Hard Iron Ore at the Cliffs Shaft Mines, Ishpeming, Michigan

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At the Cliffs Shaft Mine, for many years the premier hard iron ore mine of Michigan, bodies of ore typically are localized in the upper part of the Negaunee iron-formation, close beneath Goodrich Quartzite in the axial part of the Marquette synclinorium. Individual ore bodies may be as much as 100 feet thick and extend laterally for many hundreds of feet. The cluster of ore bodies making up the Cliffs Shaft deposit has an overall length of about 4,500 feet from east to west parallel to the axis of the synclinorium and a width of 1,500 feet from north to south. The deposit extends beneath much of the City of Ishpeming, from a short distance west of the city limits to almost the east edge of the city. The ore-bearing zone generally does not reach more than 150 feet stratigraphically into the iron-formation from the base of the Goodrich Quartzite. Folding of the ore-bearing zone and the overlying and underlying rocks took place as part of the folding of the synclinorium and carries the ore to varying depths below the land surface. Folding has placed the ore-bearing zone in anticlinal, synclinal, and monoclinal configurations.

Hard ore is compact, massive, and non-porous, and varies in color from blue black to reddish black, steel gray, or reddish dark blue. Over the years of mining (approx. 1880-1965), the ore has had an iron content of 58 to 62.5 percent, silica of 5 to 7 percent, phosphorous of .09 to .13 percent, and manganese of .2 to .8 percent. The iron mineral is mainly specular hematite, but magnetite octahedra are sprinkled through the hematite masses in places. Original iron-formation laminations are preserved in some hard ore and remnants of red chert (jasper) and gray chert beds are incorporated in the ore in places. Hard ore and jaspilite have metamorphic recrystallized fabrics in which specular hematite crystals or hematite and quartz grains are locked together and have remained virtually intact since the end of Middle Precambrian time.

Bodies of hard ore occur almost exclusively in jaspilite iron-formation, but in a few places, with appropriate changes in composition and texture, may extend into overlying Goodrich Quartzite. Since the early days of mining in the Marquette district, the Goodrich-Negaunee contact has been recognized as a guide in the search for additional deposits of hard ore. The Goodrich immediately overlying Negaunee iron-formation is quartzite, conglomerate, or an argillaceous slaty rock. Basal Goodrich conglomerate generally is quartzite and contains fragments of the underlying jaspilite iron-formation. Hard ore deposits that extend into the Goodrich become conglomerate ore--a mixture of typical detritus of the Goodrich Quartzite and a hematite or hematite-magnetite matrix (derived from erosion of the underlying iron-formation). The Goodrich-Negaunee contact in the Cliffs Shaft mine thus is an erosion surface, but one along which there is little or no angular discordance. The virtual lack of an angular discordance suggests that the anticlines and synclines in which orebodies are now distributed did not exist prior to deposition of the Goodrich.

Jaspilite, which almost invariably underlies and partly encases the irregularly shaped and distributed orebodies, typically is interlayered specular hematite and red chert (jasper) but includes some interlayered magnetite-jasper and martite-jasper. Jaspilite is underlain in turn by sideritic iron-formation. The zone of jaspilite between hard ore and sideritic iron-formation is of irregular thickness, commonly 10 to 100 feet, or more. In some places in the mine, the selvage of jaspilite between hard ore and sideritic iron-formation is only inches thick. Jaspilite beds have been seen in a few places in the mine to pass along strike into chert-carbonate beds, and small "islands"--unoxidized remnants--of chert-carbonate iron-formation in a few places are surrounded by jaspilite. Sideritic iron-formation below jaspilite is notably free of alteration and veining. It is clear that at least some jaspilite was derived by alteration of chert-carbonate iron-formation, and that alteration probably moved downward from above the contact of jaspilite and carbonate iron-formation.

