Beach Placer Deposits of India, their Distribution, Mineralogy and Sustainable-Mining with Reference to Placer Ilmenite

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Abstract: ***The placer mineral deposits along the east coast of India are known for the economic concentration of ilmenite, garnet, sillimanite, zircon, monazite, etc. Out of thismineral the ilmenite is most abundant followed by garnet and sillimanite. These resources are distributed in beach and dune environment of east coast. Some of the most important deposits in Andhra Pradesh and Odisha include Kakinada, Bhimunipatnam, Srikakulam, Bhavanapadu, and Chatrapur. etc. These deposits are explored and ore resources have been estimated by atomic minerals division department of Atomic energy, government of India. These deposits are identified along the East and West coasts of India and the total heavy mineral content (THM) of these placers ranges from 12% to 15% by weight. Out of these total heavy mineral content Ilmenite forms almost 40% of the THM. However, the abundance of other minerals varies from deposit to deposit. The details pertaining to mineralogy, industrial uses and production figures of placers in general and ilmenite in particular, compared to other countries have been presented.The scenario of placer ilmenite at world level compared to Indian potential has been reviewed. An attempt is made to present the possible environmental impacts to be considered on the sensitive coastal ecosystem, before initiating mining and processing of these placer sand deposits.It is suggested thatenvironmentally friendly methods of mining and processing may be insisted to reduce the impact on the environment***

Keywords: Placers, ilmenite, mineralogy, environmental impact, beach, resources, THM, Sustainable mining

1. Introduction

The costal land forms of east and west coasts of the Nation contain significantly important placer mineral deposits. The minerals like ilmenite, rutile, garnet, zircon, monazite and sillimanite are occurring in these deposits. The controls like source rock geology, coastal geomorphology effective drainage network and favorable climatic conditions favored the formation of rich placer deposits in coastal environments.

Important deposits occur in the coastal environments of Kerala (Chavara), Tamil Nadu (Manavalakurichi, Midalam, Vayakallur), Andhra Pradesh (Kakinada, Pentakota, Bhimunipatnam, Konada – Kandivalasa – Mukumpeta – Bendi creek – Donkar), (Sanaekasangi – Gopalpur, Chatrapur, Bajarkot, Satpara and Puri) and Maharastra (Kalbadevi, Newre and Malgund).

In recent years the importance of titanium in modern technology has been realized. Technological development is aimed at strategic and economic applications which are mostly dependent on titanium, zirconium and rare earths, in the form of their metals / compounds or alloys. The placer deposits are the treasure houses for ilmenite, rutile, leucoxene – all titanium minerals, zircon – ore for zirconium and hafnium, monazite – source for cerium and other light rare earths, garnet – the most preferred abrasive and sillimanite – an excellent refractory mineral. These economic importance have prompted beach sand exploration and exploitation in this country

Titanium

The element titanium in the periodic table has the symbol Ti and atomic number 22. Physically it is light, strong, lustrous, corrosion-resistant (including resistance to sea water and chlorine) transition metal with a white-silvery-metallic color. It has applications in strong lightweight alloys (most notably with iron and aluminum) and its most common compound, titanium dioxide, is used in white pigments. Examples include white pigment, consisting of titanium oxide is used, is tippex and commonly used white paint to repaint walls. Substances containing titanium are called titaniferous. Titanium occurs in numerous minerals with the main sources being rutile and ilmenite, which are widely occurring on Earth. There are two allotropic forms and five naturally occurring isotopes of this element; Ti-46 through Ti-50 with Ti-48 being the most abundant (73.8%). One of titanium's most notable characteristics is that it is as strong as steel but is only 60% its weight. Titanium's properties are chemically and physically similar to zirconium.

These placers deposits are formed by the interactonof the terrestrial processeswith the coastalhydro-dynamics.The heavy minerals along with sediments which are derived mechanically from source rocksare contributed to the sea by various processes transportation are selectively panned and sortedand then deposited at suitable locations, by the action of waves and currents.The factors controlling the formation of beach placers are source rocks, geomorphology of the area, climate, drainage pattern, coastal processes, neotectonics etc.The heavy minerals are concentrated by a combination of these processes in the upper part of the beach,wherethe action of the wind mayerode them andformheavy mineralrich coastal dune deposits (Kudrass,2000). The formation of beach placers has been shown (Fig-1). Indiahassome of thelargest placer deposits along its coasts.

