus). Subdivided into two sub layers, IIB and IIA. Layer IIA is further subdivided into western- and eastern facies.

LAYER IIB - TIPPECANOE SEQUENCE - Middle Ordovician flysch with basal limestone (Balmville, Jacksonburg limestones).

Not metamorphosed / Metamorphosed
 Martinsburg Fm. / Manhattan Schist (Om - lower unit).
 Normanskill Fm. / Annsville Phyllite

Subaerial exposure; karst features form on Sauk (Layer IIA[W]) platform.

~~~~~**Surface of unconformity**~~~~~

**LAYER IIA[W] - SAUK SEQUENCE**

Western shallow-water platform (L. Cambrian-M. Ordovician)

- Copake Limestone
- Rochdale Limestone
- Halcyon Lake Fm.
- Briarcliff Dolostone
- Pine Plains Fm.
- Stissing Dolostone
- Poughquag Quartzite
- Lowerre Quartzite [Base not known]

**LAYER IIA[E] - TACONIC SEQUENCE**

Eastern deep-water zone (L. Cambrian-M. Ordovician)

- Stockbridge or Inwood Marbles
- (€-Oh) Hartland Fm.
- (€-Om) Manhattan Fm. (in part).

**[Pre-Iapetus Rifting Event;** extensional tectonics, volcanism, rift-facies sedimentation, and plutonic igneous activity precedes development of Iapetus [Layer II = passive continental margin I] ocean basin. Extensional interval yields protoliths of Pound Ridge Gneiss, Yonkers granitoid gneisses, and the Ned Mountain Formation (Brock, 1989, 1993). Followed by a period of uplift and erosion. In New Jersey, metamorphosed rift facies rocks are mapped as the Chestnut Hill Formation of A. A. Drake, Jr. (1984)].

~~~~~**Surface of unconformity**~~~~~

LAYER I - PROTEROZOIC BASEMENT ROCKS

Many individual lithologic units including Proterozoic Z and Y ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks identified, but only a few attempts have been made to decipher the stratigraphic relationships; hence, the three-dimensional structural relationships remain obscure.

~~~~~**Surface of unconformity**~~~~~

**[Grenville orogeny;** deformation, metamorphism, and plutonism dated about 1,100 Ma. After the orogeny, an extensive period of uplift and erosion begins. Grenville-aged (Proterozoic Y) basement rocks include the Fordham Gneiss of Westchester County, the Bronx, and the subsurface of western Long Island (Queens and Brooklyn Sections, NYC Water Tunnel #3), the Hudson Highland-Reading Prong terrane, the Franklin Marble Belt and associated rocks, and the New Milford, Housatonic, Berkshire, and Green Mountain Massifs.]

~~~~~**Surface of unconformity**~~~~~

In New Jersey and Pennsylvania rocks older than the Franklin Marble Belt and associated rocks include the Losee Metamorphic Suite. Unconformably beneath the Losee, in Pennsylvania, Proterozoic X rocks of the Hexenkopf Complex crop out.

**Table 03 - Fluorescent Minerals of Franklin and Sterling Hill
(R. C. Bostwick, 1982, Table 1, p. 198.)**

FLUORESCENT MINERALS OF FRANKLIN AND STERLING HILL

Species in italics are those which fluoresce more intensely under long wave ultraviolet radiation; most Franklin fluorescent species are much more brightly fluorescent under short wave ultraviolet radiation. Listed colors are fluorescent colors. (Compiled May, 1982.)

| | | |
|--|--|--|
| <i>Aragonite</i> — white, cream, green | Guerinite — white | Powellite — yellow |
| Barite — white, cream, blue-white, tan | Gypsum — blue | Prehnite — pink |
| Barylite — pale blue | Hardystonite — blue-violet | Scapolite group — red, cream, yellow, pink |
| <i>Bustamite</i> — red | Hedyphane — orange, cream | Scheelite — yellow |
| Cahnite — cream | <i>Hemimorphite</i> — white, green | <i>Smithsonite</i> — yellow |
| Calcite — white, cream, yellow, orange, red, green, pink | <i>Hodgkinsonite</i> — red | <i>Sphalerite</i> — orange, yellow, blue |
| <i>Celestite</i> — cream | Hyalophane — red | Svabite — orange |
| <i>Cerussite</i> — yellow | <i>Hydroalcite</i> — cream | <i>Talc</i> — cream |
| Chondrodite — yellow | Hydrozincite — blue | Thomsonite — white, cream |
| Clinohedrite — orange | Johnbaumite — orange | Tilasite — yellow |
| <i>Corundum</i> — red | Manganaxinite — red | Titanite — tan |
| Diopside — blue, cream | Margarite — blue | Tremolite — blue, cream |
| Dypingite — blue | Margarosanite — blue, red, cream, orange | Uranospinite — green |
| Edenite — blue, greenish-blue | Microcline — blue, red | Uvite — yellow |
| <i>Epsomite</i> — cream | Mimetite — orange | Willemite — green, yellow-orange, yellow |
| Esperite — yellow | Monohydrocalcite — green | Wollastonite — orange, yellow |
| <i>Ettringite</i> — cream | Norbergite — yellow | Xonotlite — blue |
| Fluoborite — cream | Oyelite — violet, white | <i>Zincite</i> — yellow |
| Fluorapatite — blue, violet-blue, orange | Pectolite — orange | Zircon — yellow-orange |
| <i>Fluorite</i> — green, blue-green, violet | Phlogopite — yellow | |
| | Picropharmacolite — white | |