Numerous irregular intrusive bodies and dikes of chloritized greenstone--metagabbro and metadiabase--cut iron-formation and bodies of hard ore in the mine. Most such bodies appear to predate Goodrich Quartzite, but some bodies that lie along or extend across the contact of the two formations are younger in age than the Goodrich. Most intrusive bodies in contact with hard ore, other than thin dikes, dip under the ore, so that the ore generally occurs between the greenstone and the Goodrich hanging wall. The irregular-shaped areas of iron formation caught between the intrusive bodies and the Goodrich contact make for a very complex configuration and distribution of individual bodies of hard ore, but all in proximity to the folded Goodrich contact. The magnetite content of ore and iron-formation typically increases perceptibly within 1-2 feet of intrusive rock and in some places a septum of nearly solid magnetite, an inch or so thick, borders the contact with intrusive rock. Iron-formation near contacts with intrusive greenstone may be mainly interlaminated magnetite and gray chert. Minor yellow sulfide also occurs in a few places along contacts between intrusive greenstone and iron-formation.

In the axial part of the Marquette synclinorium at the Cliffs Shaft deposit, the Negaunee and Goodrich formations as well as the erosional contact between them, and the adjacent ore-bearing zone, are bent into a number of west-trending folds. The zone of jaspilite and enclosed bodies of hard ore follow the folded erosion surface up and down. The folds are more or less disrupted by faults that generally also have an east-west alinement. Fold plunges are westward in the western part of the deposit in general conformity with the plunge of the synclinorium. In the central 2,500 feet or so of the deposit, beneath the western and central parts of the city of Ishpeming, fold axes flatten and then reverse to a gentle eastward plunge in the eastern part of the deposit. Almost at the very east end of the deposit, fold plunges reverse again and the ore bearing zone bends upward to the east. The deepest ore at the west end of the mine is about 300 feet above sealevel and 1,100 feet below the land surface. A corresponding part of the structure and ore zone rising up plunge to the east reaches to about 850 feet above sea level in the central part of the deposit, and plunging eastward in the east part of the deposit, drops to about 600 feet above sea level. In north-south cross sections the folds can be seen to have amplitudes of 100-300 feet. Ore on the crest of the highest anticlines in the mine reaches a little more than 1,200 feet above sea level and about 200 feet below the land surface. Ore shoots in old workings, just east of the Cliffs Shaft deposit proper, continued up plunge to the east and reached the surface at Jasper Knob near the southeast corner of Ishpeming.

The aforementioned observations tend to support the weathering-metamorphic theory of C. R. Van Hise for the origin of the hard ore and some, if not all, of the jaspilite in the Cliffs Shaft mine. The principal considerations are as follows:

1) The spatial association of jaspilite and hard ore suggests that they are related in origin, and that the relationship is controlled in some way by the contact (erosion surface) separating the Goodrich Quartzite and Negaunee Iron-formation. Relict iron-formation laminations in the hard ore indicate that the ore-grade concentration of iron was accomplished by a direct replacement of iron-formation, especially of the cherty laminations.
2) At least some jaspilite in the Cliffs Shaft mine was derived by alteration of carbonate iron-formation, and the proximity of jaspilite to the pre-Goodrich erosion surface suggests that the alteration was the result of weathering.

3) An oxide iron-formation corresponding to the present jaspilite, and ore-grade concentrations of iron corresponding to the present bodies of hard ore existed prior to the Penokean regional metamorphism and prior to Goodrich deposition. The presence in basal Goodrich conglomerate of fragments of jaspilite and hard ore indicates that both materials are essentially pre-Goodrich in age. The recrystallized fabric of jaspilite and hard ore shows that their iron-oxide composition was already established when metamorphism took place.

4) The position of intrusive greenstone bodies dipping under orebodies, suggests an analogy with some existing bodies of soft iron ore formed from carbonate iron-formation, in which underlying intrusive rock provided a barrier to the downward movement of ground water that led to a build-up of concentrations of secondary iron oxide above the barrier--between the barrier and the erosion surface. Masses of mafic intrusive rock emplaced in the iron-formation before the post-Negaunee, pre-Goodrich erosion interval could have had the same effect during that interval. However, not all intrusive bodies are clearly pre-erosion interval in age; some appear to have come later. The magnetite present in many bodies of hard ore adjacent to contacts with intrusive greenstone apparently is a product of contact metamorphism, so is not readily explained unless the intrusive rock was emplaced after the ore-grade concentration of iron had taken place. The simplest explanation is that mafic intrusive bodies were emplaced before and after the erosion interval, and before regional metamorphism.