Review Article
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A guide to rapid identification of heavy minerals and highlights of heavy mineral distribution pattern along Indian coasts

Abstract

The economic potential of heavy minerals is very important .and has been discussed by a number of workers. The Heavy minerals are very helpful for provenance studies and have been used for correlation of stratigraphic units. Detail studies of some heavy minerals help in understanding the transport history and give a clue to processes and environment of deposition. Morphological character and colour of Heavy minerals has sometimes been used to locate the source rocks more categorically. The distribution pattern and mineral assemblages can also help in understanding the transport and direction of dispersal, the geomorphologic changes, tectonic implication, environmental discrimination, and depositional history. Modern generation scientists are allergenic to identification of heavy mineral grains under microscope. It is still used in some cases as a tool to corroborate with research findings. This important field is being neglected because of proper identification. In this paper attempt is being made to give a guide line for rapid identification giving different steps from detailed studies around Indian Coasts.

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Introduction

Importance of Heavy minerals is known to all geologists from a long time. The economic potential of heavy minerals is very important .and has been discussed by a number of workers earlier.[1–12] The Heavy minerals are mainly helpful for provenance studies. They have also been used for correlation of stratigraphic units. They help in understanding the transport history and give clue to processes and environment of deposition. They have also played important role in study of sea level changes. Morphological character and colour of heavy minerals has sometimes been used to locate the source rocks more categorically. The distribution pattern and mineral assemblages can also help in understanding the transport and direction of dispersal. The geomorphologic changes, tectonic implication, environmental discrimination, depositional history and a process response depositional model have also been very useful. Unfortunately because of sophistication and entry of mathematics, modern generation scientists are allergenic to identification of heavy mineral grains under microscope .The author has identified and studied more than 1000 heavy minerals in detail during the last 4 decades and gathered an impression that this important field is being neglected because of proper identification . Hence an attempt is being made here to give a guide line for rapid identification.

Step 1: Train the eyes to get a first hand idea of the mineral by look only. This can be achieved by studying a large number of standard slides. The author collected the individual grains of different minerals from Mineral Separation Laboratories and mounted them for detailed studies.

Step 2: Find the important identifying character of commonly occurring mineral. For convenience examples of few important minerals are given below:

a. **Andalusite:** Moderate Relief, weak birefringence, prismatic cleavage, weak Pale pink Pleochroism to colourless
b. **Apatite:** Moderately high relief, prismatic form, weak birefringence, colourless, straight extinction.
c. **Casseterite:** Very high relief, prismatic, yellowish, reddish brown, colour, Pleochroism in brown yellow or red.
d. **Epidote:** Yellowish green colour, weakly pleochroic in yellow– green colour, high Relief; Straight extinction in prism
e. **Garnet:** Very high relief, Isotropic, colourless with inclusions, absence of cleavage
f. **Kyanite:** Colourless, high relief, Bladed flakes, moderate birefringence, Parting present
g. **Monazite:** Prismatic, euhedral, rounded, egg shaped, strong to very strong birefringence
h. **Rutile:** Yellow to Reddish brown Feebly Pleochroic, Straight Extinction, Very High Relief
i. **Sillimanite**: Prismatic, Straight Extinction, strong birefringence, High interference colour
j. **Sphene:** Diamond shaped, euhedral crystals, Very high relief, Pleochroism in yellow and brown
k. **Staurolite:** High relief, Prismatic, straight Extiction. Pale yellow to yellowish brown Pleochroism
l. **Tourmaline**: Prismatic, euhedral, strongly plechroic, moderate relief. Colour variation seen
m. **Zircon:** Very high relief, strong birefringence, Elongate, equant, euhedral grain with inclusions.
n. Important Properties of common Heavy Minerals has also been given in a summarized form in Table 1.

Some of the important Heavy minerals under the Microscope have been shown in Figure 1.