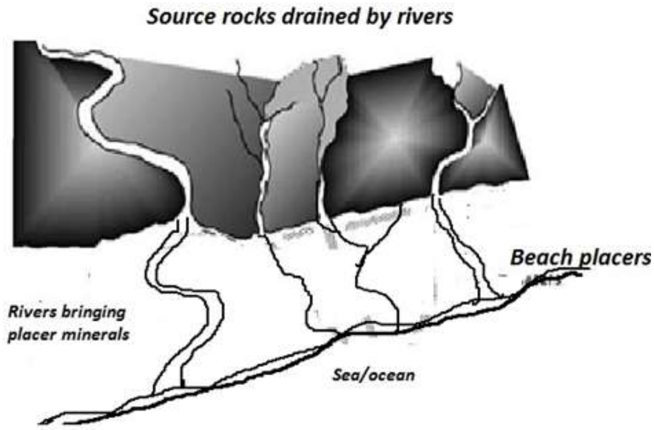

Figure 1: Formation of Placer Ilmenite

Indian Placer deposits

Important deposits occur in the coastal environments of Kerala (Chavara), Tamil Nadu (Manavalakurichi, Midalam, Vayakallur), Andhra Pradesh (Kakinada, Pentakota, Bhimunipatnam, Konada – Kandivalasa – Mukumpeta – Bendi creek – Donkar), Orissa (Sanaekasangi – Gopalpur, Chatrapur, Bajarkot, Satpara and Puri) and Maharastra (Kalbadevi, Newre and Malgund). In Indian context the deposits are of variable grade (10-16%) ofTHM. The economic minerals commonly occur include ilmenite, rutile, leucoxene, zircon, monazite, garnet and sillimanite. The abundance percentage and reserves of heavy mineral pockets differ from deposit to deposit. Most important deposits of the country are Rushikulya, Chatrapur and Gopalpur in the state of Orissa; Bhavanapadu, Kalingapatnam, Srikurmam, Bhimunipatnam, Kakinada and Nizampatnam deposits in the state of Andhra Pradesh; The deposits in Tamil Nadu are Kudiraimozhi, Ovari and Manavalakurichi In Kerala; Chavara and Ratnagiri in Maharashtra. Nearly 40-55% of the global ilmenite recovery is from coastal deposits. India is in the top five countries having huge deposits of ilmenite. The detailed exploration programs conducted by AMD has resulted huge deposits of placer minerals on both East and West coasts (Fig-2)

Figure 2: Beach placer deposits of India

2. Previous Studies

Mahadevan and Sriramdas (1948) reported the black sand concentration along the Visakhapatnam-Bhimunipatnam coast, Andhra Pradesh for the first time. The other studies include Viswanathan (1957), gave an account of the beach sand placer deposits of Neendakara-Kayamkulam in Kollam district, Kerala and Manavalakurichi in Kanyakumari district, Tamil Nadu.The occurrence of monazite-bearing black sands along the southern and southwestern coast of India was discovered by Schomberg, a German. Rao (1973, 1976, 1977) presented data on heavy mineral reserves of beach placers of Neendakara-Kayamkulam, Kerala, Manavalakurchi, Tamil Nadu and Chatrapur, Orissa . Rao et al. (1989) investigated the occurrences of placer minerals along the southern parts of Andhra coast between Ramayyapatnam (Nellore) and Vashista Godavari (Kakinada). Ali et al. (1989, 1998) researched the placer deposits of Ratnagiri district, Maharashtra and broughtout the influence of geology, geomorphology and the Late Quaternary sea level oscillations in the derivation of inland and beach placer deposits of India. Rao et al. (1990) gave a comprehensive account of the heavy mineral concentration and reserves of deposits between Lawson's Bay and Bhimunipatnam-Konada (north of Visakhapatnam), Andhra Pradesh. Banerjee et al. (1996) discussed the role of placer minerals in the economy of India. Roy et al. (1998); Panda et al. (1998); Vishwanathan et al. (1998); Rao et al. (1998) and Murthy et al. (1998) presented the textural data, evolution of the coast and heavy mineral association in the sand deposits of Andhra Pradesh and Tamil Nadu. Exploration carried out by Atomic Minerals Directorate for Exploration and Research (AMD) during the past five decades has resulted in identifying placer deposits along the coastal stretches of Maharashtra, Kerala, Tamil Nadu (including inland placers), Andhra Pradesh and Orissa. Jagannadha Rao et.al.,(2005), recorded based on the geochemical and ore mineralogical aspects, ilmenite of Visakhapatnam – Bhimunipatnam placer sand deposit, Andhra Pradesh has less TiO_2 and more total iron contents, as compared to its stoichiometric composition, the hematite phase in ilmenite incorporate excess iron in the structure of ilmenite.

