CHAPTER 1
PLACER GEOLOGY AND INDIAN DEPOSITS

1.1 INTRODUCTION

Placers are mineral deposits that have been formed by the mechanical concentration of mineral particles from weathered debris. They occur in beaches, rivers, dunes and offshore areas. The minerals that constitute the placer deposits are resistant to chemical breakdown and have high density and durability. For any placer deposit to form the conditions to be satisfied are the following:

1) a primary source for the mineral placers, which are usually crystalline rocks.
2) a suitable weathering environment, which is required to liberate the minerals from the source rocks and
3) agents of transportation like running water, wind etc. which move the placer-forming minerals to the zones of concentration where they are deposited.

The placer deposits encompass a wide range of minerals having varying specific gravity. For the sake of convenience, they have been classified (Emery and Noakes, 1968) as (1) heavy heavy minerals with specific gravity between 6.8 and 21. eg: native gold, cassiterite etc., (2) light heavy minerals with specific gravity between 4.2 and 5.3. eg: ilmenite, rutile, monazite, zircon, and (3) those with densities falling between 2.9 - 4.1. eg: garnet, sillimanite, hypersthene etc. Folk (1974) divided the heavy minerals into four groups, based on their physical and chemical nature namely, opaques, micas, ultra-stables and meta-stables.
Placers are classified into (1) eluvial, (2) alluvial or fluvial, (3) eolian, (4) beach placers, and (5) fossil placers based on their mode of transportation and site of deposition.

1. Eluvial placers: These are formed upon the release of minerals from the rock matrix. This is the embryonic stage in the development of placers. The noted Indian examples are the cassiterite, columbite and tantalite placer deposits of Bastar district, Bihar.

2. Alluvial placers: They represent the next stage in the placer formation. The heavy minerals are introduced into the fluvial system by the action of runoff, gravity or by the erosion process of streams themselves. The most famous examples are the deposits of the Colorado river which caused the famous California Gold Rush in the 19th century. In India, xenotime deposits in the Singhbhum shear zone are fluvial in origin.

3. Eolian deposits: wind is the agent of concentration of these deposits. They occur in arid/semi arid regions, where the influence of wind is strong and sufficient vegetation does not exist to cover the soil. Wind action progressively concentrates the heavy minerals by blowing away the associated light minerals, and over a period of time give rise to the deposits eg: Australian gold deposits. Teri deposits of Tamil Nadu are also of eolian origin.

4. Beach placers: Such placers are formed by the interaction of the terrestrial processes with the coastal hydrodynamics. The heavy minerals among the sediments, that are contributed to the sea by various processes of transportation are selectively panned and sorted and then deposited at suitable locations, by the action of waves and currents. The factors controlling the formation of beach placers are 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, where the action of the wind may erode them and form heavy mineral rich coastal dune deposits (Kudrass, 2000). Most of the important deposits of ilmenite, rutile, zircon, monazite and garnet are found in form of beach placers. India has some of the largest placer deposits along its coast.

5. Fossil placers: Placers formed in the geologic past, which were removed from the sub aerial environment by factors like changes in climate and/or epirogenic movements and eustasy are called fossil placers or submerged placers. Along the coast of India considerable reserves of fossil placers are known to occur, which are formed during the previous low stands of sea level. The fossil placers may form the source of recent deposits.

1.2 FACTORS CONTROLLING THE FORMATION OF PLACER DEPOSITS

Climate: Climate influences the weathering processes, which ultimately decomposes the rock matrix and liberate the minerals. Tropical to subtropical climate promotes chemical weathering, which has given rise to a decomposed stage of crystalline rocks called laterites. This could be considered as a pre-concentration process of the placer minerals. Most of the rich placer deposits of the world are in tropical regions.

Drainage Pattern: The fluvial processes act as a conduit of sediment transport from the source rock to the zone of concentration. In their youthful stages, the erosive power of rivers is strong and they release heavy minerals from the parent rock and transport them down stream. In Kerala, the west flowing rivers with their steep gradient was the major
agent of erosion and transportation of sediments to the Arabian Sea, which gave rise to the placers along the southwest coast.

Coastal processes: The beach deposits are essentially a result of the coastal hydrodynamics of rivers and currents. The waves sort out the heavy minerals and transport them onshore based on their size and specific gravity. The direction and strength of the coastal currents and the geomorphology of the coast determine the location of the deposit.

1.3 PLACER DEPOSITS OF INDIA

The history of placer deposits as a source of economic minerals began with the discovery of monazite in the beach sands of Manavalakurichi (Tipper, 1909). This was first worked in 1911 and rapidly developed with the establishment of TiO₂ (titania) pigment industry in Europe and America. In early 1930's, India accounted for 80% of the total ilmenite production in the world.

