IRON ORE DEPOSITS
OF THE NEW JERSEY HIGHLANDS

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History

Iron mining activity in the New Jersey Highlands probably began about 1710 (Sims, 1958). Maximum production was attained in the early 1880's when New Jersey ranked second only to Michigan in iron ore production. For several years before and during 1880 New Jersey was the leading iron ore producing state.

Geologic Setting

The magnetite concentrations of the New Jersey Highlands are emplaced in a Precambrian complex of metamorphic and igneous rocks. The metamorphic rocks have reached the granulite facies (Turner and Verhoogen, 1960) and the igneous rocks (principally granites) were emplaced in a very deep-seated "catazonal" setting (Buddington, 1959). The Precambrian rock units include Granite, Quartz-Oligoclase Gneiss, Hypersthene-Quartz-Oligoclase Gneiss, Pyroxene Gneiss, Amphibolite, and Marble. A description of these rock units accompanies this guidebook (Puffer, this guidebook).

Characteristics of the Ore:

(1) The principal iron ore mineral throughout the New Jersey .Highlands was magnetite, but a minor amount of hematite was also recovered. Both the magnetite and hematite typically contain exsolution lamellae of ilmenite and are described by Baker and Buddington (1970) as ilmeno-magnetite and ilmeno-hematite. These two ore minerals are commonly accompanied by minor to trace quantities of hemo-ilmenite (ilmenite containing exsolution lamellae of hematite) or titano-hematite (hematite containing titanium in solid-solution.)

(2) The chemical composition of the magnetite ore is quite variable. The TiO_2 content of magnetite concentrate from the Sulphur Hill deposit (a skarn) is 0.10 weight percent (Table 1) and is not accompained by any titanium oxide. Magnetite from the Edison deposit contains 0.70 weight percent TiO_2 and is associated with ilmeno-hematite, whereas magnetite from the Mount Pleasant deposit contains 1.30 weight percent TiO_2 and is accompanied by traces of hemo-ilmenite. There does not, however, appear to be any consistent structural or regional variation in the composition of the magntite. The composition of magnetite from the southern structural block of the Highlands is not consistently higher or lower than magnetite from the northern structural block.

(3) The occurrences of the magnetite ore range from a highly dispersed or disseminated mode to a highly concentrated vein mode. The largest magnetite concentrations occur as pod shaped lenses that grade into leaner material. The lenses are described as shoots while the low grade rock between them are called pinches.

(4) The magnetite concentrations are found emplaced in a variety of rock types. The most typical host rocks are Quartz-Oligoclase Gneiss, Amphibolite, Pyroxene Gneiss, Quartz-Potassium Feldspar Gneiss, and Marble Skarn. With few (if any) exceptions the host rocks are sedimentary units or interbedded volcanics that have been metamorphosed into granulite facies rock and then invaded by granites in a deep-seated "catazonal environment (Buddington, 1959).

(5) The magnetite concentrations are, without exception, emplaced concordant to the foliation of the metamorphic host rock.

(6) The magnetite concentrations are typically (probably without exception) veined with magnetite bearing pegmatites. The pegmatite veins are small, concordant, and comply with each of the characteristics of typical magnetite bearing pegmatites described by Puffer (1975).

(7) The magnetite concentrations are rarely found more than a few hundred meters away from a granite. The granite is most typically an alaskite but some deposits are located near Hornblende Granite and less commonly near Pyroxene Granite.

(8) Potassium feldspar, quartz, plagioclase, biotite, and hornblende are the principal gangue minerals associated with magnetite. Other silicates, oxides (principally hematite), sulfides (principally pyrite and / or pyrrhotite), and carbonates (principally calcite) are irregualrly distributed among the magnetite concentrations.

TABLE 1

Source of Iron

There are at least three plausible sources for the iron that is found concentrated as magnetite deposits scattered throughout New Jersey Highlands: (1) Aqueous fluids released from magmas that formed the granites of the Highlands (particularly alaskite magmas), (2) The sedimentary sources of the metamorphic host-rocks that contain the magnetite concentrations, and (3) Aqueous fluids released from metasedimentary gneisses (particularly the Quartz-Oligoclase Gneiss) and Amphibolites.

Although each of these three sources and perhaps other sources may have contributed some iron, the relative importance of the various sources has been a controversial issue.

