

Heavy mineral placers

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Heavy mineral placer deposit is defined as “Alluvial, [Material (minerals or rocks) transported by rivers and deposited usually at points along the flood plane of river], Elluvial, [Material which is still at or near the points of its formation] and Colluvial [Material which is transported by gravity], which contains economic quantities of valuable minerals such as gold, tin and platinum etc. Placer deposit can also be defined as a “mineral deposit formed by the process of mechanical concentration of mineral particles from weathered debris”. These heavy minerals (Table 1) have higher specific gravity (>2.8) and are resistant to chemical and mechanical attack than ordinary rock forming minerals.

Table 1. Economically important heavy minerals [Ordered in increasing specific gravity (g/cm³)].

Mineral	Sp. Gravity	Hardness	Composition
Tourmaline	3.1	7	NaMg ₃ Al ₆ B ₃ Si ₆ O ₂₇ (OH, F) ₄
Diamond	3.5	10	C;
Topaz	3.6	8	Al ₂ SiO ₄ (P, OH) ₂ ;
Garnet	3.8 - 4.2	7-7 ^{1/2}	(Fe, Mn, Mg) ₃ Al ₂ (SiO ₄) ₃
Corundum	4.0	9	Al ₂ O ₃ ;
Rutile	4.2 - 4.3	6 ^{1/2}	TiO ₂
Chromite	4.3 - 4.6	5 ^{1/2}	FeCr ₂ O ₄ ;
Ilmenite	4.3 - 5.5	5 ^{1/2}	FeTiO ₃ ;
Xenotime	4.4 - 5.1	4 ^{1/2}	YPO ₄ ;
Zircon	4.4 - 4.8	7 ^{1/2}	ZrSiO ₄ ;
Pyrrhotite	4.5 - 4.6	4	Fe _{1-X} S;
Magnetite	4.9 - 5.2	6	Fe ₃ O ₄ ;
Monazite	4.9 - 5.3	5 ^{1/2}	(REE, Th)PO ₄ ;
Pyrite	5.0	6-6 ^{1/2}	FeS ₂ ;
Columbite	5.4 - 6.4	6	(Fe, Mn)(Nb, Ta) ₂ O ₆ ;
Scheelite	5.9 - 6.2	5	CaWO ₄ ;
Thorite	6.7	4 ^{1/2}	ThSiO ₄ ;
Cassiterite	6.8 - 7.0	6 ^{1/2}	SnO ₂ ;
Wolframite	7.1 - 7.5	4 ^{1/2}	(Fe, Mn)WO ₄ ;
Uraninite	7.5 - 10	5-6	UO ₂ ;
Cinnabar	8.0 - 8.2	2 ^{1/2}	HgS;
Platinum	14 - 19	4	Pt
Gold	15.6 - 19.3	2 ^{1/2}	Au

Formation

The formation of heavy mineral placers requires a primary source and it involves processes of *weathering*, *erosion*, *transportation* and *concentration*. (Cronon, 1980)

Primary source

Heavy mineral concentrations are generally derived from the weathering of normal igneous, sedimentary or metamorphic rocks. Typical heavy mineral assemblage of these rocks is shown in Table 2.

Table 2. Selected detrital heavy minerals and their source rocks.

Rocks	Heavy minerals present
Granites, granodiorites, rhyolites (acid rocks)	Magnetite, monazite, tourmaline, zircon, Cassiterite
Basalts, dolerites, gabbros (basic rocks)	Chromite, ilmenite, leucoxene, titanomagnetite, magnetite, rutile, zircon
Metamorphic rocks	Garnet, leucoxene, magnetite, tourmaline, rutile
Pegmatites	Monazite, tourmaline, zircon
Hydrothermal veins	Cassiterite, pyrite, wolframite, gold, platinum

Weathering and erosion

Weathering and erosion of the placer mineral source has to take place in order to release the minerals concerned for transportation to their site of deposition. In the process of weathering, chemically stable minerals are not decomposed as the surrounding rocks are dissolved and disintegrated these stable minerals remain unaffected and later subjected to transportation.