Economic significance of placer titanium minerals

Ilmenite is the most abundant titanium mineral, with the chemical formula $FeO.TiO_2$. When ilmenite is partially oxidized (in nature), and partly leached, the proportion of iron oxide in it goes down, while that of TiO_2 goes up. This altered ilmenite, known generally as leucoxene contains variable amounts of TiO_2. Rutile, a naturally occurring crystalline variety of is normally less abundant, but most sought after. The main source of ilmenite, rutile and leucoxene are the sand type placer deposits occurring at or near sea coasts. Ilmenite also occurs in massive rock formation in the form of titaniferous iron ores, associated with hematite and magnetite. A different allotropic form of rutile, known as anatase, is also reported in large amounts in Brazil. Perovskite is another titanium mineral, with the chemical formula $CaO .TiO_2$, offers good promise as potential source for titanium in future. The major titanium producing countries in the world are Australia, Canada, South Africa, Norway, U.S.S.R., Malaysia, India, Finland, China and SriLanka (Lynd, 1985). The World's major titanium reserves are shown in table 1.1 (World Mining Annual, 1988) along with the ilmenite production capacity per annum of different countries.

The major use of rutile and ilmenite is in the production of titanium dioxide pigment, for surface and paper coatings and in plastic industries. Rutile is also used in welding rod flux coating. Titanium carbide is used in commercial cutting tools. Titanium metal and its alloys are used in aerospace applications, gas turbines etc.

In placer type deposits, ilmenite, rutile and leucoxene occur normally along with other valuable minerals such as zircon, monazite, garnet and sillimanite. All these constitute the heavy minerals, the amount of which is quite variable from deposit to deposit. Quartz and shells form the major gangue. Mining of these deposits is usually done by dredging, shovelling or drag-lining. These minerals occur in relatively coarse size and in fully liberated form, hence no size reduction is needed, unlike in the processing of other ores. Pre-concentration is usually carried out at the mining site itself, in order to reduce the bulk to be treated in the subsequent separation stages. Gravity separation using spirals and/or Reichert cones is invariably preferred all over the world for pre-concentration.

Field distribution

The placer sands containing ilmenite mainly confined to beach and dunal environments of the coast. The minerals in the placer sands which are also called heavy minerals exhibit different features like massive concentrations, density, stratification, wind ripples, water ripples…etc. these features are very characteristic of placer sand deposits of east coast of India (**Fig 3**).

Figure 3: Ripple marks and Density stratification in Placer sand deposits

Mineralogy

Quartz: Quartz is the only light mineral, while all the other minerals come under heavy mineral group. This mineral occurs in highest amounts among the minerals in all the sediments. The quartz from the beach sands is generally rounded. The quartz grains from the dune sands are generally angular and also have sharp edges. The grains from both the beach sands and dune sands are generally fresh. Red sediments consist of quartz grains of both angular and rounded variety, grains with fresh nature and grains coated with iron oxide are also common. Some quartz grains of red sediments contain inclusions of kyanite and sillimanite.

Garnet: The garnets are granular, pink and reddish in colour, in fine fractions, they are in light colour, and pitted nature is well exhibited in coarse grains. Various types of inclusions were observed, especially in grains which are coarse and reddish in colour. The inclusions are generally sillimanite, kyanite and spots of iron oxide. Grains showing 'garnet in garnet' were also observed. The pinkish varieties are abundant in beach sands. The grains of garnet in red sediments are found to occur in highly altered state and perhaps they were largely contributed to the 'red colour' of the red sediments.