1. **The Alaskite Source:** It has been suggested by Buddington (1966), Baker and Buddington (1970), Smith (1933), Sims (1958) and others that hydro-thermal fluids emanating from granite magma carried iron into the meta-sedimentary country rocks intruded by the granite. According to Baker and Buddington (1970), the release of iron from the igneous magma transformed some of the granite into iron impoverished alaskite. This suggestion is supported by:

(a) The close spatial association of most of the magnetite concentrations with alaskite (see maps accompanying Baker and Buddington (1970), Hotz (1953), and Sims (1958).

(b) The barium enrichment of the feldspars associated with the magnetite ore; an enrichment that may have been induced through hydrothermal activity (Baker and Buddington, 1970). Uranium mineralization also accompanies some of the Highland magnetite deposits (Klemic and others, 1959) as well as minor sulfide mineralization.

(c) The occurrence of iron ore in a wide variety of rock types, each of which presumably had a different origin and a diferent capacity to concentrate ore through means other than hydrothermal activity.

On the other hand, each of these supporting statements are inconclusive. Detractors might argue that:

(a)The alaskite-iron ore association may be coincidental since the alaskite magma has intruded into positions close to a large percentage of the various Highlands rocks.

Principle Host Rock	Mine Name	TiO$_2$ Content
"Skarn" of Sims and Leonard (1952)	Rossville	0.27[1]
	Sulphur Hill	0.10[1]
"Oligoclase-Quartz-Biotite Gneiss" and "Albite-Oligoclase Granite Gneiss" of Sims (1958) and "Quartz Oligoclase Gneiss" of Baker and Buddington (1970)	Righter	1.58[1]
	Beach Glen	1.13[1]
	Lower Baker	1.10[1]
	Richard	0.30[2]
	Mount Pleasant	1.30[2]
	Scrub Oaks	0.49[2]
	Elizabeth	1.08[2] (average of 2 analyses)
	Hurd	0.93[2] (average of analyses)
	Hibernia	0.85[3] (average of analyses)
	Fairview	1.80[3]
Amphibolite	Dodge	3.01[1]
	Ford	2.43[1]
	Leonard	1.10[2] (average of 2 analyses)
	Scott	1.31[4] (average of analyses)
"Quartz-Potassium Feldspar Geniss" of Baker and Buddington (1970)	Edison	0.73[5] (average of analyses)
	Sherman-Bunker	1.01[5] (average of analyses)

1. X-Ray Fluorescence analyses - This Study
2. Sims (1958)
3. Collins (1969).
4. Hager and others (1963).
5. Baker and Buddington (1970).

(b) Barium, uranium or other elements may also have been supplied by fluids released from the metasedimentary rocks or may have a syngenetic origin.

(c) Iron supplied by fluids released from the metasedimentary rocks may also have diffused into a variety of rock types before or during the emplacement of the granite magma.

It might also be argued that few typical hydrothermal mineral assemblages are found associated with the iron ore. But if the iron precipitated in a catazonal environment some of the most typical hydrothermal minerals, including several hydrous silicates, would be outside of their stability field. In addition, the foliated nature of the iron deposits suggests that the ore was emplaced before anatexis rather than as a late, perhaps deuteric, release of iron from a granite magma. But even if the iron was released as a late emanation from granite it may have been foliated by subsequent metamorphic events. The alaskite magma, therefore, remains neither proven or disproven as a source of iron ore.

2. **A Syngenetic Source:** Some of the metasedimentary rocks of the New Jersey Highlands may have always contained considerable iron ever since deposition as an iron rich sediment (Nason, 1922; Kastelic, 1980). Palmer (1970) also suggested a syngenetic origin for the iron ore of the Benson, New York deposit which has been described by Buddington (1966) as very similar to some of the Highlands deposits particularly the Edison deposit. Their suggestion is supported by:

(a) The strata bound nature of the ore and lack of any cross cutting structural relationship.

(b) The foliated nature of the ore which suggests that ore emplacement preceded metamorphism and subsequent igneous activity.

On the other hand, detractors might argue that:

(a) If iron was emplaced from fluids emanating from either granite magma or metamorphic rocks in a catazonal environment it is unlikely that cross cutting structures would be capable of penetrating down into catazonal depths. Catazonal environments are almost by definition devoid of cross cutting structures (Buddington, 1959).

(b) Both alternative origins allow for the possibility of a continuation of metamorphism following ore emplacement that could account for the foliated nature of the ore.

(c) If iron was originally precipitated as iron carbonate, as suggested by Kastelic, 1980 and Palmer, 1970 then why is so little iron carbonate found in the Franklin Marble? And why have the carbonates of the Franklin Marble survived the same metamorphic processes that allegedly destroyed the carbonate precursors of the iron ore at most Highlands locations?

