



India is blessed with a long coastline of more than 7500 km, including islands. The erosion of rocks results in coastal placer minerals, which find many applications.

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Coastal Placer Minerals

READERS of *Phantom (The Ghost Who Walks)* comics would know about the time when Phantom (Mr. Walker) takes his wife Diana Palmer to his private beach Keela-Wee for the honeymoon. They swim in the sea, roll in the sand rich in gold particles, enter into the ancient House of Jade and once this rite is finished they are wed.

Perhaps Lee Falk, who in 1936 created the comics, must have had in mind coastal or placer deposits of gold! The word 'placer,' derived from the Spanish word 'placea,' refers to an alluvial or glacial deposit of sand or gravel. Placers occur in a variety of sites: along the coasts, on raised and submerged beaches, buried and exposed river valleys and in deserts.

Placer or heavy (due to high specific gravity) minerals form by mechanical concentration and natural gravity separation of mineral particles derived from weathered rocks. The formation of placers requires factors such as: climate, source rock, weathering, transport, deposition, concentration, high specific gravity (>2.88) of minerals and their resistance to chemical and mechanical attacks.

Climate: The Earth has different climatic zones: tropical, dry, moderate, continental and polar. In these areas there would be distinct and variable weathering, erosion and transport of the rocks. For example, in cold and glaciated regions, there would be limited physical weathering and less concentration and more dispersion of the weathered material and placers would not

form. In contrast, in cold, non-glaciated areas low-grade placers can occur.

In regions of humid temperature, the rocks would be less altered and low-grade placers could form. Arid to semi-arid areas would be affected by fluvial activity and this could result in moderate placers. The most suitable areas are those affected by humid tropical climate where chemical weathering occurs and results in high-grade placer minerals.

Source Rocks: The source rocks could be igneous, sedimentary, metamorphic or a mixture. These rocks have unique mineral assemblages that contribute to the placer minerals. For example, the acidic or silicic rocks like granites and rhyolites have monazite, tourmaline, and zircon while basic or mafic rocks like gabbros and basalts contain ilmenite, magnetite,



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rutile etc. in appreciable quantities. Metamorphic rocks such as schists and gneisses host garnet, tourmaline, magnetite etc., and hydrothermally formed rocks would contain cassiterite (tin), pyrite (iron sulphide), wolframite (tungsten), gold, and platinum amongst others.

Erosion & Weathering: Through a natural process of weathering, dissolution, abrasion and transport the surface of the Earth is worn. The weathered material is removed from the source and deposited in a favourable site.

Biological weathering occurs when the roots of plants and trees, growing between outcrops or in the cracks of rocks, widen and fragment the rock

Weathering causes breakdown of the rocks and is brought about by physical, chemical and biological processes. Some ways of physical weathering are the constant action of wind and water on rocks because of which the rocks are broken down to fragments. In case of chemical weathering the rock's composition would change e.g., the conversion of basalt that has several elemental oxides to laterite, which has predominantly iron oxides.

Biological weathering occurs when the roots of plants and trees, growing between outcrops or in the cracks of rocks, widen and fragment the rock. Such features can be seen along roadsides or from the plants that grow in crevices of a building. Weathering could result in spalling of the outcrops and formation of spheroidal structures.

During weathering the minerals would be variably affected due to their resistance and composition e.g., olivine and calcic plagioclase weathers first while quartz remains unaltered.

Transport: The weathered material would be transported by natural agents such as water, wind and glaciers. Humans to a large extent (e.g., by quarrying and mining) and animals and birds (small grains of sediments stuck to their body) also transport the eroded material. But these methods of transport are insignificant as compared to the natural ones, which can transport huge amounts of eroded material of different sizes to far distances.

Water is the most effective and powerful medium of transport, mainly in humid tropical places. Rainfall results in streams and rivers that flow from mountains and hills. During the course of travel a river has three stages: youth, mature and old age. At each stage the quantum of material transported and the intensity of the water flow are remarkable. During the youthful stage

(source) the river is highly energetic and cuts through the hills and mountains and carries boulders and cobbles.

The abrasion of the rocks results in coarse to medium size sands, which are transported during the mature stage of the river when its energy level is lower. Continuous abrasion and rolling of the particles would form fine size sands that are transported and deposited at the mouth of the river. When the water velocity drops or if the materials are of high density then deposition occurs at the upper reaches or knick points of a river. If the transportation continues then the sediments are deposited along and beyond the shoreline and even into the sea.

Wind transports smaller particles especially in arid regions and in areas of high velocity wind. Minerals that are lighter (quartz) or flaky (mica) would be carried farther than a heavier one (ilmenite, garnet). Although this process is insignificant, a huge amount of sand can be moved in no time across vast distances. As the velocity of the sediment-laden wind drops, sand deposition occurs resulting in dunes in deserts and along the coasts.