Sillimanite: Sillimanite is found as slender prisms or fibers or needles and sometimes rounded in shape. The elongated needles of sillimanite are in some cases slightly bent. The mineral is colourless, shows very high refractive index and higher order zonal polarization colours. The sillimanite is abundant in red sediments compared to that of beach and dune sands.

Rutile: Rutile grains with amber and red colour are found to be present. Long crystals of rutile are seen in some samples. The colour of this mineral is generally varying from red to reddish brown. Inclusions of opaques and iron oxide coatings are often present. It has a very high refractive index. The coloured grains are weakly pleochroic from reddish brown to brown.

Zircon: The zircon is perfect and rounded. The grains are commonly prismatic with pyramidal terminations. Some grains are well rounded and are seen along with euhedral grains. The colour varies from colourless to light brown. The perfect crystal forms are generally coloured. The zones are numerous, thin and closely packed. The zones are alternately clear to turbid in appearance. Zoned crystals are generally larger than other zircons. Sometimes rutile grains were observed as inclusions in zircon.

Monazite: The monazite grains are generally well rounded, squared and angular grains were also observed, these grains are with dark borders because of their very high refractive index. The grains are usually yellow in colour but some grains of light colour and brown colour were also observed. Generally the grains are clear and transparent. Rarely they are translucent and contain dust like inclusions.

Kyanite: Irregular and sharply angular grains of light blue kyanite are observed. Pleochroism is weak. Refractive index is high. The grains are more in number in red sediments when compared to beach and dune sands.

Others: The minerals like hypersthene, hornblende, epidote etc. which are rare and uncommon are grouped as others; They occur in minor amounts in beach and dune sands and almost absent in red sediments. Hypersthene occurs as prismatic grains with irregular terminations. These grains are usually brownish green in colour and show pleochroism.

Grains of prismatic hornblende occur in small amounts. They are green in colour. Pleochroism is from pale green to dark green. Prismatic cleavages are seen. Small amounts of epidote grains with rounded and greenish in appearance were also observed.

The opaque heavy minerals are ilmenite and magnetite. The non-opaque heavy minerals are represented largely by garnet, sillimanite, zircon, rutile, monazite and minerals like hypersthene and hornblende in smaller amounts. The lone mineral in the light mineral group is quartz. The distribution of the minerals in various size groups are mentioned below for each type of sediment.

Ore Mineralogy of Placer Ilmenite: In almost all placer deposits of India, the total heavy mineral content (THM) varies between 12% by weight to up to 15% by weight, in this almost 50% as composed by ilmenite content. The ilmenite appears to occur mainly fine to very fine fractions of beach sand (from +120 ASTM mesh size to +230 ASTM mesh size 125 microns to 63 microns) respectively. When observed under the binocular microscope,themajority of ilmenite grains is well rounded and reflecting black in color (Fig-4). The reflected light microscopy of ilmenite indicate excellent exsolved phases which strongly suggest that their derivation from igneous parentage.