The process of weathering can be defined as a natural process of disintegration and decomposition of rocks and it is a static process. Generally the companion process of weathering is erosion, which is natural removal and transportation of weathered material, and is a dynamic process. (Miller) 1964

The rate of weathering depends on nature of rocks and conditions of weathering agents, which operate upon them. In general, the minerals formed at higher temperature are more prone to weathering. This is probably due to the atomic structure of the minerals. The weatherability series of rock forming minerals proposed by Goldich (1938) is as below:

Mafic Minerals		Felsik Minerals
Olivine	Most	Ca-plagioclase
	Weatherable	Ca-Na-plagioclase
Pyroxene		Na. Plagioclase
		K. Felspar

Amphibole	Muscovite
	Quartz
Biotite	Least
	Weatherable

Atmospheric gases and temperature changes are the outstanding weathering agents. Additional help is provided by water and its dissolved chemicals. Depending upon the agencies involved the weathering process is broadly divided into two types:

- 1) Mechanical weathering/physical weathering, and
- 2) Chemical weathering.

Mechanical weathering

Breaking up of the rock with little or no changes in its composition. It is more confined to the regions of cold climates. Agencies that are carrying out mechanical weathering are freezing of water, temperature change, mechanical action caused by organisms and trees etc. Less important agencies are lightning and impact of raindrops etc.

Freezing of water

In cold climates and on mountain tops, (in the sub-zero temperature zone). Alternate freezing and thawing of water results in breaking up of rocks. Hard rock contains many joints and fractures. Surface water may fill such openings and on freezing this water expand by 9.2% of its volume and exerts high pressure, which may widen the opening or joints. Repeated freezing and thawing finally breaks the rock into fragments. (Macdonald, 1983)

Temperature change

Temperature variations at the earth's surface range from about -20°C to $+50^{\circ}\text{C}$ when rock is subject to temperature changes, all parts of the rock do not expand and contract at equal rates and therefore repetitive stresses of various intensities are set up which cause rock to break. This process is effective in barren and desert areas, where temperatures are more than 40°C during day time.

Mechanical action of organisms

Both directly and indirectly plants and animals accomplish considerable work of rock disintegration. Tree trunks and roots insert themselves in rock cracks and as they grow they exert pressure, which finally leads to disintegration. The impact of other processes like lightning and raindrops are relatively less significant.

Chemical weathering

Chemical weathering results in breaking up of the rock with change in the composition. It is more active in warm and humid climates where rainfall is more and

contains significant quantity of CO_2 (Carbon dioxide). This maximum rainfall nourishes plant life, which assist chemical activity. Agencies that are carrying out chemical weathering are i) Solution (rain water + CO_2 + decomposed organic acid which acts as solvent for limestones or calcareous sand stones) and ii) carbonation, oxidation and hydration.

Solution

Gases like oxygen and carbon dioxide get dissolved with rainwater and it becomes weak solution of carbonic acid which acts as solvent. Sometimes the solvent power is increased by the presence of other acids formed by decomposition of organic matter. When such water acts on rocks, calcareous or lime material is dissolved resulting in disintegration of rock. (Holmes, 1965)

Carbonation, oxidation and hydration

Carbon dioxide (carbolic acid), which occurs in air, has power of chemically uniting with some minerals. Thus, rock-containing calcium, iron with which carbolic acid combines to form carbonates of calcium and iron, are easily taken into solution and rock crumbles. (Miller 1964)

Oxygen occurs in air and dissolved in water which combines with other chemical elements like iron in minerals like Pyrite, hornblende, mica, augite etc and disintegrate common example is rusting of iron, where iron combines with oxygen and water.

The process of hydration consists of chemical union of water with certain compounds like iron in minerals where iron reacts with oxygen to form iron oxide and then unites with water to become brown hydrated iron oxide, which is removed. (Miller 1964)

Transport

Transport of placer minerals takes place mainly by running water and with hot dry winds. The unstable products of primary source are removed by aqueous processes, leaving behind chemically stable minerals called placers. These stable minerals either remain in residual particle or get transported by streams. Further, agitation within the stream causes settling of heavy minerals to the bottom and continuously enrich the deposit by removing lighter fractions. Transport process will move the placer minerals to beach zone and may even transport further offshore (Cronan 1980)

Concentration

Once liberated from parent rock, placer minerals get concentrated by hydraulic processes primarily because of density contrasts with lighter silicates with which they generally occur. Settling velocity of any grains immersed in water will depend upon their density if shape and surface textures are similar following the

Stroke's law. Consequently, the size of the grains that settles together on the bed will be inverse function of their density. During transport down the rivers or offshore, a decrease in the energy level of environment can lead to their deposition.

