TRIP D: EXCURSION TO THE STERLING AND FRANKLIN AREA IN THE HIGHLANDS OF NEW JERSEY

By Eugene A. Alexandrov
Queens College
of The City University of New York

GEOLOGY ALONG THE ROAD BETWEEN LONG ISLAND AND THE HIGHLANDS OF NEW JERSEY

The geological trip to the Highlands of New Jersey starts at Queens College in Flushing and crosses the western part of Long Island in Queens County, the East River, Manhattan, the Hudson River, the Palisades, and the Lowlands of New Jersey.

Long Island.

Long Island forms the northernmost portion of the unsubmerged continental shelf, or the Coastal Plains of North America, stretching as far south as Florida, and west and southwest along the Gulf Coast to the Yucatan Peninsula.

The bedrock underlying the sedimentary sequence consists of undifferentiated metasedimentary rocks represented by schists and gneisses. Granodiorite occurs in the northwestern corner of Queens. Boreholes in Rockaway park revealed the presence of pegmatites and granite without signs of metamorphism (Perlmutter, 1949) and are probably of a Lower Paleozoic age. It appears that some of the gneisses can be correlated with the Precambrian Fordham Gneiss in Manhattan and the Bronx. The dolomitic limestone is apparently equivalent to the Inwood Marble, while the mica schist is similar to Manhattan Schist. So far the basement rocks are of very limited economic interest as a source of water which is of poor quality and insufficent quantity (Perlmutter, 1949). The bedrock crops out at the surface near Long Island City and Astoria in Queens County and dips at 80 feet per mile to the southeast where it is at 1100 feet below sea level at the Queens-Nassau boundary. The sedimentary sequence covering the metamorphic basement of Long Island is about 1200 feet thick in the southeastern part of Queens. It consists of Upper Cretaceous Raritan and presumably Upper Cretaceous Magothy Formations. The Raritan Formation contains the Lloyd Sand Member which is an aquifer. The Magothy Formation contains thin water-bearing zones yielding water for domestic purposes. The Cretaceous sediments are overlain by Jameco Gravel and Gardiners Clay of Pleistocene age. Jameco Gravel is an aquifer tapped in southern Queens by many wells. Gardiners Clay is covered by Upper Pleistocene deposits usually correlated with the Illinoian and Wisconsin stages of glaciation. The topography of Long Island features two terminal moraines, the Ronkonkoma moraine passing from east to west under the Queens College campus, and the younger Harbor Hill moraine. The Harbor Hill moraine forms a chain of hummocks north of Hillside Avenue in Queens reaching to elevations of 200 feet above sea level. The Long Island Expressway crosses the Ronkonkoma moraine west of Queens College.

Queens Midtown Tunnel.

Long Island is separated from Manhattan by the East River which is not a river in a pure sense, but a salt water channel connecting Long Island Sound with Upper New York Bay. The channel of the East River was excavated along the north-striking outcrops of limestone formations. The Queens Midtown vehicular tunnel crosses the East River from Brooklyn to Second Avenue and 36th Street in Manhattan. The ground for the project was broken on October 2, 1936, by President F. D. Roosevelt, and the regular operations of the tunnel started on November 15, 1940. The maximum annual capacity of the tunnel is 16,000,000 vehicles. The construction was preceded by drilling exploratory boreholes along the river crossing at 200-foot intervals. The tunnel was shield driven and includes two cast-iron-lined tubes, about 31 feet in diameter, and each 6000 feet long. The depth of the top of the tube below river bottom at the Manhattan pierhead is 55 feet (Singstad, 1944). The tunnel was excavated partly through Fordham Gneiss, Inwood Marble, and Manhattan Schist, which form ridges along the river channel filled with overburden (Berkey, 1948).

Manhattan.

Manhattan is crossed along the 34th street to the entrance to Lincoln tunnel. The island of Manhattan is underlain by Precambrian Fordham Gneiss which is overlain unconformably by presumably Lower Paleozoic Inwood Marble and Manhattan Schist. Schist injected with granite forms the west side of Manhattan along the Hudson River. The entire rock complex represents the southernmost part of the Manhattan prong. The age of metamorphism of the Manhattan Schist was dated by the potassium / argon method as 360 million years (Long and Kulp, 1956, 1962). Relict ages as old as 480 million years suggest Cambrian or later age. According to the fossils (Pelmatazoa) found in a bed of marble at the base of the Manhattan Schist north of New York City, the Manhattan Schist is tentatively correlated with the Middle Ordovician Trenton Formation (Ratcliffe and Knowles, 1968).

Lincoln Tunnel.