However, by the 1950's the ilmenite production marked a sudden decrease in the country. This owes, in part to the discoveries of new deposits in Australia and Canada and the presence of undesirable impurity like chromium and ferric iron in Indian ilmenite. However, after the nationalization of all the major deposits, the national production of ilmenite and rutile has increased over the years. The current production rate is of the order of 140,000 tons for ilmenite and 6000 tons for rutile. Governmental concerns like the Indian Rare Earths Ltd. and Kerala Minerals and Metals Ltd. are involved in the production and marketing of the placer minerals.

Over the last few decades new deposits have been discovered in placers like Chattarpur in Orissa, Visakapatnam in Andhra Pradesh in the east
coast and Ratnagiri in Maharashtra in the west coast of the country. Along the coastal stretches of Tamil Nadu, deposits of heavy minerals occur in the inland areas in the form of Teri sands. The current reserves of the placer minerals in India, are as follows; 278 million tonnes (MT) of ilmenite 13.49 MT of rutile, 18 MT of zircon, 7 MT of monazite, 84 MT of sillimanite and 86 MT of garnet (AMD, 2000). The major placer concentrations of India are located along the east and west coasts (Fig. 1.1).

1.3.1 Ratnagiri Deposits

High concentrations of placer minerals occur along Jaigarh and Vijaydurg in Maharashtra particularly in the bays of Kalbadevi, Mirya and Ratnagiri bays. Heavy minerals range from 1-91% with 1-52% of ilmenite. Ilmenite assays about 50-52% TiO₂. The placers in Bhatya, Purangad and Goankhede contain high content of magnetite (40-60%) and limonite/haematite (25-35%) with relatively low ilmenite (5-25%). The total reserves of the heavy minerals are estimated to be around 3.45 MT. The break up of the reserves of the constituent minerals in million tonnes is as follows: 1.67 of ilmenite, 0.08 of leucoxene, 0.009 of zircon, 0.53 of magnetite (Ali et al, 1998).

The provenance of the heavy minerals is attributed mainly to the Deccan Trap provinces. The Kaladgis consist of both granitic and metamorphic rocks and the gneissic basement of south Konkan forms a secondary source of heavy minerals. Extensive areas of Deccan Traps are overlain by laterites.
Fig. 1.1 Major placer deposits of India
1.3.2 Chavara Deposit

This deposit, popularly known as Quilon deposit is one of the largest and richest in the world. It extends to about 22 km with a width of around 500m. It stretches as a barrier beach between Neendakara, at the mouth of Ashtamudi estuary and Kayamkulam. The deposit has a maximum depth of 15m and is estimated to contain about 12.7 MT of ilmenite, 1 MT of rutile, 1.9 MT of zircon and 0.41 MT of monazite and 6 MT of sillimanite (Fig. 1.2).

The heavy mineral content of the beach is about 50% with a maximum of about 80% in some places. Of these, ilmenite accounts for the bulk of the heavy minerals consisting of about 68%. The content of other minerals are as follows: leucoxene 2%, rutile 7%, zircon 6% monazite 1%, sillimanite 14% etc. The garnet content is rather low compared to other deposits (0.35%). However, the ilmenite of Chavara has a high content of chromium (0.12% Cr₂O₃) and ferric iron (24.18% Fe₂O₃), which render it undesirable for pigment manufacture, in spite of high TiO₂ content of 60% (Ali et al, 1998).

The dunes behind the beach are rich in heavy minerals constituting about 40-50% of sediment. The estuarine systems adjacent to the Chavara deposits, namely, Ashtamudi and Kayamkulam contain about 3 to 7.5 % of heavy minerals. Investigations by Atomic Minerals Division and Geological Survey of India have revealed that off Kayamkulam-Anjengo sector, the heavy minerals occur as discontinuous patches with concentration ranging from 5-20%. The total reserves in lakes and seabed are estimated to be about 57,860, 151 tonnes (Soman, 1997).

The placer deposits are located in the southwest margin of the Indian Shield, where the Archean lower crust metamorphosed to granulite grade
Fig.1.2 Beach placer sands of the Chavara deposits

Fig.1.3 Beach placer sands of the Manavalakurichi deposits
as represented by the charnockite-khondalite rocks and migmatite gneisses (Refer Fig. 3.1). The khondalite suite comprises a series of interlayered metapelite rocks like garnet sillimanite gneiss ± graphite, garnet biotite gneisses and garnet quartz feldspar and their migmatised equivalents. Locally bands of biotite rich gneisses and calc silicates also occur. At many places khondalites are intercalated with bands of charnockites and pyroxene granulites. Progressive transformation of khondalite to charnockites and retrogressive of charnockites to garnet biotite are observed.