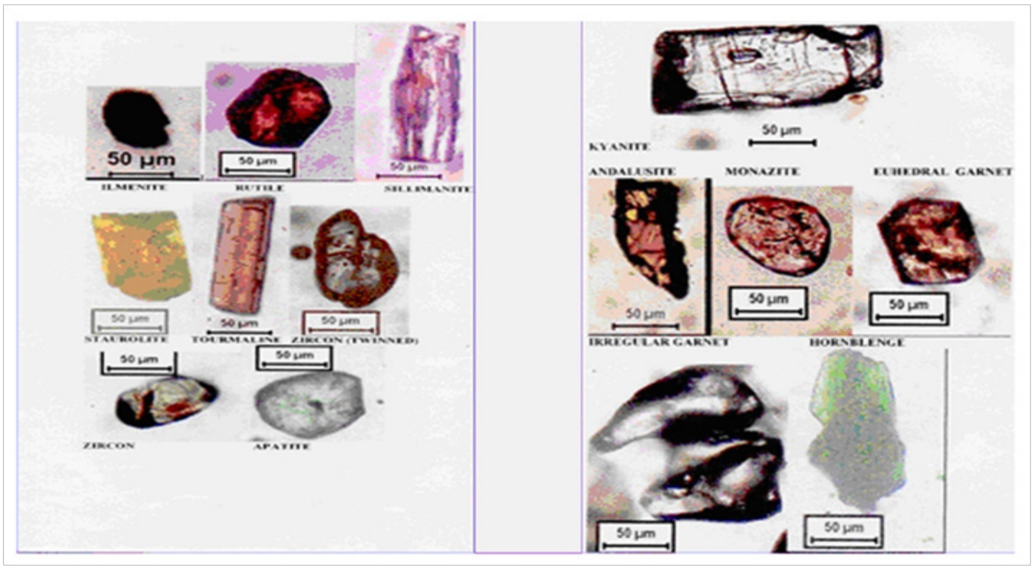

Figure 1 Commonly occurring important heavy minerals as shown under microscope.

Distribution pattern & mineral assemblages from east and west coast of India

Heavy minerals are deposits of high specific gravity, resistant minerals associated with beaches, rivers, sand dunes, buried channels, back waters, in the relict sand bodies and shallow offshore areas. Sometimes they form important economic deposits by the process of mechanical concentration due to weathering, transportation and deposition in suitable locations as stated above. Commonly occurring minerals formed in this way are magnetite, ilmenite, monazite, zircon, columbite, cassiterite, scheelite, wolframite etc. From a detailed study of Thousands of selected samples from the East and West coast of India and deep sea sands, and study of distribution maps of heavy minerals from different sectors of Indian shelf notable differences were recognized in the proportion of certain minerals. These have been discussed in several publications by the author earlier[13–24] and also in the book by the Author Mallik.[25] There is an influx of certain minerals in the eastern and western shelf of India as indicated in the Table 2 below:

A number of mineral assemblages characteristics of particular river basins could be delineated on the basis of the distribution pattern of the heavy minerals. Details of these studies have been dealt separately.[25] The heavy mineral suite indicates a number of stable and unstable minerals related to drainage basin of important rivers. There is an influx of garnet, sillimanite, zircon, apatite, opaques and glauconite in the eastern shelf sediments. Abundance of garnet and sillimanite in the eastern shelf is due to greater contribution of these minerals from the khondalitic rocks of the Eastern Ghat Mountains. Greater amount of Zircon is derived from the charnockite of this region. Apatite in the eastern shelf is derived from the granite rocks and kodurites occurring in parts of Orissa and Andhra Pradesh. In the western shelf relatively higher proportion of pyroxene may be attributed to Deccan Traps. The hornblende in these sediments is derived from the lower part of the Dharwars of the western Mysore, where amphibolite, hornblende schist and granulites occur in abundance. Muscovite is derived from the Mica schist, gneisses and pegmatites. The mineral assemblage of the different rivers like Hooghly, Dhamra, Godavari, Krishna etc. is different and can be distinguished easily.