(d) Since iron is found concentrated in several different rock types throughout the Highlands, a unique sedimentary environment capable of concentrating iron cannot, therefore, apply to each of these several rock types.

(e) A syngenetic origin is not easily applied to the thick almost pure magnetite vein mode of occurrence of some of the Highlands iron ore deposits (such as the Davenport Deposit).

(f) The very low Ti/Fe ratios found at most of the ore deposits rules out most common detrital sediments as the principal source of iron and the absence of significant jasper or its metamorphic equivalent rules out the kind of sediments associated with the syngenetic iron ores of the Lake Superior type.

3. **The Quartz-Oligoclase Gneiss as a Source:**
A metamorphic diffusion mechanism such as that proposed by Hager and others (1963) and Collins (1969) may have mobilized considerable iron in the New Jersey Highlands. Recrystallization of an amphibolite into pegmatite, plus magnetite plus an iron depleted gneiss has been suggested by Hager and others (1963) as the origin of the Scott iron deposit. On a much larger scale, metamorphic processes may have also released iron from the widespread Quartz-Oligoclase Gneiss of the New Jersey Highlands (Puffer, this guidebook). If the Quartz-Oligoclase Gneiss is a metasedimentary rock as suggested by Sims (1958) Collins (1969) and Puffer, (this guidebook), it presumably underwent considerable prograde metamorphism to reach the granulite facies. Since water is generally released during each progressive stage of metamorphism a solvent for iron is generated that may be chemically equivalent to any hydrothermnal fluids released by the granitic magmas. Iron carried by aqueous fluids released by metamorphic processes may have diffused into any available sheer zone or low pressure zone. Precipitation of iron may have been forced by decreasing temperatures and pressures. This suggestion is supported by:

(a) The close spatial association of Quartz-Oligoclase Gneiss with most of the iron deposits of the New Jersey Highlands. (See maps accompanying Baker and Buddington (1970), Sims (1958) and Hotz (1953).

(b) The unusually low iron content of the Quartz-Oligoclase Gneiss. Regardless of whether the precursor of the Quartz-Oligoclase Gneiss was a graywacke (Puffer, this guidebook) or an igneous rock (presumably a tonalite, Baker and Buddington (1970), the iron content is low. About three percent iron oxide

must be subtracted from a typical graywacke or tonalite to yield the average Quartz-Oligoclase Gneiss (Puffer, this guidebook).

(c) The way that the Fe/Mg ratio of ferromagnesian silicates decreases in response to increasing temperatures thus releasing iron given a fixed supply of magnesium. Biotite, for example, as it occurs in very high grade metamorphic environments will respond to this phenomena within temperature ranges approximating granulite facies conditions (Wones and Eugster, 1965). Iron rejected by such ferromagnesian silicates would be partitioned into any available aqueous phase rather than precipitate in place as an oxide. There is both empirical evidence (Mackin, 1968; Puffer and Peters, 1974) and experimental evidence (Martin and Piwinski, 1969) that iron is highly soluble in high temperature aqueous fluids generated by silicate systems. Water generated by the prograde metamorphic conversion of aqueous phases into anhydrous phases may have been the solvent that transported the iron.

(d) The common association of Highlands iron ore with magnetite bearing pegmatites. The same aqueous fluids may be responsible for the development of both the iron ore and the magnetite bearing pegmatites. Both the pegmatites and the iron ore were presumably deposited in the same low pressure zones.

(e) The association of iron ore with a potassium rich mineral assemblage. Both biotite and potassium feldspar are typically found as gangue minerals accompanying the magnetite. Both potassium and iron are depleted from the Quartz-Oligoclase Gneiss and probably were transported together in the same aqueous fluids. These fluids were probably mobilized when hydrous ferromagnesian silicates (particularly biotite) broke down in response to prograde metamorphism approaching the granulite facies.

The principal weakness with the Quartz-Oligoclase Gneiss source rock hypothesis is the lack of evidence pertaining to the pre-metamorphic iron content of the Quartz-Oligoclase Gneiss and the lack of evidence pertaining to the solubility of iron in any aqueous fluids released during metamorphism. These weaknesses, however, are shared by the granite magma source rock hypothesis. Fluids emanating from either source would actually have much in common.