The charnockite suite consists of hypersthene and/or diopside bearing granulite, their retrograded equivalents, hornblende granulites and hornblende biotite gneisses. The Achankovil lineament forms the general boundary of the khondalite migmatite complex from the northern charnockite terrain. Along this zone, discontinuous patches of cordierite bearing gneisses occur within an 8-10 km wide zone. The rocks of the area show evidences of polyphase deformation and they are intruded by dolerite dykes and pegmatites.

The western fringe of the area is covered by the tertiary formations of the Malabar Super Group with a maximum thickness of 628m consisting of variegated sand stone, clays and lignite belonging to Warkkalai beds and fossiliferous limestone, sandy and calcareous clays and sands of Quilon beds. The crystalline rocks and Tertiary sequence are overlain by laterites at many localities. They are the products of three phases of lateritisation.

The hinterland of the Chavara deposit is drained by nine rivers from Neyyar in the south to Periyar in the north and is bordered on the coast by the estuarine system the evolution of which is inextricably linked to the evolution of the deposit.
1.3.3 Manavalakurichi Deposit

It is located in the Kanyakumari district of Tamil Nadu. It is one of the oldest known deposits, which was first worked for its monazite. The deposit extends to a length of about 6 km, from the north of Muttom promontory to Kolachel, with an average width of 45m (Fig. 1.3).

The total average content of heavy minerals is around 39%. Of these, ilmenite forms the major constituent (24%), with rutile (1.8%), leucoxene (0.9%), zircon (2%), monazite (1%), sillimanite (3.5%) and garnet (5.5%). Ilmenite contains about 56% TiO₂. The monazite has a total of 58% REE oxides and 8% ThO₂. The total reserves of heavy minerals in the Manavalakurichi-Kolachel stretch are estimated to be about 1.6MT. Ilmenite amounts to about 1 MT. The reserves of other minerals estimated are as follows: 0.075 MT of rutile, 0.035 MT of leucoxene, 0.082 MT of zircon, 0.043 MT of monazite, 0.23 MT of garnet, 0.14 MT of sillimanite and about 6850 tonnes of kyanite. The area north of Kolachel to Midalam has been found to contain workable deposits of heavy minerals estimated to about 0.5 MT. The reserves of ilmenite and rutile are worked out to be around 0.31 MT and 15,300 tonnes respectively (Chandrasekharan et al, 1988).

The hinterland consists of khondalite suite of Archean age composed of quartzite of arenaceous facies, calc silicates with pockets of crystalline limestone representing calcareous facies and quartz garnet sillimanite graphite schists and gneisses or argillaceous facies. Charnockite intrudes into khondalites in some places.

Muttom and adjacent areas are characterised by extensive occurrence of fine sandy loam known as Teris. Their genetic properties are disputed, though generally an aeolian origin is ascribed to them. The vegetation is
of semi arid type and the topography is similar to Bad Lands of the United States.

1.3.4 Teri sands of Tamil Nadu

These inland deposits occur along parts of south eastern coast of Tamil Nadu in the form of Teris in parts of Tirunelveli, Chidambranagar, Ramanathapuram districts. They standout prominently in the area, at elevations of 30-60 m. They occur as widely separated isolated patches with dimensions ranging from a few hectares to about 6000 hectares. They are found about 0.1-10 km inland from the beach placers in a semi arid setting. Seven such deposits with an aggregate area of 144 km² have been identified (Krishnan et al, 1994). They are Navaladi Periathalai, Kudiramolai, Sattankulam, Kuttampuli, Surangudi, Kilakarai and Kulathur with heavy mineral concentration ranging from 6-17%. The average mineral grade is about 10% with reserves of 123 MT (AMD, 2000). The split up of the total reserves are as follows, 77.2 MT of ilmenite, 4.03 MT of rutile, 3.9 MT of leucoxene, 7.07 MT of zircon, 1.2 MT of monazite, 12MT of garnet and 17 MT of sillimanite.

The Sattankulam and Kudiraimoli deposits have reserves of about 22 and 13 MT of total heavy minerals respectively. While Sattankulam area contains about 14.3 MT of ilmenite, 1.4 MT of rutile, 1.1 MT of leucoxene, 0.96 MT of zircon, 0.21 MT of monazite and 4.3 MT of sillimanite, the Kudiraimoli deposit contain estimated reserves of minerals as follows: 9.3 MT of ilmenite, 0.63 MT of rutile, 0.38 MT of leucoxene, 0.46 MT of zircon, 0.11 MT of garnet and 1.9 MT of sillimanite (Ali et al, 1998).