The Lincoln vehicular tunnel crosses the Hudson River to New Jersey from 39th Street in Manhattan. The tunnel consists of three tubes which are respectively 8215, 7400, and 8008 feet long from portal to portal, the length of the underwater portion being 4600 feet in each case. The main sections of the tunnel were shield driven under compressed air. Work on the first tube started in 1934. The second tube was completed in 1937, and the third tube has been added recently, making accommodations for six lanes of traffic in all tubes. Cast iron segments were used for lining. The tunnel was excavated in Recent river silts and sands at depths ranging from 50 to 75 feet below the river bed. The depth of water in the Hudson River above the tunnel reaches 55 feet. The river sediments are underlain by Manhattan Schist and the Triassic sedimentary Newark series, separated by an unconformity approximately at the middle of the tunnel (Fluhr, 1941).

The Triassic Basin of New Jersey.

The cliff of the Palisades on the western bank of the Hudson River consists of the Upper Triassic diabase sill. It has chilled zones along the hanging wall and along the footwall. An olivine layer with magnetite and chromite formed above the chilled zone in the lower part of the sill as the result of gravitational settling of minerals which crystallized first (Widmer, 1964). The sill is about 1000 feet thick and dips at approximately 15° to the northwest. It is followed higher in sequence by red continental Triassic shales, sandstones, and argillites underlying the lowlands forming part of the mid-New Jersey Piedmont. The youngest sediments in this area contain varved clays formed in the Hackensack and Passaic glacial lakes (Lewis and Kümmel, 1940). Farther west, along Route 3 near Rutherford, harder Triassic sandstone forms higher elevations. The Triassic sediments are intercalated with three basaltic lava flows featuring columnar jointing and pillow structure. The lava flows cover an area of over 500 square miles and attain a thickness of 800 feet Potassium/argon measurements on the Palisades diabase and associated basalts indicate their age as 190 million years (Erickson and Kulp, 1960). The diabase and basalt are quarried extensively as traprock and contribute substantially to the economy of the State of New Jersey. The openings and veins in traprock contain some sixty low-temperature minerals, including ten zeolite minerals (Mason, 1960). Excellent specimens of zeolites from New Jersey are on display at the American Museum of Natural History in New York. Copper desposits connected genetically with diabase and basalt were mined in this area between 1693 and 1810 (Widmer, 1964). The thickness of Triassic rocks reaches at least 10,000 feet at the border fault near Boonton. The accumulation of the wedge-shaped body of Triassic sediments was contemporaneous with faulting and represents a taphrogeosyncline (Kay, 1951).

The Highlands of New Jersey.

The Highlands are part of the Reading prong of the New England physiographic province and extend in a northeastern direction across southeastern Sussex and Warren, and northwestern Passaic, Morris, and Hunterdon counties. They are 10 to 25 miles wide and form elevations up to 1000 feet above sea level. The climate in the Highlands is cooler than in the rest of New Jersey. In the south of the State the growing season is almost 8 weeks longer than in the Highlands (Widmer, 1964).

The Highlands consist of parallel ridges formed by Precambrian metamorphic rocks. The absolute age of pegmatites cutting these rocks is about 1100 million years (Long and Kulp, 1962). Therefore, the metamorphic formations are older than the pegmatites. Lower Paleozoic sediments occur in the Highlands in grabens and along faults. There are some 24 mappable rock units among the Precambrian formations such as marble, quartzite, skarn, pegmatites, quartz diorite, four kinds of granite, and 15 kinds of gneisses including several granite gneisses (Widmer, 1964). The thickness of the Precambrian sequence is over 6000 feet. The older group of Precambrian rocks is represented by metamorphically altered shales, sandstones, calcareous sands, and volcanics. The younger group of formations includes Franklin Marble with the world-famous deposits of zinc and manganese.

Iron was produced in the Highlands as early as 1710. The operations continued through the Revolutionary War contributing to the victory of the American forces. The number of magnetite mines grew until 1880 when 136 mines were operating. However, the last mines in the Dover area closed down recently, mainly because of conflict with labor unions. The magnetite ore bodies have the shape of laths or pods parallel to the linear structure and bedding in gneisses (Buddington, 1966) The magnetite ores in gneisses and amphibolites predominantly occur on the flanks of anticlines, the cores of which are commonly quartz-oligoclase gneiss. The ore bodies average 2 to 20 feet in width with the largest reaching 75 feet. Vertically the ore bodies range from 200 to 450 feet. The deepest mine reached the depth of 2000 feet below the surface (Widmer, 1964). The content of iron in ore bodies ranges from 35 to 60 percent. Recently the region started to attract attention because of the established existence of several deposits containing yttrium- and rare-earth-bearing minerals (monazite, allanite, spencite, xenotime, gadolinite, doverite, and others) associated with the iron deposits. Yttrium is used in the electronics industry and was recently sold at prices ranging from $250 to $390 per pound. The deposits examined do not contain sufficient quantities of yttrium and the rare earth elements to be recoverable under present economic conditions (Williams, 1967).

