Placer Heavy Mineral-Sand Deposits, with a Provenance of Basic Rocks: A Potential Source for a Low-Cost, Raw Material of Iron Ore for Steel-Making

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Abstract: Iron ore, in the form of hematite, magnetite, limonite and siderite, is the essential raw material for steel-making. As the grade of mined Fe-ore and its resources are gradually depleted, it is proposed that the placer heavy mineral-sand deposits, having the provenance of basic rocks and notable concentration of Fe-ore minerals such as, at places, in the west and east coasts of India, after due mineral-processing like magnetic separation, pelletization etc., can be a potential, low-cost, additional source of raw material of Fe for steel-making.

Keywords: Heavy mineral-sand deposits, basic provenance, Fe-ores, raw material, steel-making.

Introduction: Raw materials of steel-making comprise essential iron along with coking coal and limestone. As the iron in the form of ore/pellets consists of dominant hematite (69.9% Fe) and lesser magnetite (72.4% Fe), limonite (59.8% Fe) and siderite (48.2% Fe). These minerals never occur alone, with the metal content of real ores is lower [1]. Grade-wise, the iron ore is classified as the benchmark/standard ore (62% Fe), low-grade ore (<59% Fe) and high-grade ore (>63.5% Fe), with the last due to many beneficial features in steel-making carries a higher premium price of US$ 1-2 for every 1% increase in Fe over the standard ore [2]. Globally, around 2.5 billion tonnes of iron ore mined annually and the seaborne market is ~1.45 billion tonnes. Overall, the global market's Fe-grade is going down, since the best available grades from existing mines have been mined. China, with the largest market for iron ore, is also the largest importer of seaborne iron ore with ~1200 million tonnes (Mt), followed by the European Union, Japan and South Korea, each with ~/< 100 Mt, while the largest exporter for seaborne iron ore is Australia with an export of ~ 900 Mt, followed by Brazil (~250 Mt), Ukraine (<50 Mt) and India (<50 Mt) in the year, 2020. Of the global exports of the iron ore by grade, the low-grade ore accounts for 19%, mid-grade ore (59 to 63.5% Fe) 44% and high-grade ore 37%. As the mining-grade and resources of iron ore are going down due to ever increasing demand of steel and alloy & superalloy steel, any additional source of raw material with a low-cost, secured, assured and long-lasting supply-chain, is highly welcome for the steel industry. In this note, such a potential source is proposed in this communication in the form of placer heavy mineral-sand deposits (HMSDs) with a provenance of basic rocks, with a few examples of India's west and east coasts, together with a general account of their mineral-processing for Fe-ores as raw material in steel-making.

HMSDs: The placer HMSDs comprise sand-size (2 mm to 0.063 mm) and finer heavy minerals (HMs with specific gravity of >2.89) and dominant quartz, admixed with finer silt and clay. Generally, the HM composition in the placer mineral-sands depends mainly on the provenance or source-rocks from which HMs are (i) liberated due to weathering, (ii) transported by rivers, tributaries and streams, (iii) deposited along the sea-coast and (iv) concentrated by repeated action of waves, tides, air, etc., resulting in the beach and dune HMSDs. For example, much of the India's east and SW coasts, (i) HMSDs include ilmenite, garnet and sillimanite as major (each of >1 wt. % of raw sand, RS), and zircon, rutile, monazite and magnetite as minor (<1 wt. % of RS) due to their provenance rocks of acid-intermediate granulites (khondalites, charnockites, leptynite and granite gneiss), granitoids and reworked sediments. As compared to (i), (ii) where the provenance of HMSDs comprises basic-ultrabasic rocks like basic charnockites, Deccan traps (basalts), ferruginous laterite etc., the HMs are of ilmenite and more of pyriboles (pyroxenes + amphiboles), magnetite, limonite, and hematite, with the examples of the Ratnagiri and its adjoining areas in Maharashtra coast of the west coast and Nizampatnam of Andhra Pradesh in the east coast of India. As (i) contains the valuable heavy minerals (VHMs), such as ilmenite, rutile, leucoxene, zircon, monazite, garnet, and sillimanite, which contain some of the critical minerals [3], such as Ti, Zr, Hf and light REEs, as compared to that of (ii), the former has been much exploited. The mode of grain-size of HMs is generally varies from 0.125 to <0.063 mm. Economic-grade placer HMSDs occur worldwide and are mainly as the shoreline deposits along the coasts of Australia, Brazil, India, Sri Lanka, Mozambique, Madagascar, SE USA etc.