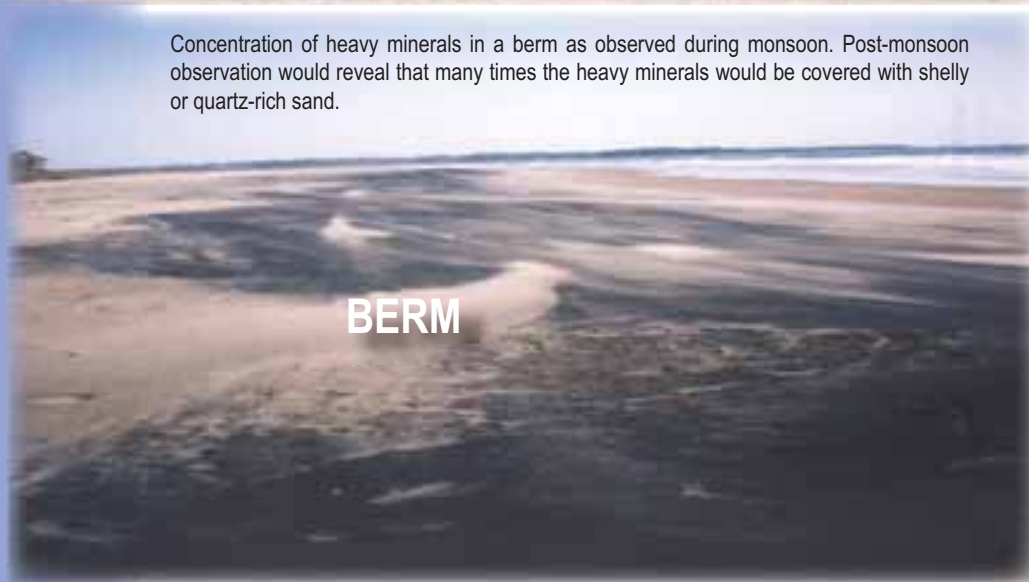
Dunes can be of different shapes and dimensions and host heavy minerals. Erosion of the coastal dunes would lead to effective sorting of the particles from the near- to the off-shore regions.

Transport of eroded materials by glaciers occurs in high latitude and snow bound regions. As a glacier creeps and moves it carries the rocks and sediments lying in its path and deposit them elsewhere to form moraines. In the event the glacier melts enroute then the rocks that are carried would be left behind and these are called as 'erratics' since such transported rocks differ from the locally present ones. These moraines and erratics sometimes get re-worked through the fluvial systems during summer when



Selective sorting has resulted in two distinct sediments. In the foreshore is white shelly, quartz-rich sand while in the background is berm with heavy minerals.

Selective Sorting



Concentration of heavy minerals in a berm as observed during monsoon. Post-monsoon observation would reveal that many times the heavy minerals would be covered with shelly or quartz-rich sand.

the ice melts and form placers of heavy minerals such as gold and platinum.

Deposition: The weathered and transported materials would be deposited in different locales. The parameters that influence deposition, amongst others, are: a reduction in the velocity of the transporting medium, characteristics of the materials (size, shape, morphology, density, composition etc.), physiography of the area (lakes, rivers, ponds, valleys, beaches, continental shelf, deep sea etc.), natural and man-made obstacles (hills, cliffs, dykes, groins, jetties, breakwaters, etc.) and anthropogenic (mining, quarrying) reasons.

The deposition of sands along the coast would be controlled by winnowing action wherein the incoming (swash) waves would move the sands inshore

while the outgoing (backwash) ones would carry the lighter minerals offshore. The sediments would finally move into the seas and oceans that form the depots, even if the process takes thousands and millions of years.

Concentration: The concentration and thickness of heavy mineral sands depend on factors such as the coastal geomorphology (shape, slope, sand texture, presence of promontories, etc.), velocity and direction of wind and waves, seasonal changes along the coast, and the distance between the debouching rivers and the coast.

In due course some minerals would be concentrated in a favourable place. Extensive field observations, intensive laboratory work and resource evaluation could then indicate whether the minerals

Transport of eroded materials by glaciers occurs in high latitude and snow bound regions.

can be exploited economically for use. If so, then the requisite permissions and licenses need to be obtained to mine the sands from the government. The sands can either be used within the country or exported.

Similarly, placers could be mined for tin, ilmenite, zircon, monazite, gemstones (e.g., diamond, ruby) etc. The type of deposits mainly depends on the source rocks together with other factors.