Buddington (1966) reviews attempts to explain the origin of magnetite ores which are expressed in hypotheses advocating the metasedimentary origin, hypogene replacement, leaching and reconstruction of country rocks as a source for iron, iron concentration in pegmatitic solutions, concentration of iron in solutions during the development of alaskite magma, structural and microstructural controls in localization of ore bodies, and the hypothesis of metasedimentary beds modified by hypogene solutions. Sims (1958) suggested that all of the iron was derived from granite magma. Hagner (1966) pointed out that the host rocks could be a source for magnetite ore during regional metamorphism. Buddington (1966) indicates that the hypothesis of origin by direct contribtutions, and emplacement by magmatic emanations, has the most support. However, he points out that it is not precluded that the magnetite deposits in the gneisses are metasedimentary beds modified by hypogene solutions. The last point of view seems to be the best founded. It is noteworthy that the banded magnetite-bearing gneiss contains layers and thin bands rich in magnetite alternating with those containing only small amounts of magnetite. This phenomenon is peculiar to the sedimentary rocks in which the iron mineral is of primary sedimentary origin.

THE STERLING-FRANKLIN AREA IN NEW JERSEY.

The deposits of zinc and manganese at Sterling Hill and Franklin in Sussex County are the main point of interest of this excursion. The region has been the most important producer of zinc east of the Mississippi River. The two ore deposits are 3 miles apart. Pinger (1948) refers to some evidence that the Dutch miners prospected the Sterling ore outcrops in 1640 for hemimorphite, $Zn_4(Si_2O_7)(OH)_2 \cdot H_2O$, for the making of brass. The red color of zincite (ZnO) deceived the early prospectors who mistook it for cuprite (Cu_2O). However, in 1812 zincite was used to make paint. Metallic zinc was first recovered from zincite ore in 1838. Franklinite, $(Fe, Zn, Mn)(Fe, Mn)_2O_4$, was used in 1854 to produce zinc oxide, and willemite (Zn_2SiO_4) became the source of zinc in 1866. The ore body at Franklin was worked out and abandoned in 1954. The Sterling Hill ore body has been worked since 1870 (Widmer, 1964). Manganese and iron present in the ore are used to make spiegeleisen (an alloy of iron and manganese).

General Geology.

The ore bodies of Sterling Hill and Franklin are in Precambrian Franklin Limestone known also as the "White Limestone." The width of the outcrop of this limestone ranges from one half to two miles and extends from Ogdensburg in a north-eastern direction to Big Island in New York State. A fault east of the ore deposit is parallel to the strike of folded Franklin Limestone. It brings the Cambro-Ordovician Kittatinny Limestone, known also as "Blue Limestone," in contact with Franklin Limestone.