Morphological character and colour of the heavy minerals in interpreting the source rocks

It is known that colourless to pale pink garnet is characteristic of Khondalites (garnetiferous sillimanite schist and gneiss), pink of Charnockites and deep brown to deep pink is characteristic of gneissic rocks. Based on these facts and on the basis of the study of shelf sediments of Godavari delta, it has been estimated that garnet of first variety is predominant in north of Godavari delta (50–100%), pink variety constitutes up to 50% and dark brown to deep pink variety up to 12%. Major portion of the sediments seem to have been derived from Khondalites. Pink garnets are absent in samples from south of Godavari delta to north of Krishna delta. South of Krishna delta colourless to light pink garnet predominates over deep brown garnet since khondalites and charnockites are the main contributors of sediments in this area.[13] Large and rounded zircons result due to long transport and recycling. Zircons are derived from a number of rocks studies by Siddiquie and Murthy[27] & Viswanathan and Murthy.[28] show that in parts of Eastern Ghat and Madras district rounded and rounded terminated zircons and those showing overgrowths are characteristic of derivation from khondalite, charnockite and gneissic rocks respectively.

Sediment transport and direction of dispersal

The mineralogical study of the offshore sediment gives valuable information on sediment transport. The study in the southern part of Ganges delta suggests south– southeasterly dispersal pattern noted from the distribution maps of the various mineral. Dispersal pattern shown by hornblende, tremolite–actinolite, zircon, monazite, opaques indicate a southerly or southeasterly transport in the eastern part. For the western part the transport direction is in northward direction. The data also tallies with the grain size studies. A comparative study of the mineralogy of the short cores with the DSDP sites in the Bengal Fan suggest that the sediments are transported far off to the south in the deep ocean situated thousands of kilometers away from the shores. Turbidity current played the most important role in the sediment transport. Thus the long distance sediment transport is clearly evident from the mineralogy of the Ganges delta mouth sediment and the mineralogy of the sandy layers in the DSDP site 218 in the Bengal Fan.[19–23] Off Mangalore in the western coast, a comparison of the mineral distribution pattern in the coarse and fine fraction differs in the size of the area of concentration. Based on the enlargement of the area of concentration in the fine fraction the direction of dispersal can be ascertained. The transport in the oceanic environment is accompanied by current carrying the material in traction or suspension and thus the interpretative direction of transport is quite clear and can be comparable with the current direction prevailing in the area.[5] In Godavari and Krishna river shelf the heavy mineral brought by the Godavari and Krishna river is deposited to the north of the delta as a result of the north and northeasterly current along the east coast of India and is well documented by the concentration pattern of the heavy minerals brought by these rivers.[13]

Geomorphological changes

Isolated concentrations of sillimanite, kyanite, monazite, zircon, orthopyroxene and hornblende occur in the offshore areas along the northern end of Gurpur bar near Mangalore. Such concentrations at the river mouth are anomalous and they are not related to present day feature. These concentrations represents the earlier debouch pattern of the Gurpur River. The southerly drift of the sediments initiated the formation of the Gurpur bar, which gradually deflected the course of the river southward and finally the river now joins the Netravati River in the south.

Tectonic implications

Detailed mineralogical studies of the deep sea sands of the Indian Ocean suggest two mineralogical associations

1. Hornblende– Opaque association with varying amounts of pyroxene– garnet, epidote, zircon etc.
2. Biotite– Muscovite– Chlorite assemblage.

A particular set of mineral assemblage is not associated with any particular stratigraphic interval in the recent sediment. Stability of provenance during short interval of time is indicated by similar mineralogy of the top and bottom layers of the short cores. However, long drill cores of the Ganges and Indus cone reflect tectonic instability resulting mineralogical variations. There is a change of provenance from high to low grade metamorphic rock to granitic, volcanic, and basic and pegmatite source during the Miocene– Pliocene intervals in the Himalayas. Maximum sediment supply from the mountains in the upper Miocene has been inferred by the maximum quantity of the heavy minerals (as high as 36% by weight). Distinct pulses of turbidity current activity was responsible for bringing more quantity of heavies with the terrigenous inputs and ultimately the fact can be correlated with the corresponding uplift of the Himalayas.