The 5 Es

An investigation of placer minerals would involve the 5Es i.e., exploration, environment, exploitation, enrichment and economics. There are many ways to explore for placer minerals such as by using satellite and aerial photographs for rapid assessment. But ground field work is most important and commences with a reconnaissance survey to identify, collect samples and observe the coastal features.

After data and sample analyses the potential area is demarcated for detailed surveys (geological and geophysical) and bulk sample recovery. The area is studied for environmental impact assessment and environmental monitoring and planning for which there would be collaboration between geologists, chemists, biologists and coastal and environmental engineers.

To exploit the minerals mandatory permissions from the various governmental and local bodies are needed to obtain a prospecting mining license. One of the simplest ways to recover the placer sand is by manual scooping but sophisticated machines are also used.

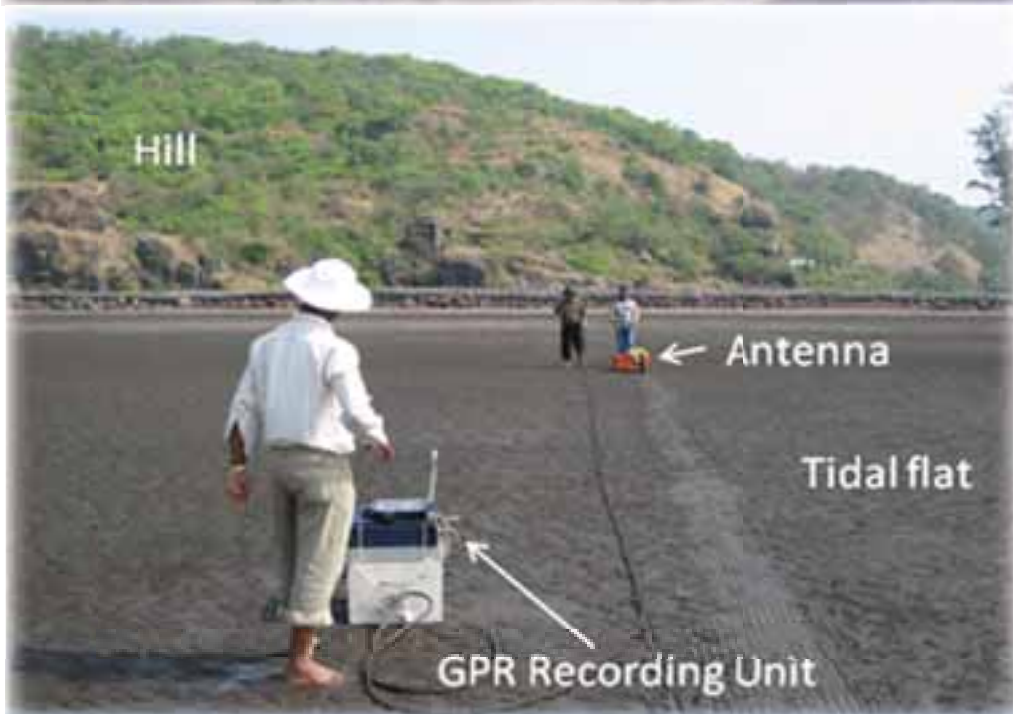
Enrichment involves separation of the required placer minerals from the sands through simple flotation/sinking, magnetic separation and other routes that are carried out on an industrial scale. Once the mineral of interest has been separated it needs to be processed and purified to extract the metal either by sulphate or chloride route.

The economical aspects of placer mining would involve the cost to benefit ratio, which would encompass the money



Typical layering of light (quartz) and heavy (ilmenite/magnetite) minerals as noticed in a 1 m depth pit.

As a glacier creeps and moves it carries the rocks and sediments lying in its path and deposit them elsewhere to form moraines.



A ground-penetrating radar (GPR) surveying along tracks across a tidal flat. A GPR consists of an antenna to send electrical signals that penetrate the sand layers, a measuring wheel to record the distance covered and a laptop to store and analyse the collected subsurface sediment information.

Coastal Minerals of India

Heavy minerals are found in mineable quantities in India, Australia, USA, Canada, South Africa, Sri Lanka, Brazil, Norway and Malaysia. India is blessed with a long coastline of more than 7500 km, including islands. The erosion of rocks results in coastal placers such as rutile, ilmenite, zircon, monazite, garnet and sillimanite in various sites such as beaches, dunes and berms.

The first four minerals are termed as 'prescribed' or 'atomic' minerals. Explorations for coastal placers have been undertaken but the promising areas are in parts of Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh and Orissa.

In 1909, Schomberg (German) discovered monazite deposits of Travancore (Kerala) and this was later exported. Subsequently, ilmenite was exported in 1922 and for more than a decade India was the main global supplier of ilmenite. In 1950, the Department of Atomic Energy established the Indian Rare Earths Limited (IREL), a public sector undertaking at Alwaye, Kochi (Kerala).