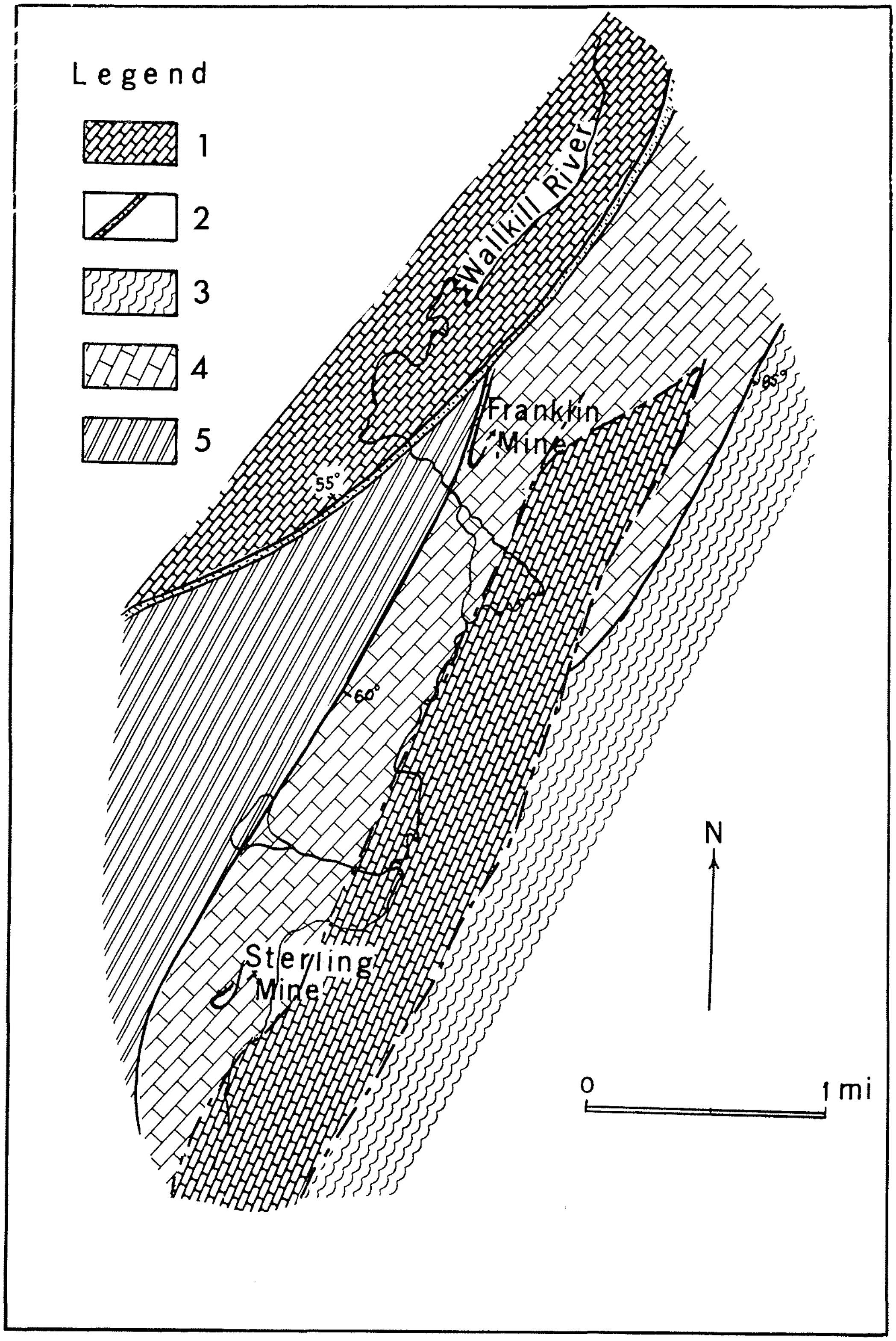

FIG. 1. GEOLOGIC MAP OF FRANKLIN-STERLING AREA.
(AFTER PALACHE)
1. CAMBRO-ORDOVICIAN KITTATINNY LIMESTONE;
2. CAMBRIAN HARDYSTON QUARTZITE;
3. PRECAMBRIAN BYRAM GNEISS;
4. PRECAMBRIAN FRANKLIN LIMESTONE;
5. PRECAMBRIAN POCHUCK GNEISS.

follows: franklinite 40 percent, willemite 23 percent, zincite less than one percent, gangue silicates 11 percent, carbonates (calcite) 25 percent. Wilkerson (1962) indicates that in some places the ore consists entirely of franklinite with calcite, in other places it consists of willemite with franklinite and calcite, and still in other places it consists of willemite, zincite, and franklinite in calcite. It is difficult to establish zones characterized by definite mineral assemblages. However, it appears that zincite is typical of the lower part of the ore body. Metsger et al. (1958) point out that in the paragenetic sequence willemite is first and is followed in an undetermined order by tephroite, zincite, and franklinite.

The total number of minerals reported by mineral collectors from Franklin and Sterling mines is 194. In 1935 Palache described 148 of these minerals in detail, and in 1962 Wilkerson described 42 minerals. About thirty of these minerals are fluorescent. The most common fluorescent minerals are calcite and willemite. Calcite fluoresces because it contains manganese and traces of lead. It is claimed that 26 of the Sterling and Franklin minerals have not been found anywhere else in the world. Many of these minerals continue to be found in the operating Sterling Hill Mine of the New Jersey Zinc Company and in two open pits in Franklin, the Buckwheat open cut and the Trotter Mine. Both open pits are operated commercially. The minerals found in the area are displayed at the Franklin Mineral Museum, Inc., on Evans St. and at the Gerstman Private Museum on Walsh Road in Franklin.

Metsger (1962) points out that marble associated with the ore contains about 2.5 percent manganese. Oxidation of manganese as the result of exposure results in light brownish stain. A diffusion halo of zinc exists around the Sterling ore body and there appears to be a spectrographic lead halo present in the surrounding rocks.

The origin of the ore was explained in several ways. Opinions were expressed that the ore bodies are metasedimentary, that they were formed as the result of magmatic emanations, that they are pyrometasomatic, that they represent an ore magma of sulfides altered by metamorphism, that they have been deposited as sulfides and carbonates which weathered to oxides and hydroxides subsequently metamorphosed, and that they are high-temperature replacement deposits. Palache (1935) suggested the metasomatic origin for these deposits of hydrous zinc and iron minerals, and probably for the carbonates of zinc and manganese. The depositing solution is believed to have derived its metals from the products of oxidation of an older sulfide deposit. As the result of regional metamorphism these minerals were changed to their present composition. More recrystallization occurred after the formation of pegmatites and more minerals were deposited during subsequent hydrothermal activity. Minerals typical of the surface oxidation conditions formed when the ore bodies were stripped of overburden by erosion. Pinger (1948) is critical of Palache's hypothesis because in his opinion it fails to explain the lack of segregation of zinc and iron upon oxidation of mixed sulfides as it is common of many other deposits. Pinger indicates also that solution effects accompanying metasomatic deposits are lacking in New Jersey. Referring to the deposition by hot brines at the bottom of the Red Sea of sediments containing 56 percent Fe_2O_3, more than 6 percent ZnO, and 1.3 percent MnO, Callaham (1966) suggests that the controversial stratiform zinc and manganese deposits of New Jersey are of volcanic-sedimentary origin. Takahashi and Myers (1961) used a thermodynamic approach to the determination of temperature at which the minerals formed as we find them today. The absence of wollastnite indicates a maximum temperature of formation of $680^{o}C$. The occurrence of tephroite indicates the minimum temperature of $530^{o}C$. The absence of rhodochrosite and occurrence of calcite indicate that the