HMSD along the coast of Maharashtra, west coast of India: Of the 720 line-km coastline of Maharashtra, 20 line-km in the Ratnagiri district has been explored by the Atomic Minerals Directorate of Exploration and Research (AMD), Dept. of Atomic Energy, Govt. of India for the potential of placer heavy mineral-sand. Eight occurrences were identified, viz., Purangad, Gaonkhed, Randapar, Bhatya, Ratnagiri, Kalbadevi, Newre, Malgund and Varvada (north 16°49'-17°15' lat.; east 73°14'-73°20' long.), from the south to north of the west coast of India. The beach and some dune HMSDs of the above, each with a length of a few km and a width of a few hundred meters, are characterized by the (a) provenance mostly consists of Deccan traps (basalt flows, ~65 Ma) with laterite capping; (b) grade of total heavy minerals (THMs) is 25-46 wt. %; (c) mode of heavy minerals (HMs) is 0.074 mm; (d) HMs include mostly ilmenite, limonite and pyriboles, with minor to accessory magnetite, leucoxene, garnet and zircon; and (e)

reserves (in metric tons) in a few potential HM-bearing areas are as under: (i) Kalbadevi (17°02'00" to 17°05'30" N : 73°17'10" to 73°17'18" E): Ilmenite: 152,409, Magnetite: 559; and (ii) Newre (17°03'00" to 17°05'50" N :73°17'20" to 73°18'00´E): Ilmenite/Goethite: 550,478, Magnetite: 22,087 and Limonite: 137,954) [4].

Nizampatnam HMSD, along the east coast of India: The Nizampatnam (north 15º54'30" lat.: east 80º40'00" long.) beach and dune HMSDs, south of the River Krishna in the Guntur district, Andhra Pradesh, extends over a coastal length of ~25 km with a width of 600 to 900 m. It is characterized by the (a) provenance that comprises dominant basic charnockites and lesser khondalites and granite gneisses; (b) grade of THM is ~ 16 wt. %; (c) mode of HMs is 0.074-0.063 mm; (d) HMs include mostly ilmenite, pyriboles and magnetite, with accessory zircon, monazite, sillimanite, garnet and rutile; and (e) HMs reserves, up to a maximum depth of 12m, are a few tens of Mt, with grade and tonnage of major heavy minerals are as follows: ilmenite: grade of 41.43% of THM and resource of 20 Mt; pyriboles: 35% of THM and 17 Mt, and magnetite: 16.5% of THM and 8 Mt [5] and [6].

Mineral processing of Fe-ores from HMSDs: The Fe-ores of magnetite, ilmenite, and limonite, present in the HMSDs with a provenance of basic rocks, as shown in the above examples, due to their magnetic susceptibility, can be separated, concentrated, and purified by low-intensity and high-intensity wet/dry magnetic separators during the processing of HM-sand. As magnetite and limonite in HMSDs are in the fine-grain size (<0.1 mm), these fines either directly or better after making pellets, may be used as raw material in steel-making. In the case of ilmenite ($FeO.TiO_2$ with ~35 to 55% FeO) from the HMSDs, it is earlier proposed that the by-product Fe, generated during the processing of ilmenite to high-value TiO_2-enriched products, such as synthetic rutile/anatase, Ti-dioxide pigment, Ti-sponge, and Ti metal all of which have major applications in the industries aerospace, defence, pigments, alloys, welding electrodes etc, can be used as a raw material for steel-making [7]. It may be added that due to variation of the characteristics of HMSDs like grain-size of raw-sand, size-mode-composition of HMs and gangue etc., an optimum flow-sheet for obtaining Fe-ores from mineral-sands should be established, after laboratory and pilot-plant scale of mineral processing.

Advantages of Fe-ores from HMSDs: The above proposed Fe-ores, viz., magnetite, limonite, and Fe-generated from the processing of ilmenite to high-Ti products from HMSDs have the following advantages: (i) cheaper, (ii) less-expensive due to low-cost, open-pit mining of placers, (iii) separation of HMs from gangue in mineral sands by efficient mineral processing techniques such as gravity and magnetic separations, and (iv) resources of the mineral-sand being abundant, the supply chain will be long lasting, assured and secured. In view of these, the proposed placer heavy mineral-sand deposits, with a provenance of basic rocks, is a potential source for a low-cost, raw material of iron ore for steel-making, which will be a win-win case for both the industries of steel and mineral sands.

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