**Table 4 - The Fluorescent Minerals of Franklin and Sterling Hill
Tabulated by Fluorescent Color.
(R. C. Bostwick, 1982, Table 2, p. 199-200.)**

**THE FLUORESCENT MINERALS OF FRANKLIN AND STERLING HILL
TABULATED BY FLUORESCENT COLOR**

Although fluorescent minerals exhibit a remarkable diversity of color, here they are categorized as red, pink, orange, yellow/tan, green, blue, violet, and white/cream. Fluorescent intensity is described as strong, moderate, weak, or very weak. All listings are based on first-hand observations made by the author.

Fluorescent mineral occurrence relative to the various mineral assemblages at Franklin and Sterling Hill is noted parenthetically. A typical notation (O, C: F, SH), means that the mineral may be found with the ore and calc-silicate assemblages at both Franklin and Sterling Hill.

Abbreviation of Terms

- AC = altered calc-silicate occurrence
 C = calc-silicate occurrence
 F = Franklin location
 FM = Franklin marble occurrence
 LW = long wave ultraviolet radiation (366 nanometers)
 O = ore occurrence
 P = "pegmatite" occurrence
 SH = Sterling Hill location
 SW = short wave ultraviolet radiation (254 nanometers)
 V = vein mineral occurrence
 W = weathering mineral occurrence

Red Fluorescence

- Bustamite:** Moderate red fluorescence LW; weak SW. (C: F)
Calcite: Strong orange-red fluorescence, brief phosphorescence SW; weaker LW. (O, C, AC, V, P when associated with ore bodies: F, SH) (very rarely FM)
Corundum: Moderate red fluorescence LW; weak SW. (FM)
Hodgkinsonite: Weak red fluorescence LW. (V: F, SH)
Hyalophane: Weak red fluorescence SW. (C, AC: F)
Manganaxinite: Strong to weak orange-red fluorescence SW; weaker LW, very weak phosphorescence. Lack of obvious phosphorescence distinguishes it from calcite. (AC: F)
Margarosanite: Weak red, orange, or cream fluorescence LW. Strong blue, often with zoned red fluorescence SW. (Platy masses or disseminated in feldspar, AC: F)
Microcline: Weak red fluorescence SW. (C, AC, P: F, SH)
Scapolite group: Moderate red fluorescence SW. (P, FM)

Pink Fluorescence

- Apatite group:** Moderate dull orange-pink fluorescence SW. Also see fluorapatite listing under orange fluorescence. (O, C: F, SH)
Calcite: Moderate pink fluorescence, brief orange-red phosphorescence SW and LW. Rare. (V, W: F, SH)
Prehnite: Moderate creamy orange-pink or "peach" fluorescence SW. (White platy form often associated with pectolite and margarosanite, AC: F)
Scapolite group: Moderate pink fluorescence SW. Rare. (C, SH)

Orange Fluorescence

- Calcite:** Moderate orange fluorescence and phosphorescence SW. (A rare vein coating associated with fluorescent zincite: SH)
Clinohedrite: Strong orange fluorescence, persistent phosphorescence SW; weaker variations of intensity LW. (Coatings on hardystonite, several other forms, C, AC, V: F)
Fluorapatite: Strong to weak fluorescence SW; very weak (if any) fluorescence LW. Dominant member of apatite groups but not necessarily distinguished by fluorescence from svabite, hedyphane, mimetite, and johnbaumite. (O, C, V, P: F, SH)