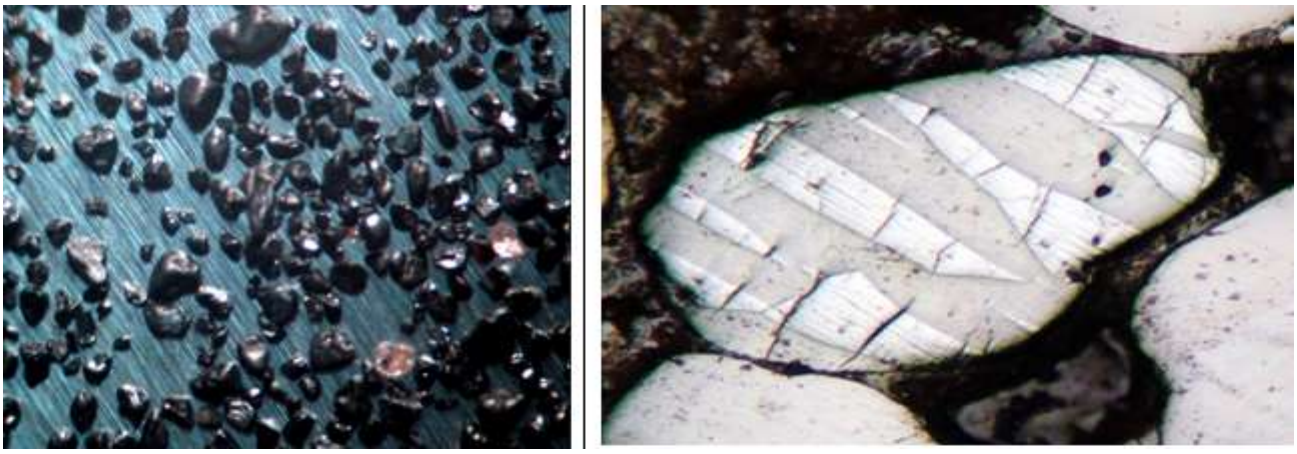

Figure 4: Ilmenite grains under binocular microscope and grain showing exolved phases under reflected light

Resources

The average grade of total heavy minerals in these deposits is 10-25% of which 30-35% is ilmenite. The overall statewide reserves of ilmenite and rutile which occur together in beach sand deposits are furnished in Table -2.

Table 1: Proved Ilmenite Resources/Deposits in India

State/Deposit	Ilmenite reserves in (million tonnes)
Andhra Pradesh	
1. BhavanapaduHukumpeta	10.18
2. Kakinada (Phase I-VIII)	13.84
3. Kalingapatnam	5.80
4. Narsapur	2.92
5. Nizampatnam	19.26
6. Srikumama (South)	8.60

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7. Visakhapatnam (Bhimunipatnam)	2.88
8. Amalapuram (Phase I-III)	3.10
9. Pandurangapuram-Voderevu (Baptala-Chirala Coast)	10.39
10. Vetapalem Coast (Chirala Coast)	5.31
	82.28
Kerala	
1. Chavara Barrier beach	13.17
2. Chavara Eastern Extension (Phase-1)	17.02
3. Chavara Eastern Extension (Phase-II)	49.26
4. Trikkunnapuzha-Thotapally Beach and eastern Extension	9.50
5. Alapuzha-Kochi	5.88
	94.83
Maharashtra	
1. Ratnagiri	3.68
Gujarat	
1. Moti Daman-Umbrat coast	2.77
Odisha	
1. Brahmagiri (Phase-IV)	37.98
2. Chatrapur	26.72
3. Gopalpur (Phase I-IV)	6.39
	71.09
Tamilnadu	
1. Kudiraimozhi	22.86
2. Ovari-Periyatalai-Manapadu (Teri)	24.01
3. SattankulamTeris	41.26
4. Cuddalore-Pudupattuchavadi	4.67
5. Vayakallur (Block I-IV)	3.54
6. Manavalakurichi	2.04
7. Midalam	1.64
	100.02

(Source: Indian Minerals Yearbook (2015). Part-III (Mineral reviews), 54th edition, Ilmenite and Rutile, Government of India, Ministry of mines, Indian bureau of mines, Nagpur)

Table 2: Total Resources of Ilmenite (In Million Tonness)

State	Total Insitu	State	Total Insitu
AP	163.05	Maharastra	3.74
Jhrakhand and Bihar	0.73	Odhisa	96.44
Gujarat	2.77	Tamil Nadu	179.02
Kerala	145.70	West Bengal	2.05
		Total	**593.50**

(Source: Indian Minerals Yearbook (2015). Part-III (Mineral reviews), 54th edition, Ilmenite and Rutile, Government of India, Ministry of mines, Indian bureau of mines, Nagpur)