The minerals are also selectively concentrated by sifting and winnowing away the fine-grained constituents or by gravity settling in case of large particles. In this process, the minerals, which are initially widely dispersed, get concentrated into deposit of ore grade. This process is more effective on beaches and in the nearshore zone where wave action is predominant. As water depth increases, the energy level of depositional environment decreases. As a result, the opportunity of selective concentration of mineral reduces.

Rivers

Concentration of placer minerals occurs locally in the rivers draining through suitable source area and where the energy level in the river drops sufficiently to allow placers to settle down, e.g., Stream placers of golds, Cassiterite. Emery and Noakes (1968). Rivers and streams are the most favorable environment for heavy minerals. During the period of sea level lowering many rivers drained out across the area, what is now submerged and known as continental shelf. Some of these rivers were draining through mineralized area on land and before their submergence got placer minerals deposited in their valleys just as some rivers do it on land today and the placers in buried valleys are formed (Fig.1).

Beaches

Placer mineral formation on beaches results due to process of selective sorting of beach sediments in the inter tidal zone due to waves and currents. During this process the lighter minerals are removed to the offshore, leaving behind the heavy minerals [Fig.1]. Beaches are favorable sites for light heavy minerals, e.g., ilmenite, magnetite, rutile, zircon etc. whose specific gravity ranges between 4.2 to 6. Moderate to high energy environmental conditions exist on beaches and such conditions are required to concentrate placer minerals in to a rich deposit. (Emery and Noakes, 1968) But seasonal and latitudinal effects can influence beach placer mineral processes (Cronan, 1980)

Offshore areas

As indicated before, drowned river valleys containing placer minerals occurs on some continental shelves, eg. cassiterite of Cornwell [U.K. and S.E. Asia]. The second occurrence of offshore placer comprises those formed in the past on ancient beaches but now submerged. Many continental shelves contain submerged terraces, which were once, beaches and are generally parallel to the present coast eg. Ratnagiri coast, Maharashtra, India (Ramana et.al; 1990, Gujar

and Guptha 1993)Placer concentration of limited size can be occur due to submarine erosion of mineralized bed rocks on the sea floor. In addition transport of placer minerals from land and their deposition in the offshore or by submergence of coastal tract. Offshore placer deposits can be formed eg. Offshore ilmenite deposits of Konkan Maharashtra. (Siddiquie et.a; 1982, Rajamanickam, 1983, Gujar 1996 and references cited therein).

Classification

Heavy mineral placers are grouped according to their sp. gravity into three groups: (Emery and Noakes, 1963)

Heavy.Heavy minerals (Sp.gr. 6.8 –21.): Platinum, Gold, Cassiterite

Light heavy minerals (Sp.gr. 4.2 – 5.3): Ilmenite, Zircon, Rutile, Monazite

Gemstone (Sp.gr. 2.9 – 4.1): Diamonds.

Heavy Heavy minerals

This group consists of minerals and metals like gold, platinum, and cassiterite. These placers occur mainly in streams, near to their source, because of their high sp. gravity. Intrusive igneous rocks and metamorphic rocks are mostly the primary source for heavy placers (Table 3).

Table 3. Important Placer Deposits of the world.

Country	Climatic zone	Mineral Deposit	Present Studies
Australia	Arid/temperate	Ilmenite, zircon, Monazite, rutile	Onshore deposits exploited. Offshore exploration completed in some parts.
Canada	Glacial, cold	Gold, cassiterite	Exploration completed
China	Humid temperature	Zircon, ilmenite	Offshore exploration in process
India	Humid tropical	Ilmenite magnetite, zircon, monazite, rutile	Onshore deposits under exploitation, offshore exploration completed in some areas.
Indonesia	Humid tropical	Cassiterite	Exploitation in progress
Japan	Humid tropical	Ilmenite, magnetite	Exploration completed, exploitation at few places in progress.
Malaysia	Humid tropical	Cassiterite	Exploration in process
New Zealand	Arid/temperate	Gold, ilmenite, Zircon,	Exploration in process
South Africa	Arid/Humid tropical	Diamond, ilmenite, zircon	Exploration in process for gemstones, and for ilmenite & zircon exploration completed
Sri Lanka	Humid tropical	Ilmenite, zircon, monazite	Exploration complete (partly)

Country	Climatic zone	Mineral Deposit	Present Studies
Thailand	Humid tropical	Cassiterite	Under exploitation
USA	Glacial, humid temperate.	Gold, cassiterite, platinum, ilmenite, magnetite, zircon	Exploitation in process for some deposits. Exploration completed.

and a high energy environment of wider extent is needed to concentrate them (Table 3 & 4).