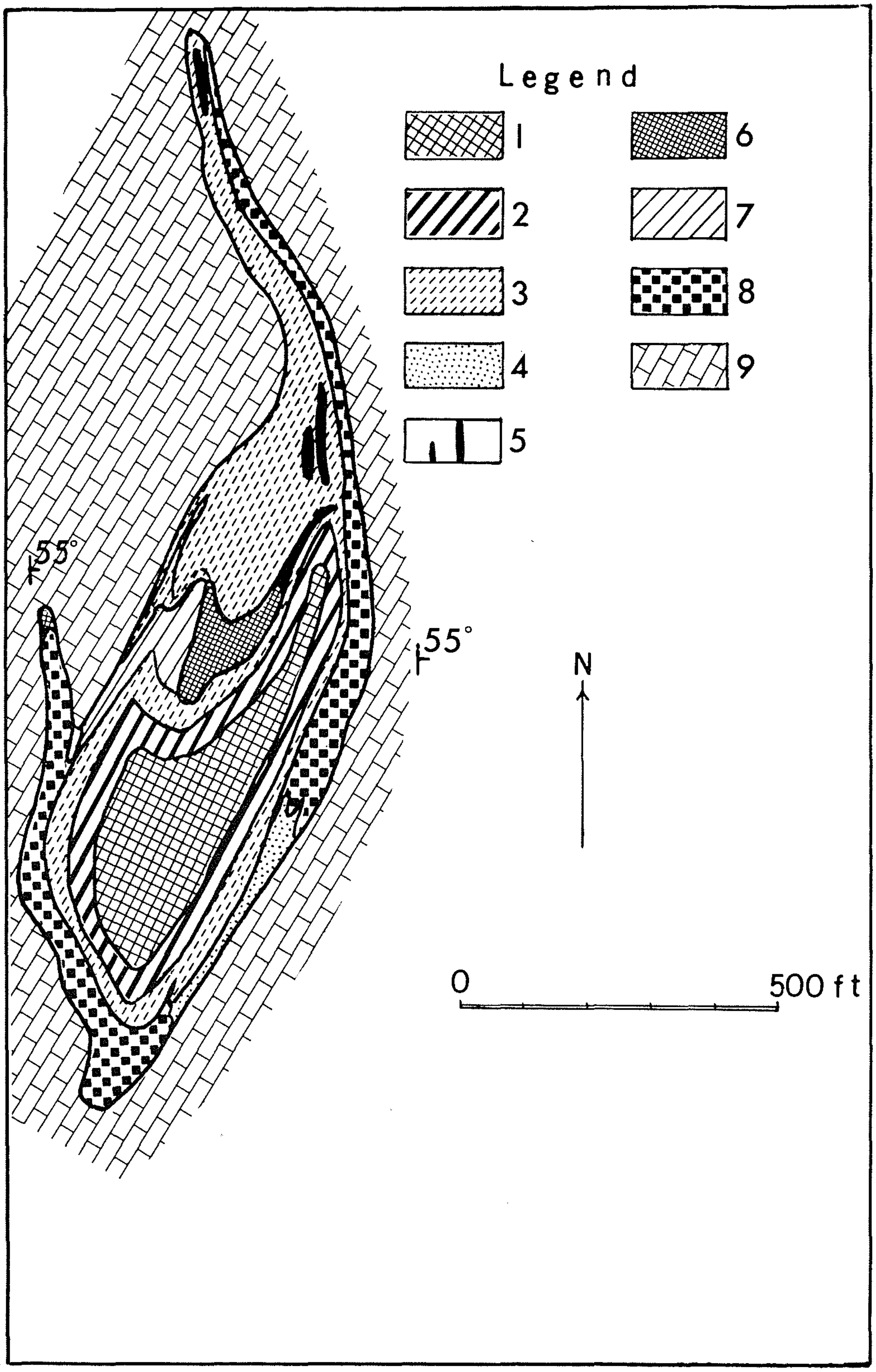

FIG. 2. GEOLOGIC MAP OF STERLING HILL ORE BODY.
(AFTER METSGER)

1. MUD ZONE;
2. GNEISS;
3. PYROXENE LIMESTONE;
4. FRANKLINITE ZONE;
5. BROWN WILLEMITE;
6. BLACK WILLEMITE;
7. CENTRAL ZINCITE;
8. OUTER ZINCITE;
9. FRANKLIN LIMESTONE.

Farther east a second fault cuts the Kittatiny Limestone along the strike bringing it in contact with Precambrian Byram Gneiss. In such a manner the Kittatinny Limestone fills a graben in the Precambrian formations. On the western side the Franklin Limestone formation overlaps the Precambrian Pochuck Gneiss. The eroded surface of both Pochuck Gneiss and Franklin Limestone is covered unconformably by Cambrian Hardystone Quartzite dipping at 55° to the northwest.