The Teris are believed to be formed due to aeolian action in an aridsemi arid climate. The sediments owe their origin to the Eastern and Western Ghats, tertiary sandstones and limestones and Cuddalore beds.
1.3.5 Visakapatnam Deposit

Black sand deposits occur in the Visakapatnam-Bhimunipatnam coastal stretch of Andhra Pradesh for a length of 37 km with a width ranging from 150m to 1 km. The average heavy mineral concentration is about 20% with ilmenite (9%), rutile (0.6%), monazite (0.09%), zircon (0.3%), garnet (4%) and sillimanite (4%). The total reserves are worked out to be between 6.18-2.88 MT of ilmenite. The split up of the reserves of the different minerals encompass 5.8 MT of ilmenite, 0.03 MT of magnetite and 0.005 MT of garnet (Anon, 1983). The assay of this mineral is about 49% TiO$_2$. The coastal stretch between Kakinada and Tandava river contain a total heavy mineral content of about 70 MT with a grade of about 12%. The reserves of ilmenite are about 30 MT (AMD, 2000).

The lithology of the area consists of charnockite and khondalite group of rocks of the Eastern Ghats Province. Granites and granitic gneisses also exist in the rock assemblages. A part of the sediment for the deposit formation may have been brought by large drainage systems like Krishna and Godavari, which flow through a range of lithologic successions like Deccan Traps, Cuddapah sedimentary formations and tertiaries of Rajamundry sequence.

1.3.6 Chatarpur Deposit

This deposit falls in the Ganjam district of Orissa near Gopalpur. It extends to a length of 22 km with an average width of 1.54 km. The average grade of the heavy mineral is about 20% with ilmenite (8.80%), rutile (0.38%), monazite (0.27%), garnet (6.70%), zircon (0.31%) and sillimanite (3.40%). The total reserves are estimated to be 46.61 MT with a grade of about 20.22% (Ali et al, 1998). Of these, ilmenite constitutes about 20.3 MT. The assay of TiO$_2$ in ilmenite is around 50%.
The heavy minerals are essentially derived from the Eastern Ghats province, which consists of khondalites, charnockites with their migmatised equivalents. Frequent exposures of anorthosites have been reported.

1.4 BACKGROUND AND OBJECTIVES

Among the minerals present in various placer occurrences, ilmenite deserves an important stress due to its industrial implications and its high concentration. An indepth study on the this mineral is essential on its mode of concentration, temporal relation between placer formation and geomorphic cycles, quality differentiation of ilmenite in various locations, influence of lateritisation and other exogenic processes on the mineral, mineralogical and geochemical factors capable of distinguishing spatially different ilmenite deposits to gain an understanding on the origin and nature of the present placer ilmenite.

Systematic studies are lacking on the chemical heterogeneity within individual deposits. Trace element distribution is important as they too determine the quality of the ilmenite ore. Nowadays, the titanium pigment production has become so specialized that the absence or presence of a particular trace element determine the suitability of the ore to be manufactured to pigments for definite end use. In addition, they serve as geochemical signatures of the various weathering processes and provenance characteristics. Such investigations are lacking for the Indian deposits, in spite of our abundant reserves of ilmenite. Since the ilmenite ore in a deposit is a composite of differently weathered fractions, the mineral phases, which form subsequent to alteration is an indicator on the quality of the deposit and point to the structural and chemical changes accompanying alteration. Physical properties like magnetism
and specific gravity are dependent on the ferrous-ferric ratios in the mineral and thus are direct functions of alteration patterns of the mineral. The occurrence of intergrowths of other mineral phases with ilmenite holds a definite clue on their genesis and the accompanying temperature and pressure conditions. They also influence the ore quality and the beneficiation techniques to be adopted in the mineral processing. Investigations tracing the physical and chemical changes of ilmenite, since their release from the country rocks to being deposited as constituent of placer deposits in the beach, through the progressive weathering environments of laterite, sedimentary rocks, rivers and estuarine systems have not, so far been attempted. Studies as above mentioned are not only useful to unravel the different physical and chemical changes accompanying ilmenite alteration, but also, given the economic significance of ilmenite, would have industrial implications. Only a multifarious approach encompassing the above aspects can give a broad and clear picture of the different physcio-chemical characteristics of ilmenite under different geologic set ups and its associated alteration phases. The present investigation is taken up in this backdrop with the following objectives

- Determination of associated minerals/phases associated with the alteration of ilmenite using XRD, TGA and Mössbauer methods
- Characterization of ilmenite concentrates from Chavara and Manavalakurichi deposits as regards the variation of physical properties like magnetism with compositional change
- Sequence of tropical alteration stages in ilmenite grains from the latertisation process to placer concentration in the beach
- A comparison of the Chavara and Manavalakurichi beach placer deposits from the aforesaid perspectives