Combined Sources

If aqueous fluids containing iron were driven out of the Quartz-Oligoclase Gneiss during prograde metamorphism approaching granulite facies conditions, these fluids would have been chemically similar to those driven out of any granite magma emplaced into the same "catazonal" environment. The solubility of iron in such fluids would presumably be controlled to a large degree by the same temperature and pressure considerations. Fluids simultaneously emerging from both sources may also have mixed with each other since there would have been a tendency for both fluids to migrate toward the same low pressure zones. The ultimate source of iron precipitated out of such a mixed fluid would be completely problematical. Still further mixing with at least some syngenetic iron would also be expected. It may, therefore, be impossible to ever sort out the exact contribution of iron from each source, unless, of course, this is accomplished during the anticipated lively discussion of the various possibilities that will hopefully take place among field trip participants.

The Edison Magnetite Deposits

The Edison Magnetite Deposits are located about three miles east of the town of Ogdensburg, New Jersey (Stop # 3). Iron was extracted from the Edison Deposits from 1772 to 1899 (Baker and Buddington, 1970). Most of the magnetite ore is disseminated within a biotite and sillimanite rich phase of a Quartz-Potassium Feldspar Gneiss. The Gneiss is locally a 1000 ft. wide N-E striking band of rock bounded on the southeast by Quartz-Microcline Gneiss and on the northwest by Syenite Gneiss (see map accompanying Baker and Buddington, 1970). The foliation of the Quartz-Potassium Feldspar Gneiss dips vertically or steeply to the southeast. It is a metasedimentary rock that is locally composed of variable amounts of potassium feldspar, quartz, sillimanite, and magnetite with accessory garnet, apatite, monazite, spinel, corundum, epidote, fluorite, zircon, ilmeno-hematite, pyrite, molybdenite, and chalcopyrite. The virtual absence of plagioclase feldspar from the host rock of the ore results in a very high K/Na ratio. The potassium feldspar of the ore contains over two percent barium (Baker and Buddington, 1970), and is non-perthitic. Alteration enhanced by acid solutions leached from the sulfides has deeply altered some of the rock, particularly were sulfides are concentrated. Some of the potassium feldspar has been deeply altered to sericite and some of the magnetite has been altered to martite.

Seams of magnetite and ilmeno-hematite bearing pegmatites are found throughout the Edison Deposits. The pegmatites were probably precipitated from aqueous fluids released from the metasedimentary host
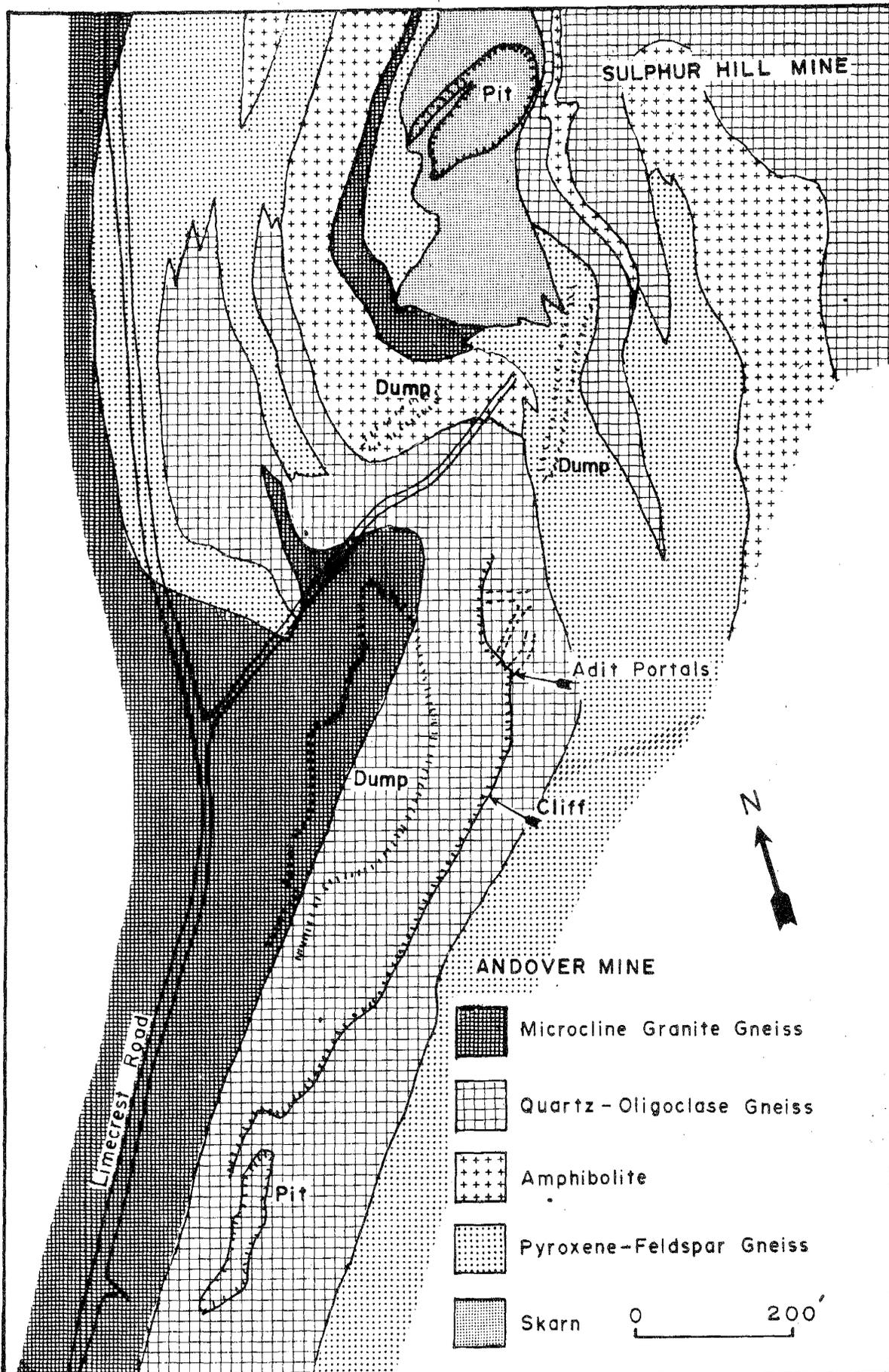
Fig. 1 Geologic map of Andover and Sulphur Hill mining district, New Jersey. This map is a slightly modified portion of a more detailed map by Sims and Leonard (1952). Some very highly altered rock described by Sims and Leonard (1952) as altered diabase is distributed throughout the mine area, particulary along the cliff (fault scarp?). Located near the Andover mine.