- Hedyphane:** Moderate orange fluorescence SW; weak cream fluorescence LW. (Rare vein mineral with manganaxinite, rhodonite: F)
Johnbaumite: Moderate orange fluorescence SW. Rare. See fluorapatite listing. (F)
Margarosanite: Weak orange, red, or cream fluorescence LW; strong blue, often with zoned red fluorescence SW. (Platy masses or disseminated in feldspar, AC: F)
Mimetite: Moderate orange fluorescence SW. See fluorapatite listing. (F)
Pectolite: Moderate orange fluorescence and phosphorescence SW; weaker LW. White fibrous material labelled "pectolite" is probably wollastonite. (Glassy grains associated with prehnite, AC: F)
Sphalerite: Moderate, various hues of orange often flecked with blue fluorescence, phosphorescent LW; weaker SW. (O, C, V: abundant SH, less of F)
Svabite: Moderate orange fluorescence SW. See fluorapatite listing. (F)
Willemite: Moderate yellow-orange to pale greenish-yellow fluorescence and phosphorescence SW. Often misnamed "beta-willemite." (Small crystals, powdery coatings, W: SH)
Wollastonite: Strong orange to yellow fluorescence, often with red-orange phosphorescence SW; weaker LW. (Massive and grains, C: F, SH) (Fibrous, AC: F)
Zircon: Moderate yellow-orange fluorescence SW. Rare. (Crystals, P)

Yellow or Tan Fluorescence

- Barite:** Moderate tan fluorescence and phosphorescence SW and LW. Rare. (V: SH)
Calcite: Moderate yellow to orange yellow fluorescence LW; weak, redder fluorescence SW, some phosphorescence. (Variety of forms, V, W: F, SH)
Cerussite: Moderate yellow fluorescence LW; weak SW. (Crystals, W: SH)
Chondrodite: Moderate yellow fluorescence SW; weak LW. Fluoresces same as norbergite. (FM)
Esperite: Strong lemon-yellow fluorescence, very weak phosphorescence SW; weak fluorescence LW. (C: F)
Norbergite: Moderate yellow fluorescence SW; weak LW. Fluoresces same as chondrodite. (FM)
Phlogopite: Moderate yellow fluorescence SW. (FM)
Powellite: Moderate yellow fluorescence SW; weak LW. (Associated with molybdenite, W: F, SH)
Scapolite group: Moderate to weak yellow to orange-yellow fluorescence and phosphorescence LW and SW. (FM)
Scheelite: Moderate yellow fluorescence SW; weak LW. (P: F)
Smithsonite: Moderate yellow to orange-yellow fluorescence LW; weak SW. (Coatings, poorly characterized, W: SH, F)
Sphalerite: Moderate orange-yellow fluorescence and phosphorescence LW. Rare. (O, C, V, W: F, SH)
Tilasite: Moderate creamy-yellow fluorescence SW. Very rare. (White crystallized vein material: SH)

Table 4 (cont'd)

Titanite: Weak tan fluorescence LW. (Brown crystals, FM)
Uvite: Moderate yellow fluorescence SW; weak LW. (FM)
Willemite: Moderate pale greenish yellow to orange fluorescence and phosphorescence SW; weak LW. Often misnamed "beta-willemite." (Small crystals, powdery coatings, W: SH)
Wollastonite: Moderate yellow to orange fluorescence, with a redder hued phosphorescence SW; weak fluorescence LW. (C: SH)
Zincite: Moderate pale yellow fluorescence LW, weaker SW. (Yellow veins and pods in ore: SH) This is a classic occurrence; most zincite does not fluoresce.

Green Fluorescence

Aragonite: Moderate green or cream fluorescence and cream phosphorescence LW; rarely green fluorescence SW. (W: SH)
Calcite: Moderate green or cream fluorescence, may phosphoresce cream LW; rarely green fluorescence SW. (FM) (W: SH)
Fluorite: Moderate pale green to bluish green fluorescence and phosphorescence LW, SW, and after exposure to incandescent light. Overexposure to light destroys greenish fluorescence; weak violet fluorescence remains. (O, C: F, SH)
Hemimorphite: Moderate green fluorescence, rare SW; weak white fluorescence LW. (W: SH)
Monohydrocalcite: Moderate green fluorescence SW and LW. Some phosphorescence LW. Rare. (Shiny yellow coating, W: SH)
Uranospinitite: Moderate green fluorescence SW and LW. Rare. (Dull yellow coating, W: SH)
Willemite: Strong green fluorescence, often with strong phosphorescence SW; intensity variable LW. (Many forms, O, C, AC, V and rarely P: F, SH)