Mining and separation of heavy minerals commenced in 1965 at Chavara (Kerala) and Manavalakurichi (Tamil Nadu). The IREL started production after renovating the mineral separation plants that belonged previously to the Travancore Minerals Ltd. and was jointly owned by the central and state governments of Kerala and TN. In 1986, the IREL commissioned the synthetic plant at Chatrapur (Odisha).

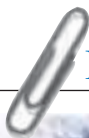
In 1986 a large plant (OSCOM) was set up at Odisha. At the IREL beach sands are concentrated and separated into six minerals – ilmenite, rutile, zircon, monazite, garnet and sillimanite. As compared to other countries, the ratio of production (0.36 mt) to reserve (278 mt,

and efforts spent and the market value of the metal or mineral at the national and international levels. Interestingly, though gold is the most sought metal and the prices per gram keep rising, there are others that are much more costly such as diamond and rare earth metals.

Uses of Heavy Minerals

Although the garnet group has six minerals, only almandine variety is most suited in industries such as water filtration, grinding and lapping (ceramics, optical lenses, metals), abrasive blasting and water jet cutting for granites, marbles, aero space composites etc.

Sillimanite (Al_2SiO_5) and zircon ($ZrSiO_4$) are extensively used in the manufacture of refractory bricks; also zircon is used to produce zirconia and zirconium chemicals, in ceramics, production of American diamonds, TV glass, power reactors etc. Titanium (being non-toxic, non-corrosive, high strength and light) from ilmenite is used in pigments, sponge metal, aircrafts, implants in human body, tennis racquets, racing cycles etc while rutile is used in the electrode industry. Monazite is a source for thorium that is used in nuclear reactors and for rare earth elements that are used in batteries, magnets and glass polishing.



A GPR survey being conducted over a dune cut. Note the garnet-rich sand (brown) alternating with Ilmenite-rich sand (black).

The Earth has different climatic zones: tropical, dry, moderate, continental and polar. In these areas there would be distinct and variable weathering,

erosion and transport of the rocks.

highest in the world) of ilmenite is dismal in India. Hence, the government decided to permit not only the private Indian companies but also encouraged foreign equity provided that this included intermediate and final value addition to ilmenite. In the mid-1980s, for the first time, the governments allowed private players to mine, process and export the garnet sands from the TN coast.

Considering the body of work on coastal placers that was carried out since the 1960's, the Council of Scientific and Industrial Research (CSIR), New Delhi took a major and timely initiative. Under the Tenth Five Year Plan (2002-2007), the CSIR funded a major Network project to study the coastal placers and capacity building. This project gave a platform to researchers studying the different aspects of the placer minerals in isolation.

Several institutions and universities collaborated to address the exploration, exploitation, enrichment and environment of coastal minerals of parts of Maharashtra, Kerala, Tamil Nadu, Odisha and West Bengal. New techniques for exploration, indigenous placer pilot mining systems and effective beneficiation and enrichment processes were developed. Also, studies were made of the changes in the environmental parameters that could occur due to placer mining.

Rules and Regulations for Coastal Mining

Under the Coastal Regulatory Zone an area of 200 m beyond the high tide line is considered as a 'no development zone.' This area is generally highly productive for heavy mineral mining (e.g., garnets along the TN coast) and is normally uninhabited.

Just as in land mining, there are proponents and opponents of coastal mining too. The former justify mining by taking recourse to the fact that no blasting and heavy machineries are used, sound and dust pollution are minimal, no effluents are involved and hence the water table is not affected, no flora are destroyed since the barren mineable zone is not useful for agriculture or horticulture and direct and indirect employments are provided. Interestingly, the companies argue that as the coastal minerals get replenished by natural processes these need to be removed else the minerals would be transported into the sea and would become either useless or more expensive to mine.

In fact, the garnet-mining companies consider coastal mining as similar to agriculture since the sand is ploughed and after removal of the garnet grains the rejects are dumped back in the same

place. Therefore, they are averse to the use of the word 'mining' as it connotes blasting, drilling, noise, etc. that lead people to conjure negative attitudes as related to mining of land ore deposits.

The opponents of coastal mining reject the above claims and point to the negative influences. Indiscriminate mining would lead to population increase and associated ill effects and environmental degradation such as destruction of the coastal villages, groundwater pollution, inundation by the sea, flooding during heavy monsoon or storms, effect on the local fishery, breeding grounds of turtles, etc. Moreover, they find that the companies mine beyond the lease areas and scrape and dig below the maximum permitted 30 m level.

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