Implications of Mineralogy, Grain Size and Texture on Liberation and Pellet Quality of Great Lakes Iron Ore

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ABSTRACT

The Lake Superior Region has been a producer of iron ore for over 150 years. Early mining operations concentrated on direct shipping ores, which are the result of post-depositional upgrading principally by deep weathering. As direct shipping ore reserves became depleted, the focus changed to the production of iron ore pellets from taconite. The post-depositional processes responsible for upgrading taconite are regional metamorphism, contact metamorphism and hydrothermal processes (Clout and Simonson, 2005). While these processes are important in iron ore genesis they can also contribute to liberation problems and in some instances reduced pellet quality (Han, 2004).

Low-grade metamorphic mineral assemblages can negatively impact liberation and pellet quality. Low-grade iron formation may contain a suite of carbonate minerals including ankerite, dolomite, kutnohorite, siderite and magnesiosiderite. Variation in the distribution and composition of siderite and magnesiosiderite makes controlling the MgO content of pellets difficult. Carbonate minerals also require calcination in the pellet induration process, which requires additional heat to be added to the system, slowing down the induration process and reducing throughput. Prediction of carbonate mineralogy and carbonate mineral chemistry is an important goal of ore characterisation for pelletising properties.

Contact metamorphism causes changes in mineralogy and grain size (Klein, 1973; Gunderson and Schwartz, 1962). Increasing the grain size of magnetite should improve its liberation characteristics. However, plant grinding targets may not allow the coarse-grained, more easily liberating magnetite ores to increase throughput and can actually result in decreased throughput due to recirculation.

While magnetite and martite ores are well understood (Lukey, Johnson and Scott, 2007) late open-space filling microplaty haematite ores are not. These ores, while composed of similar minerals, have a unique genesis that results in fine grain size and complex textures that present liberation challenges and often make interpreting laboratory metallurgical test results more difficult.

INTRODUCTION

The science of geometallurgy requires that ore characterisation be performed holistically, that is, with consideration of the impacts of ore quality on mine planning, plant performance and product quality. Geometallurgy, by definition, requires knowledge of geology, mineralogy, extractive metallurgy and pyrometallurgy. Examples of the ore characterisation challenges for the geometallurgist in the production of iron ore pellets from low-grade Proterozoic iron formation are presented here.

ORE CHARACTERISATION

Ore characterisation, by quantifying the mineralogy, grain size and the texture of ores, is an often overlooked tool in improving process efficiency. Some mineral related problems are not unique to the production of iron ore pellets, eg the problems caused by expanding clays in flotation. The negative impact of carbonate minerals in the ore on pelletising productivity and pellet quality are unique. The long and complex geologic history of Precambrian iron formations contribute to modifications of grain size and the introduction of complex textures.

Mineralogy

Common minerals can pose interesting challenges in the production of iron ore pellets. In low metamorphic grade iron ore deposits many carbonates can be encountered, including ankerite, dolomite, kutnohorite, siderite and magnesiosiderite. Carbonate fluxstone (limestone and dolomite) is also added to concentrate to achieve a Ca:Mg ratio specified by steel producing customers. However, the Ca and Mg contributed by carbonate minerals that occur in the ore must be accounted for and blended so that the appropriate amount of fluxstone can be added and the specified Ca:Mg pellet produced.

Unfortunately, predicting the Mg content of concentrate from development drilling and blast pattern data is not straight forward. At the Tilden Mine, Michigan Mg in the head sample comes from chlorite, dolomitic ankerite and magnesiosiderite (Figure 1). In the beneficiation plant chlorite and dolomitic ankerite report to the tail and magnesiosiderite to the concentrate. But, in the laboratory bench test that is used to predict concentrate grade, chlorite and siderite report to the concentrate. This poses an interesting mineralogical problem. First the amount of Mg in chlorite must be removed from the bench concentrate assay – this can be determined from the Al content. Then the amount of Mg in the dolomitic ankerite can be removed from the concentrate laboratory bench test concentrate assay. While this can be done, it requires detailed mineralogical analysis at the blast pattern scale.