Gems

This group consists of mainly diamonds, rubies, and sapphires. Out of these, only diamonds can be found in the areas far away from their primary source, because of their toughness and hardness, but other gemstones normally occur close to their source.

Light heavy minerals

The group consists of minerals like ilmenite, rutile, zircon and monazite etc. The source of the light heavy minerals is crystalline rocks (Table 2). These mineral deposits can be transported for hundreds of kilometer from their source. Generally, these deposits are confined to beaches rather than to the streams, which is due to the fact that the light heavy minerals are slightly denser than quartz and felspar with which they are associated

Names of minerals and their origin

It is very interesting to know how these different placer minerals are named. The placer minerals are named after the (A) localities from where they were discovered, or (B) after the name of scientist who discovered or (C) from the distinguishing physical property or process.

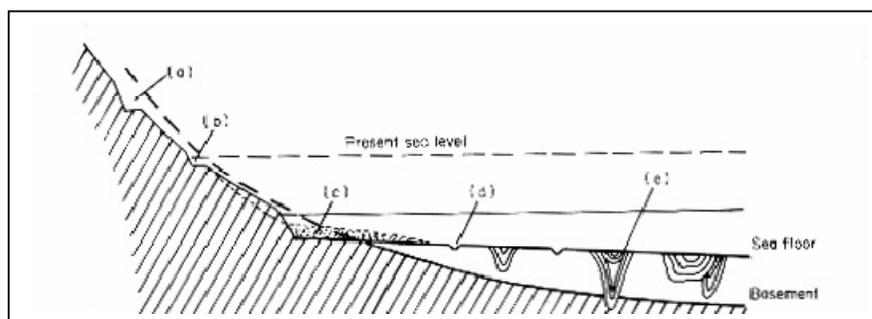


Fig. 1. Environments of possible placer mineral occurrence. (a) Placers on raised beaches, (b) Placers on modern beaches, (c) Placers on submerged beaches, (d) Placers trapped in surface depressions on the sea floor (e) Placers in buried river valleys. Adapted from Cronan (1980)

Table 4. Important Placer Mineral Deposit of India

Area	State	Mineral Deposit	Present Status
West Coast	Maharashtra	Ilmenite, magnetite	Onshore exploration completed Offshore exploration completed in north/central region.
	Goa	Ilmenite, magnetite	Onshore exploration completed
	Kerala Chavara deposits	Ilmenite, magnetite, monazite, rutile, zircon, garnet.	Onshore exploration completed. Offshore exploration completed in selected areas. Exploitation from beach deposits in progress.
East Coast	Tamilnadu Manavala Kusichi	Ilmenite, magnetite, rutile, zircon, garnet, monazite	Onshore exploration completed. Exploitation of Garnet from selected areas.
	Orissa Chatrapur Gopalpur	Ilmenite, rutile, zircon, garnet, monazite	Onshore exploration completed Offshore exploration partly completed Exploitation from beach deposit.
	Srikakulum	Andhra Pradesh West Bengal	Magnetite, garnet ilmenite, zircon Ilmenite, garnet, zircon, magnetite

Modified after Gujar (2002)

A: - Ilmenite – After locality Ilmen mountains in USSR.
 Almandite (garnet) - After the town Alabanda in ancient Asia.
 Spessartite (garnet) - After locality – Spassart Dist in Germany. B: - Geikilitite (ilmenite) – After Sir Arahibid Geikie (an English Geologist)
 Andradite (garnet) – After Portuguese mineralogist JB de Andrade Silva
 C: - Pyrophanite (ilmenite) – Greek word – Pyro – fire, phane-appear.
 Rutile – Latin word Rutilus – golden red.
 Magnetite – From being attracted to magnet.
 Pyrope (garnet) – Greek word Pyropos fiery eyed
 Grossularite (garnet) – Latin word Grossular – gooseberry
 Monazite – Greek word 'Monazein' – to be alone (isolated crystal were rare when first found)
 Tourmaline – Singhalese – turmali-means water rolled gem.