rock during prograde granulite facies metamorphism (Puffer, 1975). The concordant emplacement of the pegmatites, their small size, their lack of zoning or lithium, boron, or berrilium minerals and their catazonal metamorphic setting are characteristics that are typical of magnetite rich pegmaties found throughout the New Jersey Highlands and elsewhere (Puffer, 1975).

The Andover - Sulphur Hill Iron Deposits

The Andover iron ore deposit (Stop # 2) is located approximately two miles northeast of Andover, New Jersey. The Andover Mine was worked from some time before 1763 until 1863, whereas the adjacent Sulphur Hill mine was worked from 1855 until 1880 (Sims and Leonard, 1952).

The Andover Mine is cut into a 250 ft. wide band of N-E striking Quartz-Oligoclase Gneiss that is bounded on the northwest by microcline granite gneiss (containing accessory biotite and sillimanite) and on the southest by pyroxene-feldspar gneiss (Fig. 1). Both magnetite and hematite ore was extracted at the Andover Mine. An unaltered magnetite concentration is found at the northeast end of the Andover pit and is surrounded by a thick shell of "red ore" that is composed predominantly of hematite and silica. According to Sims and Leonard (1952) the hematite was formed by supergene alteration of hypogene magnetite.

Although the Sulphur Hill ore is rich in sulfides only minor traces of sulfides are found in the Andover ore. The Andover pit and underground workings are located along a cliff that Sims and Leonard (1952) describe as a fault scarp. They interpret the black, fine grained, highly chloritized rock exposed along the cliff as a diabase dike and suggest that it intruded during the Triassic Period.

The Sulphur Hill mine located about 500 ft. northeast of the Andover Mine is cut into a 200 ft. wide exposure of skarn (Fig. 1). The rock name skarn is used here in keeping with virtually all previous geologic references but no genetic implication is intended. Contact metamorphism may or may not have been responsible for the ore implacement. The skarn is in contact with amphibolite and pyroxene-feldspar gneiss on the northwest and with Quartz-Oligoclase Gneiss on the southeast. The skarn consists of calcite, garnet, magnetite, pyroxene, and pyrrhotite, with accessory sphalerite, galena, chalcopyrite, and molybdenite. The sphalerite is difficult to distinguish from the andradite garnet because of its dark brown color. Some of the magnetite has been altered to martite. The skarn is probably a very impure zone of Franklin Marble. Although similar iron oxide rich deposits occur in the Franklin

Marble (such as the Furnace Magnetite Deposit near Franklin, New Jersey) the Sulphur Hill Deposit is not typical of New Jersey Highlands iron mines.

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Mine Hill, Franklin Furnace.

MINE HILL, FRANKLIN FURNACE
by H. Carmiencke
from N.J.G.S., 1856, 2nd Annual