Process response depositional model

Trend Surface Analysis of HM off Mangalore indicated that linear trends of hornblende, garnet, sillimanite slope northwest. The linear trend has been controlled by the interaction of source, river flow, currents etc. The trends of mica are significantly different from those of hornblende, garnet and sillimanite. The difference is interpreted as due to the response to processes of the mineral. The mineral distribution patterns are the results of processes and response. Main process elements in order of their importance are source, river flow, current, waves and the response elements are source, mineral composition of sediments, specific gravity, shape, size and to some extent basin geometry. A process response model from such study of HM distribution pattern and has been illustrated by Siddiquie and Mallik.[26]

Environmental discrimination

Micromorphological studies of HM like ilmenite, sillimanite, monazite, rutile, garnet by SEM from Kerala and Tamilnadu indicate the development of a number of micro features. These features have been developed by mechanical and chemical processes influenced by physical properties mainly cleavage/parting etc. It is possible to make an environmental discrimination in terms of physical and chemical energy gradient from the study of these features. Structures formed by mechanical action and impact are fracturing, block formation, step formation, pitting etc. Impact marks, irregular blocks, etch– Vs, pits and grooves, step like features are formed due to the effect of chemical solution. Some structures indicate precipitation. Breakage patterns of some minerals like sillimanite indicates local source, perfect rounding and assemblage of micro textures indicate a ploycyclic nature of sediments and high– energy gradient. are sometimes formed by chemical activity. Rapid evaporation and exposure for long dry spells increase the alkalinity and etching processes. Some minerals have acted differently and the features found are a clue to the physical and chemical energy gradient. It is possible to establish a process– response– environmental model of deposition as has been done by the author earlier. Perfect rounding of monazite grains and rutile indicate a polycyclic nature and high– energy condition and a long transport condition in the deposition of environment.

Depositional history

Depositional history can be well understood from HM studies and it is possible to assume a depositional model by detailed HM studies as has been done for the Kerala beach, Studies of the riverbed and beach samples indicated a combination of two or more characteristic mineral from the major rivers of Kerala. Five HM provinces were recognized in the area. Vigorous wave activity during southwest monsoon, the long shore current and onshore offshore movement played an important role in sorting the HM sand. A three stage depositional model corresponding to initial, transgressive and regressive phases was suggested for this area (Table 3).

Conclusion

Notable differences were recognized in the proportion of certain minerals in the eastern and Western Shelf of India. The heavy mineral suite indicates a number of stable and unstable minerals related to drainage basin of important rivers. A number of mineral assemblages characteristics of particular river basins could be delineated on the basis of the distribution pattern of the heavy minerals. In Godavari and Krishna river shelf the heavy mineral brought by the Godavari and Krishna river is deposited to the north of the delta as a result of the north and northeasterly current along the east coast of India and is well documented by the concentration pattern of the heavy minerals brought by these rivers. The transport in the oceanic environment is accompanied by current carrying the material in traction or suspension and thus the interpretative direction of transport is quite clear and can be comparable with the current direction prevailing in the area. The micro features have been formed by mechanical and chemical processes influenced by physical properties mainly cleavage and parting. Structures formed by mechanical action and impact are fracturing, block formation, step formation, pitting etc. Due to the effect of chemical solution irregular blocks, etch– Vs, pits and grooves are formed. Perfect rounding and assemblage of micro textures indicate a polycyclic nature of sediments and high– energy gradient. A particular set of mineral assemblage is not associated with any particular stratigraphic interval in the recent sediment. Stability of provenance during short interval of time is indicated by similar mineralogy of the top and bottom layers of the short cores. Geomorphological changes have also been reflected from the distribution pattern in some sectors. A 3 stage depositional model involves initial supply of heavy minerals, erosion and reworking leads to formation of economic deposits in suitable environments mainly by physical processes.

Conflict of interest

In spite of the fact that heavy minerals have a great potential the study is being neglected for a long time and also the development could not progress due to conflicts of interest between the adjacent states or developing organizations The source area is very important and naturally the conflict started for sharing the benefits .The export/ import factor of the useful ores played significant role. The nearby states near the source will get maximum benefits. A number of private enterprises also play significant role and the Government has to adopt a suitable policy to solve the conflicts regarding the benefits they will get. Economic viability for study of economic deposit is important. Capital cost, operating cost are important to assess the annual revenue. Mining sector, processing sector, transporting sector plays important role in determining the annual revenue and the Govt. Should play an important role to distribute the benefits to avoid the conflict of interest between the states.

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