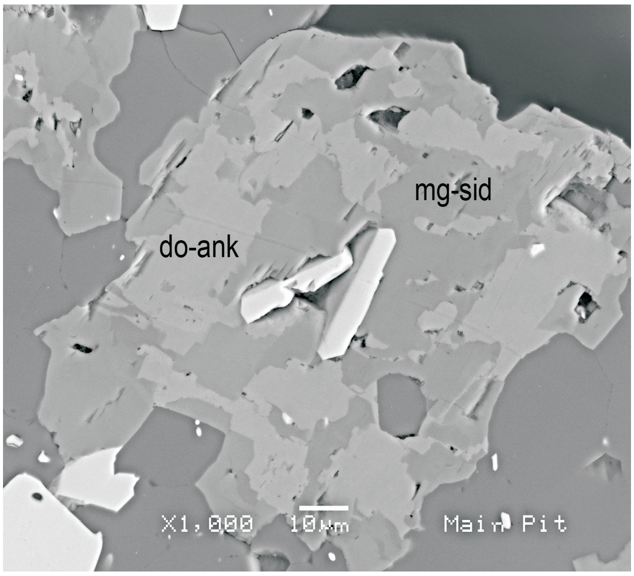

FIG 1 - SEM photomicrograph demonstrating the complexity of carbonate minerals from the Tilden Mine. Grain is composed of domains of dolomitic ankerite (do-ank) and magnesiosiderite (mg-sid).

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Carbonate minerals not only complicate making a pellet with a desired Ca:Mg, but contribute to a reduction in pellet strength as well. The endothermic calcination of carbonate minerals removes heat from the induration process and, if not compensated for, reduces pellet quality.

Grain size

Grain size can be determined directly by examination with a microscope or indirectly with timed grinds in a liberation analysis. Accurate determination of grain size is essential in determining the grinding strategies necessary for liberation. The average grain sizes of certain minerals can also be determined by X-ray diffraction.

Contact metamorphism related to intrusions can cause recrystallisation of ore minerals. At the Empire and Tilden Mines in Michigan a variety of igneous rocks intrude the orebody. Here the magnetite recrystallises at a finer size and is overgrown by recrystallised quartz grains causing more difficult liberation. The Northshore Mine in Minnesota lies within the contact aureole of the Duluth Complex. The contact metamorphism has resulted in changes in the mineral assemblages seen across the orebody. There is an increase in mineral grain size toward the Duluth Complex (Figure 2). The increase in magnetite grain size results in better liberating iron ore. Unfortunately, in this instance, better liberation results in decreased concentrate production. This is counter intuitive. The classification circuit is designed to process magnetite with a very narrow size distribution. The coarser, more easily liberated magnetite is recirculated until it is ground to the target size distribution.

Texture

Mineral textures can be modified by regional metamorphism, contact metamorphism and hydrothermal processes. Hydrothermal fluids have played an important part in enriching ores. Hydrothermal textures result from the balance between dissolution of surrounding mineral grains and growth of other grains. When dissolution and grain growth of different minerals is not balanced, one mineral may overgrow another and incorporate it as an inclusion. This can lead to difficult liberation problems. In the footwall of the Tilden Mine, quartz and carbonate minerals have been removed by hydrothermal fluids. At the same time martite grains have been overgrown with haematite (Figure 3a). When haematite grain growth occurs faster than the dissolution of quartz, quartz grains become