The Franklin Limestone is coarsely crystalline and contains bands of gneiss. It is also characterized by steeply dipping bands of disseminated tremolite, chondrodite, phlogopite, and graphite (Metsger, 1962). These bands are parallel to each other and to the contact with the underlying Pochuck Gneiss, inferring inheritance of original sedimentary bedding (Pinger, 1948). Pinger indicates that the western side of the limestone belt is calcitic and low in silica. It has been mined for blast furnace flux, lime, and cement. On the eastern side, the limestone is more siliceous. It is interesting that folds occur in the Franklin Limestone which are not reflected in the underlying Pochuck Gneiss. This is probably the result of the capacity of limestone to flow and form secondary folds between more rigid formations. Dikes of basic traprock apparently of Upper Paleozoic or possibly Triassic age cut across the limestone.

Geology and Mineralogy of Ore Bodies.

The ore bodies of Franklin and Sterling Hill in Ogdensburg are both in the Franklin Limestone. Despite an intensive program of exploration no other ore bodies were found, so far, in the area. Both ore bodies form synclines or pitching troughs, as defined by Wilkerson (1962). The Franklin ore body plunges north-northeast at 25° and that of Sterling Hill plunges 45° to the east-northeast, terminating against a fault at a depth of 2500 feet below the surface.

The ore was exposed and partially eroded as long ago as before the deposition of Paleozoic rocks. This is indicated by the presence of detrital franklinite in the Cambrian Hardyston Quartzite. More erosion occurred during the Mesozoic and Cenozoic eras, especially during the Pleistocene glaciation. Two depressions in the Franklin Limestone are filled with zincy mud. One of them occupies the core of Sterling Hill syncline. It is 300 feet long, 200 feet wide, and 675 feet deep. The zincy mud is the result of the alteration of the limestone (Metsger, 1962; Anonymous, 1966). It is possible that these depressions formed during the long period of weathering preceding the Pleistocene glaciation. Glacial boulders of franklinite were found 10 miles to the south at Sparta.

The ore bodies range in thickness from 10 to 100 feet. At Franklin Mine the ore in the western limb of the syncline was exposed for a distance of about 2500 feet, while the eastern limb was exposed for a distance of about 600 feet. At Sterling Mine the ore in the western limb of the syncline was exposed for some 700 feet, while the east limb was 1600 feet long. The two ore bodies have similar host rock, similar tabular folded structure, and similar mineralogic composition. However, the Franklin ore body is close to the footwall, while the Sterling ore body is 1000 feet above the footwall. The Franklin ore body contained more rare minerals than the Sterling Hill ore body because of association with pegmatites.

According to Pinger (1948) the approximate composition of the ore is as partial pressure of CO_2 was at a maximum of about 1000 atm. These figures, of course, indicate the conditions which existed during the process of metamorphism over 1.16 billion years ago, as indicated by a pegmatite cutting the ore body at Franklin (Long and Kulp, 1962).

It is obvious that the unique ore deposits of Franklin and Sterling Hill are a product of several geological processes. The primary ore was altered by regional metamorphism and locally by a pegmatite. Hydrothermal processes were superposed over the metamorphically altered ore. The presence of a lead halo around the ore bodies may be the result of this process. The source of metals remains not entirely clear. The volcanic-sedimentary source suggested by Callaham appears to be very plausible. Of particular interest is the presence of 2.5 percent manganese in the country rock. This manganiferous limestone has a sharp boundary with limestone containing only 0.1 percent manganese (Metsger, 1962). The country rock contains graphitic gneiss wrapping the core of the Sterling Hill syncline. Graphite from this gneiss is biogenic, as indicated by the C^{12} to C^{13} ratio (Pinger, 1948). All this evidence seems to point to the sedimentary nature of the country rock and the syngenetic nature of manganese in limestone, and appears not to preclude the syngenetic origin of the ore itself.

<u>Mining Operations in the Sterling Ore Deposit.</u>

According to the information issued by the New Jersey Zinc Company (Anonymous, 1966) the principal mine openings extending to the surface are the new main shaft inclined at 52^{o} and bottoming at 2065 feet below the lower yard level, the old main shaft bottoming at the 1850 foot level, and the safety exit. Underground development includes a winze, bottoming at the 2670 foot level below the adit level, raises, drifts, and crosscuts. Levels are cut at 180 feet, 340 feet, 430 feet, 500 feet below the adit level, and at 100 foot intervals down to the 1600 foot level. There is a level at 1680 feet, one at 1750 feet, one at 1850 feet, and a crusher station level at 1920 feet in the main shaft. The winze is connected to levels cut at 100 foot intervals down to the 2550 foot level. Mining of 3 to 4 foot beds of ore up to a maximum of 15 to 25 feet is accomplished with longitudinal stopes for the full widths of the bed. Where the ore body thickness exceeds the 15 to 25 foot range, stoping is done by means of transverse stopes, carried in a hanging-wall-to-footwall direction, leaving pillars. The ore in the pillars is mined by means of square-set stopes. The past zinc production together with the available reserves exceeds 1,000,000 short tons.