Separation of heavy minerals

Heavy minerals are minerals with specific gravity greater than that of quartz i.e. 2.65 or feldspar i.e. 2.76. A specific gravity of 2.8 is accepted as lower limit so any mineral with specific gravity more than 2.8 is heavy mineral. The method by which heavy minerals are separated in laboratory is the separation by heavy liquid (Table 5) and magnetic separation. The principle for

Table 5. The most common heavy liquids used

No.	Liquid	Composition	Sp.Gravit y	Dilution Medium
1.	Bromoform	CHBr ₃	2.88	Benzol, CCl ₄ , Xylene
2.	Tetrabromethane	C ₂ H ₂ Br ₄	2.95	--- do ---
3.	Thoulet Solution	Water Sol of KI + HgI ₂	3.19	Water
4.	Methylene Iodide	CH ₂ I ₂	3.13	Benzol, Xylene
5.	Clerici Sol.	Water Sol. of thallium, malonate and thallium formicide	4.2	Water
6.	Challan Sol. *	Water Sol. of sodium poly tungstate	2.9	Water

For separation of heavy minerals in silt size (44 to 8 microns) (modified after Krumbein and Pettijohn, 1938)

liquid separation is that “minerals with different specific gravities can be separated from each other by liquid whose specific gravity lies between the two minerals. The heavy mineral sink to the bottom and lighter minerals floats at the surface”. The apparatus used is known as the separating funnel.

The heavy minerals thus separated are washed with methyl alcohol to remove coating of bromoform or other liquid used on grains dried and then subjected to magnetic separation. Magnetic separation is based on the principle that “a large variety of minerals can be separated from one another on the basis of their magnetic susceptibility”. Here with hand magnet, highly magnetized minerals like magnetite are separated. And other minerals with distinctive magnetic susceptibility are separated from one another using 'Isodynamic separator' on different settings following Rasenblum (1958) and Flinter (1959). The detailed procedure is given by Hutchinson (1974)

Utilization of heavy minerals

Placers are restricted to areas because of special geological conditions required for their formation. They are easy for exploitation compared to the land deposits where mining involves lot of expenditure. As they are highly concentrated, the average grade of offshore deposits mined are atleast twice as high as the other land deposits.

Heavy minerals are of great value in studying 1. Provenance 2. Transport history of sediments 3. Weathering history of sediments and 4. In correlation and paleogeographic studies (Folk 1968). In addition to their use in solving academic and scientific problems, they are used for variety of industries like metal (for production of alloys), ceramics, refractories, nuclear power, biomedical, etc. From the defence point of view, ilmenite, rutile and monazite are considered as strategic minerals. Ilmenite and rutile are used as ores for titanium. Because of its high strength/weight ratio, good corrosion resistance, fatigue strength and moderate modulus of elasticity, titanium is preferred in aero-alloys, rocket parts, cutting tools and marine industries. Titanium is also used in pigment industry. Monazite is a nuclear mineral, which is mainly used as chief source of Thorium in atomic reactors in addition to photoelectric cells and gas mantles. Garnet due to this tendency of breaking into small pieces with sharp, angular and uneven faces is used as abrasive in leather industry besides its use as gemstone. Zircon due to its high melting point is used in refractory industry for preparation of heavy media in coal washing plants. Kyanite and sillimanite are used for the production of high duty refractory material and mullites, which are extensively used in metallurgical and glass industry. Chromite is used as ore for chromium in the manufacture of special steel and in the plating. Cassiterite is an oxide tin ore. The use of some important heavy minerals is shown in Table 6.

Table 6. Uses of various heavy minerals.

Name	Ilmenite	Rutile	Leuco-xene	Zircon	Monazite	Garnet	Sillimanite
Ore Minerals	Titanium TiO ₂ pigment Surface coatings Plastics and paper Industry Drilling (oil wells) Slag & flux			Zirconium Pigment Ceramics Chemicals & Compounds Refractories (steel and glass works) Toiletries, Medicine, tanning and oil	REE & Thorium Petroleum Industry Misc. metal Ceramics Illuminations Electronics Polishing & Colouring glass	Abrasive Abrasive Sand blasting Water filter	Refractory Refractory
Metal	Nuclear			As cladding Material (hafnium free); Hafnium as control rods	Source for Ree and thorium, Nuclear fuel, Control rods, Reactor Components		
Metal	Non-nuclear			Alloys Chemical Industry Photo flash Bulb	Alloys Super alloys Super Conductors Permanent magnet		
Metal	Non-nuclear			Metallurgical alloys Aerospace Chemical and desalination Plant Biomedical food and marine			

Contributions by NIO

Along the west coast of India the National Institute of Oceanography has successfully completed exploration for on-shore and off-shore heavy mineral placers for a stretch of 130km from Jaigad to Vijaydurg (1978-1991) and the results of the explorations are very encouraging and has been published in many National and International Journals. The important/ significant results of this work are summarized below.