Blue Fluorescence

Barylite: Moderate pale blue fluorescence under the iron-arc spark; weak pale blue SW; weaker LW. Possible very weak phosphorescence. Almost all material labelled "barylite" is margarosanite disseminated in feldspar. (Hard, brittle white plates occurring with red-fluorescing calcite, serpentine, C: F)
Diopside: Moderate blue fluorescence SW; cream fluorescence LW. (FM)
Dypingite: Moderate blue fluorescence and phosphorescence SW and LW. (Coatings of white hemispheres, W: SH)
Edenite: Moderate blue to greenish-blue fluorescence SW. (Green, imperfectly characterized, FM)
Ettringite: Moderate pale blue fluorescence and phosphorescence SW and LW. Due to alteration coating of gypsum, the fluorescence of unaltered ettringite is difficult to observe. (AC: F)
Fluorapatite: Moderate to weak blue fluorescence SW; weak pale violet-blue fluorescence LW. (Greenish-blue crystals, FM)
Gypsum: Moderate pale blue to white fluorescence SW; weaker LW. (W: SH)
Hydrozincite: Strong blue fluorescence SW. (White powdery coating, W: SH)
Margarite: Weak pale blue fluorescence SW and LW. (Blue "brittle mica," FM)
Margarosanite: Strong blue, often with zoned red fluorescence SW; may fluoresce weaker red, cream, or orange LW. (Platy masses or disseminated in feldspar, AC: F)
Microcline: Moderate blue fluorescence SW. (C, P: F, SH)
Sphalerite: Moderate orange (with blue flecks) fluorescence and phosphorescence LW; weaker SW. Rarely moderate blue

fluorescence and phosphorescence LW; weaker SW. (O, C, V: F, SH)
Tremolite: Moderate blue fluorescence SW; cream fluorescence LW. (Typically as prismatic crystals, FM)
Xonotlite: Moderate blue fluorescence SW; weak LW. (White, acicular, AC: F)

Violet Fluorescence

Fluorite: Moderate blue-violet fluorescence LW; weak SW. Such fluorite probably once fluoresced green but has been overexposed to light. (O, C: F, SH)
Hardystonite: Moderate blue-violet fluorescence SW; variable in intensity and occasionally brighter LW. (C: F)
Oyelite: Moderate violet, edged with white fluorescence SW; weaker LW. White fluorescing areas phosphoresce. Extremely rare. (Pink radiating masses edged with white fibers in red-fluorescing bladed manganaxinite matrix, AC: F)

White or Cream Fluorescence

Aragonite: Moderate cream to white fluorescence and phosphorescence LW; weaker SW. (V, W: F, SH)
Barite: Moderate white, blue-white, or cream fluorescence SW; weak LW. (C, AC, V: F, SH)
Cahnite: Moderate cream fluorescence and phosphorescence LW and SW. (Rare crystallized vein mineral: F)
Calcite: Moderate white or cream fluorescence and phosphorescence SW and LW. (V, W: F, SH)
Celestite: Moderate to weak cream fluorescence LW and SW. (V: SH)
Diopside: Moderate cream fluorescence LW; blue fluorescence SW. (FM)
Epsomite: Moderate cream fluorescence LW; weak SW. (White powdery coating, W: SH)
Fluoborite: Moderate cream fluorescence SW. (Resembles grains of rice; Bodnar-Edison quarry) Weak cream fluorescence SW. Rare. (Fibrous vein material: SH)
Guerinite: Weak white fluorescence SW and LW. Rare. (Lath-shaped crystals in red-fluorescing calcite, W: SH)
Hedyphane: Weak cream fluorescence LW; moderate orange fluorescence SW. Rare. (Vein mineral with manganaxinite and rhodonite: F)
Hemimorphite: Weak white fluorescence and phosphorescence LW and SW. (Thick crystal crusts, W: SH) Very rare. (F)
Hydrocalcite: Moderate cream fluorescence LW. Rare. (Microcrystals associated with gahnite and hodgkinsonite, V: F)
Margarosanite: Weak cream, red, or orange fluorescence LW; strong blue, often with zoned red fluorescence SW. (Platy masses or disseminated in feldspar, AC: F)
Oyelite: Moderate white-edging around violet fluorescence SW; weaker LW. White fluorescing areas phosphoresce. Extremely rare. (Pink radiating masses edged with white fibers in red-fluorescing bladed manganaxinite matrix, AC: F)
Picropharmacolite: Moderate to weak white fluorescence SW and LW. Rare. (Acicular crystals on red-fluorescing calcite, W: SH)
Scapolite group: Moderate cream fluorescence and phosphorescence SW and LW. (FM)
Talc: Moderate cream fluorescence LW; weak SW. (O, C, V: F, SH)
Thomsonite: Weak white-to-cream fluorescence SW and LW. Most specimens labelled "thomsonite" or "calciiothomsonite" are believed to be xonotlite. Very rare. (Radiating acicular masses with prehnite and feldspar, AC: F)
Tremolite: Moderate cream fluorescence, rare LW; blue fluorescence, typical SW. (Typically as prismatic crystals, FM)

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