GEOLOGY ALONG THE ROUTE BETWEEN THE HIGHLANDS AND LONG ISLAND

VIA GEORGE WASHINGTON AND WHITESTONE BRIDGES

Route 23 crosses the Highlands in a southeasterly direction. The Oak Ridge Reservoir marks the northwestern border of a graben in Precambrian gneisses filled with Silurian and Devonian rocks. The Silurian Green Pond Conglomerate forms a ridge crossing the road between Newfoundland and the Charlottesburg Reservoir which is underlain by Devonian shale and sandstone. The southeastern border of the graben is southeast of Charlottesburg where the rocks are Precambrian gneisses.

The fault line separating the Precambrian Highlands from the Triassic basin is crossed at Riverdale. The diabase sill forming the Palisades is crossed for the second time at the western approach to the George Washington Bridge.

The suspension-type George Washington Bridge across the Hudson River has a span from support to support of 3500 feet and is 204 feet above the surface of the water. The zinc used on the cables weighs 1,700,000 pounds and was produced from ore of the Franklin mine. The second deck of the bridge was opened in 1962.

The northern tip of Manhattan is underlain by Inwood Marble and Manhattan Schist and is featuring canoe valleys formed in the Inwood Marble. East of the Harlem River excellent outcrops of banded Fordham Gneiss can be seen in the road cut.

The East River is crossed over the Whitestone Bridge which was constructed in 1939. The main span of the bridge is 2300 feet long and 135 feet above the water surface. The solid rock on the Bronx side is at a depth of 98 feet below the surface and on the Queens side it is at 150 feet below the surface.

ROAD LOG

Mileage.		Some of the participants of the excursion will board the bus at the Sheraton Tenney Hotel at 90 Street and Ditmars Boulevard in Queens.
0.0	0.0	Queens College. Main gate on Kissena Boulevard. The bus will be boarded by the rest of participants of the excursion. Proceed north to Long Island Expressway. Turn left on the service road to the entrance to the expressway.
0.3	0.3	Entrance to L.I. Expressway.
1.1	0.8	Crossing the Ronkonkoma terminal moraine.
1.6	0.5	Grounds of the 1964-1965 New York World's Fair. Science Museum. The outwash deposits of Wisconsin age underlie the area between the terminal moraine and the East River.
8.2	6.6	Entrance to the Midtown Tunnel under the East River. The tunnel crosses ridges formed by Fordham Gneiss and Manhattan Schist, and depressions between the ridges eroded in Inwood Marble. The depressions are filled with Recent overburden.
9.6	1.4	Exit from Midtown Tunnel. Crossing Manhattan along 34th St., the underlying formations are mainly Manhattan Schist.
11.6	2.0	Entrance to Lincoln Tunnel under the Hudson River excavated in Recent sediments.
12.3	0.7	Boundary between the States of New York and New Jersey. The western part of the tunnel crosses the Upper Triassic continental sedimentary sequence underlying the diabase sill.
13.0	0.7	Exit from Lincoln Tunnel.

13.6	0.6	Crossing the escarpment of the diabase sill.
13.8	0.2	Fault in the diabase sill (a narrow valley developed along this fault north of the road).
14.7	0.9	Leaving the diabase sill. The area is underlain by Upper Triassic shales, sandstones, and argillites. Turn northwest on Route 3 crossing the Hackensack Meadows. The land rises at the entrance
19.7	5.0	to Rutherford because of the appearance of harder sandstones.
26.5	6.8	Joining Route 46.
26.6	0.1	First Watchung Mountains formed by Triassic lava.
27.0	0.4	Lava with columnar jointing on the left side of the road.
27.4	0.4	Pillow lava structure on the left side of the road.
29.4	2.0	Triassic lava of the Second Watchung Mountains.
35.5	6.1	Triassic lava of Hook Mountain near Pine Brook. Third Watchung Mountains.
41.4	5.9	Escarpment formed by the fault zone between the Precambrian Highlands and the Triassic basin (mantled by glacial till).
53.0	11.6	Entering Dover. Outcrops of Precambrian gneiss.
54.3	1.3	Turning north on Route 15. Crossing an inlier of Silurian rocks north of Dover.
66.4	12.1	Turning on Route 517 in Sparta.
70.5	4.1	Ogdensburg. Turn left on Passaic Avenue. After 0.6 miles turn left on Plant Street.
71.3	0.8	Sterling Hill Mine office of the New Jersey Zinc Co. Visit to the mining property.
73.6	2.3	Franklin, N.J. LUNCH.
74.9	1.3	Gerstmann's Private Museum of Franklin and Sterling Hill minerals, 14 Walsh Road, Franklin, N.J.
76.2	1.3	Junction of Routes 23 and 517. Proceed southeast on Route 23 to New York.
84.1	7.9	Oak Ridge Reservoir. Northwestern border of graben in Precambrian gneiss -- inlier of Silurian and Devonian rocks. Southeast of Charlottesburg the rocks are Precambrian. The fault line separating the Highlands from the Triassic basin is crossed at Riverdale.