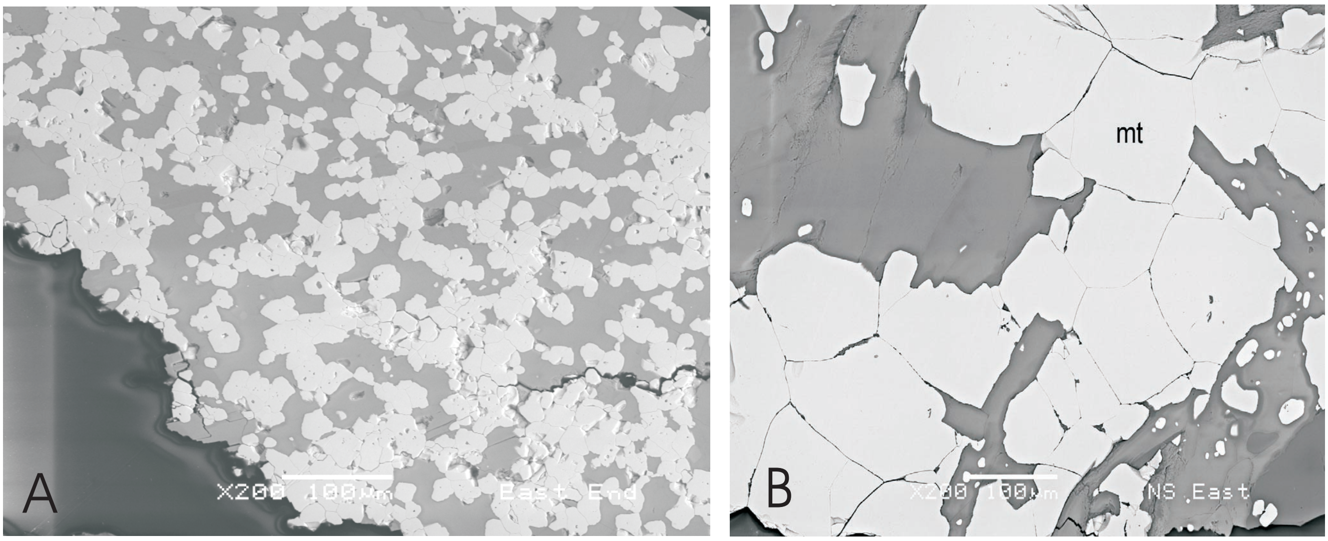

FIG 2 - SEM photomicrograph of (A) typical iron ore with fine-grained (40 - 50 µm) magnetite and (B) contact metamorphosed, mosaic textured, relatively coarse-grained (+100 µm) magnetite (mt) from the Northshore Mine (backscatter, 200X).

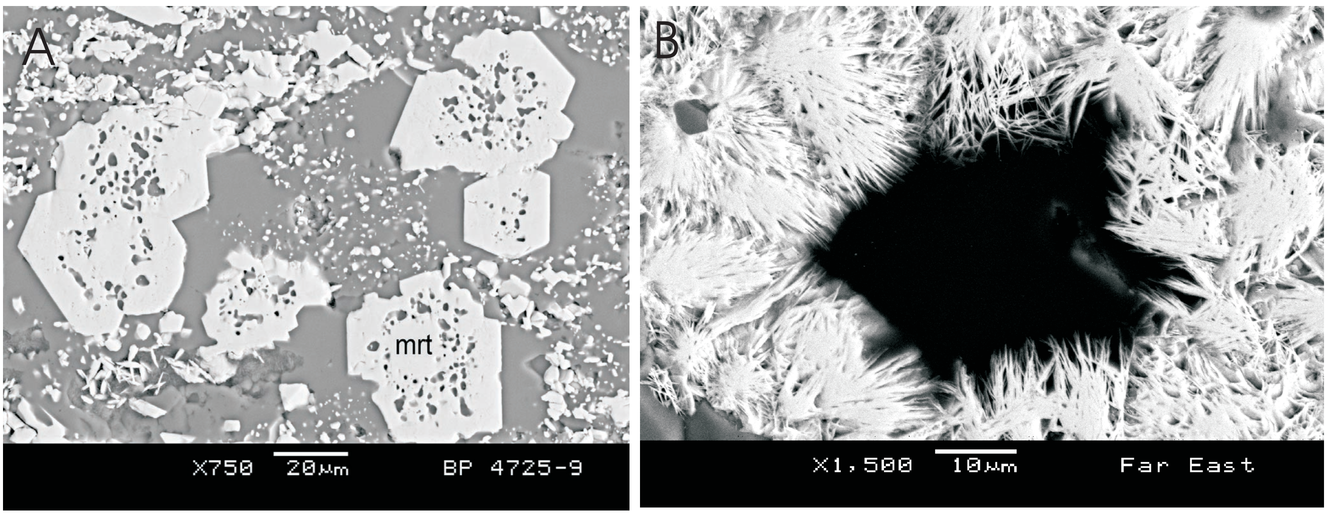

FIG 3 - SEM photomicrographs of (A) martite (mrt) grains from the Tilden Mine with quartz (dark gray) inclusions (backscatter, 750X) and open-space filling microplaty haematite (backscatter, 1500X).

inclusions in the haematite shells of the martite grains. The quartz grains in the haematite grains can be less than 3 µm, preventing practical liberation of the quartz from the haematite. The open spaces created by the dissolution of gangue minerals can also be filled by colloform and microplaty haematite (Figure 3b). Easily liberating microplaty haematite can have negative impact on the flotation process including the generation of slimes.

CONCLUSIONS

The successful application of geometallurgy in the mining of iron ore and the production of iron ore pellets requires that ore characterisation be performed with an understanding of geology, mineralogy, extractive metallurgy, pyrometallurgy and customer requirements. It requires the appropriate tools – X-ray diffraction, optical microscopy and electron microscopy. It also requires open communication between geologists, mineralogists, mining engineers, extractive metallurgists and pyrometallurgists.

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