- ❖ Promising onshore deposits (5.0 million tones) of ilmenite are proved between Jaigad and Vijaydurg.

- ❖ Extensive geological and geophysical explorations was carried out for 130 km long strip covering 13 bays to check the offshore extension of the promising beach placers (the details of the beach placer is indicated in Table 1) by using highly sophisticated techniques (bathymetry, shallow seismic, magnetics, side scan sonar and vibro coring and with mini ranger system for position fixing at 250m grid).

- ❖ Heavy mineral rich sand (with upto 64% of ilmenite extends in the offshore upto a water depth of 10-13m (3 to 5 km lateral extension).

- ❖ Shallow seismic profile indicated sand thickness to the order of 5 to 10m. Magnetic profiles established a positive co-relation between magnetic anomalies and heavy mineral concentration.

- ❖ Inferred reserves of the ilmenite to 1m sand thickness in the sand covered areas, of 94 km² are to

the tune of 12.5million tonnes. Ore beneficiation studies indicate that ilmenite is suitable for its conversion to synthetic rutile.

- ❖ Recent onshore exploration for 105 km stretch from Vijaydurg to Reddi in South Maharashtra has proved 0.5 million tonnes of ilmenite, 0.9 million tonnes of magnetite and in that area for the first time in the country the occurrence of Chromite as a placer mineral is reported.

References

Cronan DS (1980). Underwater Minerals. Academic Press, London.

Emery KO and Noakes LC (1968). Economic placer deposits of the continental shelf. In: Technical bulletin, Economic commission for Asia and Far East, pp 95 – 111.

Flinter BH (1959). The magnetic separation of some alluvial minerals in Malaya. American mineralogist 44: 738 – 751.

Folk RL (1968). Petrology of sedimentary rocks. Hemphil Austin Texas.

Goldich SS (1938). A study in rock weathering. Journal of Geology 46: 17 – 58.

Gujar AR and Guptha MVSN (1993). Evidence of climatic change during Holocene in the nearshore regions of konkan. Giornale di Geologia 55: (2) 11 – 17.

Gujar AR (1996). Heavy mineral placers in the near areas of south Konkan, Maharashtra: Their nature of distribution,

- origin and economic evaluation. Phd thesis, Tamil University, Thanjavur.
- Gujar AR (2002). Status of placer exploration in India. Proceeding of National Conference on exploration, mining and processing of beach placer in India, 24 - 25 January 2002, pp 10-19. Spic research center, VOC college, Tuticorin.
- Holmes Arthur (1965). Principles of physical Geology. The English language book society and Thomas Nelson and sons, Ontario.
- Hutchinson CS (1974). Laboratory handbook of petrographic techniques. John-Wiley and Sons, New York.
- Krumbein WE Pettijohn FJ (1938). Manual of sedimentary petrography. Appleton- century- crofts inc. New York.
- Macdonald EH (1983). Alluvial mining [The Geology, Technology and economics of placers]. Chapman and Hall London.
- Miller WJ (1964). An Introduction to physical Geology. D Van Nostrand Company inc., London.
- Pettijohn FJ (1969). Sedimentary Rocks. Oxford and JBH publishing co., Bombay.
- Rajamanickam GV (1983). Geological investigation of offshore Heavy Mineral placers of Konkan coast, Maharashtra. Phd thesis, Indian School and Mines, Dhanbad.
- Ramana MV, Gujar AR and Rajamanickam GV (1990). Shallow seismic studies on the Innercontinental shelf of selected bays, central west coast of India. Marine Geology 99: 333-343.
- Rosenblum S (1958). Magnetic susceptibility of Mineral in Frantz Isodynamic magnetic separator. American Minerologist 43: 170 – 173.
- Siddique HN, Rajamanickam GV, Gujar AR and Ramana MV (1982). Geological and Geophysical explorations for offshore ilmenite placers of Konkan coast, Maharashtra India, 3 – 6 May 1982, pp 749 – 762. Proceedings offshore Technology conference.
- Sutherland DG (1985). Geomorphological controls on the distribution of placer deposits. Journal Geological Society of London. 142 (5): 727-73