Mining and Processing

The most common mining methods employed to treat low-grade placer deposits are bulldozing, loosening with hydraulic jets and slurry pumping, draggling, bucket wheel excavating and suction dredging is most favored in view of the simplicity of operation and low unit cost. An artificial pond is crated in the mining area and the dredging and pre-concentrator units are mounted on pontoons and anchored in the mining pond. The mining is done by dredging arm moving from the base unit and the mined ore slurry is transported to the pre-concentrator plant by horses. The rejected gangue, consisting mainly of quartz is pumped to the rear side of the mining pond (dredging area) in order to reclaim the already dredged as mining progresses, the pond also advances in the mining direction. Periodically the dredging cum pre-concentrator units are moved to a different location for easy operation (Fig-5). At Manavalakurichi and OSCOM, mechanized mining by suction dredging is followed at and Chavara, the beach washings are mined by dry mining methods, where in the sand, after drying by furrowing, is mined and transported to mineral recovery plant (MRP) by country boats or tipping wagons. However, the mechanized mining is also in operation at Chavara using suction dredging. The present mining/concentration practice in the three plants. The pre-concentrate from the pre-concentrator is transported to the concentrate up gradation plant (CUP) for further concentration before transport to mineral separation plant (MSP). When the distance between water and dry mills is not much, the CUP, belt conveyors or slurry pumping to MSP transport concentrate. (MC Donald 1969, Palmer 1994).

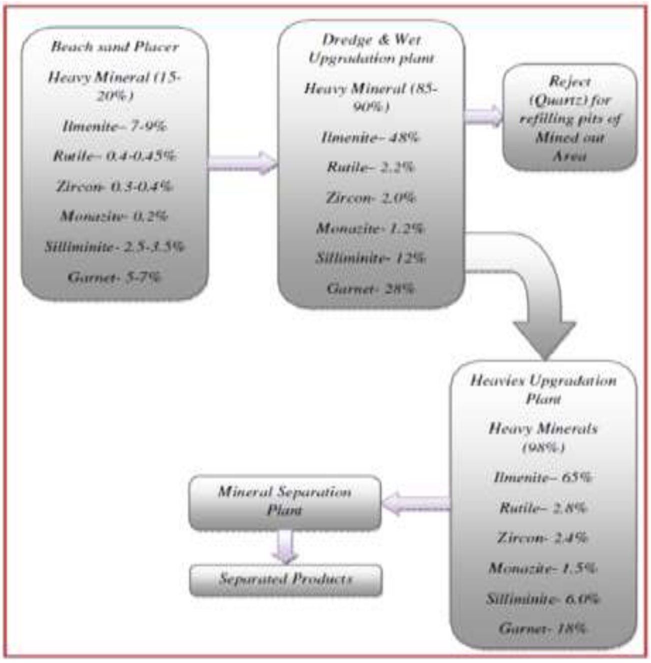

Figure 5: Processing Flow Sheet at OSCOM

As mentioned above mining and processing of the placer sands are being practiced at different deposits. Considering the potential of placer sand occurrences all along the coastal tracts of India, a suitable and scientific basis should be adopted for initiating a successful and environmentally friendly mining and processing of new deposits.

Sustainable Mining

It is well established that a set of remedial measures to minimize the environmental impact due to activities like mining etc. are in place. The primary environmental impact due to dredging will be mainly in the coastal environment, especially affects the littoral zone habitat. (Fig-6)

Figure 6: Impact of Placer Mining on Littoral Zone

In recent times the concept of "Environmental Windows" is introduced to minimize the environmental impact especially due to operations like dredging. This concept is based on the fact that the sensitive biological resources, and their habitats may be protected from potentially detrimental effects by way of conducting the operations in selective months of the year to avoid the month in which these biological resources are some sensitive to disturbance.

In addition, the following minimizing techniques can be adopted.

- Imposition of dredging performance standards to meet environmental conditions and design controls.
- Monitoring and observance of water quality conditions and standards.
- Selection of dredging equipment to minimize impact, such as the use of environmental buckets, where appropriate, to trap contaminated sediments.
- Use of silt curtains where appropriate.
- Monitoring of blasting operations to control impacts to adjacent structures of historic significance.
- Coordination of all dredging activities with the Coast Guard and other organizations.
- The equirement for the dredging contractor or the organization to file and follow a contingent plan to cover the spills and accidents.

Similar steps can be taken to replenish the dredged material back to the original place. While doing so the following mitigation measures can be initiated towards beach nourishment, habitat creation and shoreline protection.

- Habitat development, including wetlands, up-land, island, aquatic
- Beaches and beach nourishment.
- Aqua Culture.
- Parks and Recreation.
- Agriculture, horticulture and forestry.
- Strip mine reclamation and solid waste landfill.
- Multi purpose uses and other land-use concepts.
- Construction and industrial/commercial uses

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