103.6	19.5	Junction of Routes 23 and 46.
107.5	3.9	Junction of Routes 46 and 3. Continue on Route 46.
122.0	14.5	Triassic diabase sill.
124.2	2.2	George Washington Bridge.
125.8	1.6	Outcrop of Fordham Gneiss.
131.7	5.9	Whitestone Bridge. Cross Island Expressway.
139.3	7.6	Junction of the Cross Island Parkway and Long Island Expressway. Turn west on the expressway. The hills at the junction are formed at the terminal moraine.
142.7	3.4	Exit to Kissena Boulevard.
143.4	0.7	Queens College. After a short stop the bus continues to the Sheraton-Tenney Hotel.

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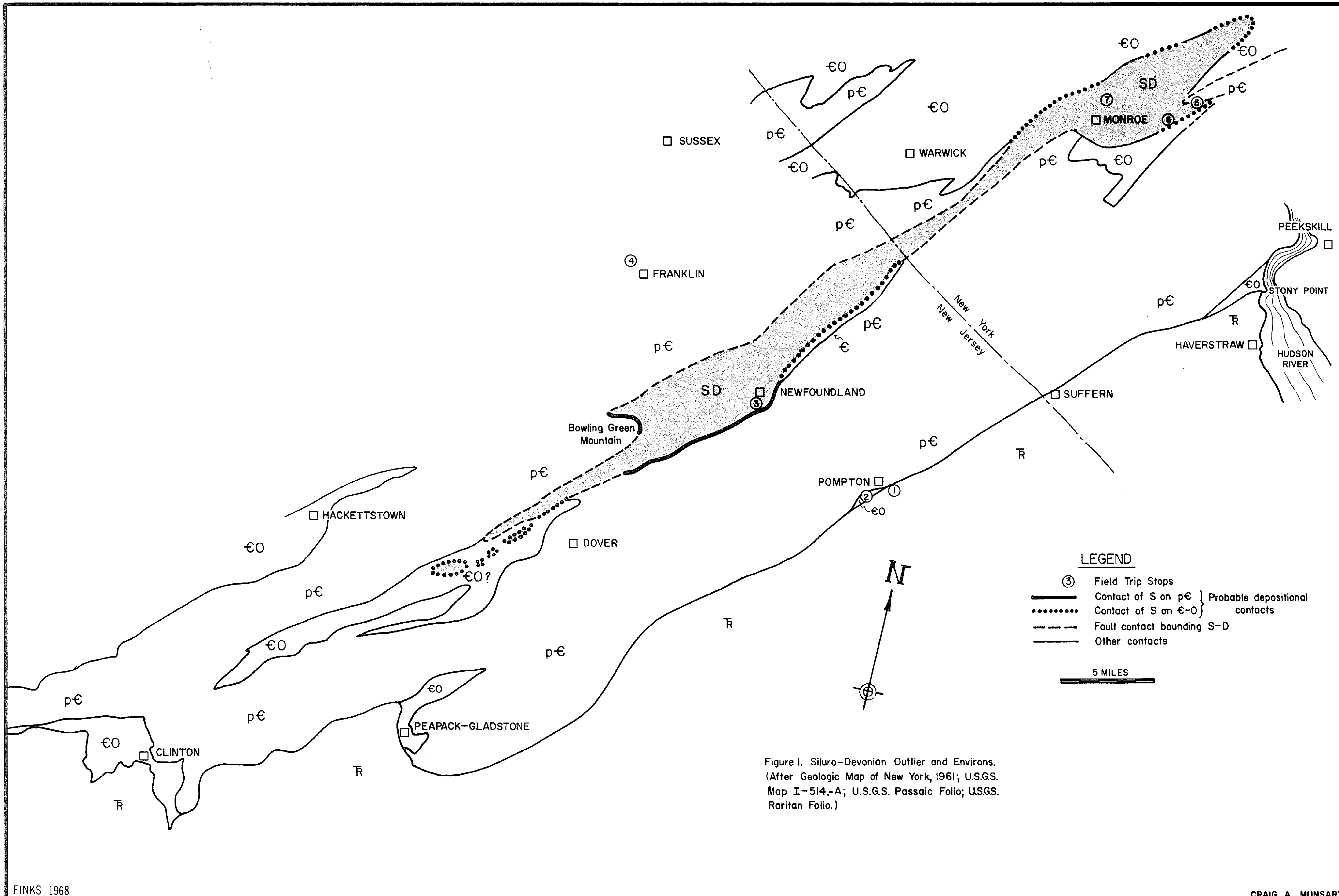

Figure I. Siluro-Devonian Outlier and Environs. (After Geologic Map of New York, 1961; U.S.G.S. Map I-514-A; U.S.G.S. Passaic Folio; U.S.G.S. Raritan Folio.)