

## HEAVY MINERALS IN THE SEDIMENTS ON THE OUTER CONTINENTAL SHELF BETWEEN VENGURLA AND MANGALORE ON THE WEST COAST OF INDIA

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### Abstract

Fifty-eight sediment samples from the outer continental shelf between Vengurla and Mangalore were analysed for heavy mineral content. The heavy minerals consist of principally opaques, hornblende, epidote, garnet, sillimanite, hypersthene and zircon, with minor amounts of andalusite, augite, kyanite, monazite, muscovite and tremolite-actinolite. This mineral assemblage and the distribution pattern define four heavy mineral provinces on the continental shelf from Vengurla to Mangalore. Further, the mineral assemblage suggests derivation from mixed metamorphic and igneous terrain with a predominant contribution from metamorphic rocks.

### INTRODUCTION

The sampled area on the continental shelf extends from Vengurla to Mangalore (Fig. 1). The average width of the shelf in this region is about 82 km and the outer edge of the shelf occurs in the range of 90 – 120 m.

The purpose of this study is to describe the heavy mineral composition of the sand fraction and establish its provenance.

### PREVIOUS WORK

Siddiquie and Mallik (1972) studied the distribution pattern of heavy minerals on the inner shelf up to a water depth of 28 m off Mangalore. Kidwai (1971), Kidwai and Wagle (1975) studied the heavy minerals of the Miramar and Morgim-Arambol beaches in Goa. Recently, Nair *et al.* (1978) studied the topography and sediments of the area between Vengurla and Mangalore. These studies indicate that topographically the shelf is featureless and smooth up to 50 m and is covered by modern fine grained sediments. Beyond 50 m to 100 m the shelf has prominences and undulations of the order of 5 m or less and the texture of the sediments changes to sand and silty sand and are relict in age (Fig. 1).

### GEOLOGIC SETTING AND DRAINAGE BASINS

The continental shelf between Vengurla and Mangalore is bordered by Western Ghats which in this region consists of Dharwarian metamorphosed rocks of gneisses, schists, quartzites, phyllites, chlorite-schists, banded hematite quartzite (Fig. 1). Extrusive and intrusive igneous rocks of Cretaceous age also occur in small outcrops. Extensive laterite formations and the presence of iron rich deposits (banded ferruginous deposits) are characteristic features (Krishnan, 1968; Radhakrishna and Vasudev, 1977). The coastal plain is about 24 km in the northern part, but increases to 78 km towards the south at Mangalore. The climate is tropical with maximum precipitation during the monsoon. Four short rivers that drain the land areas and discharge into the sea in the area are Mandovi and Zuari in Goa, Kalinadi in North Kanara, Netravati in South Kanara. Mandovi and Zuari drain mostly the metamorphic terrain consisting of quartzite, phyllite, banded-hematite quartzite, gneisses and granite gneisses of Dharwar age but extrusive igneous rocks of Deccan trap also occur in the drainage basin of the Mandovi river. Further south, the

Kalinadi and the Netravati also drain through Dharwarian metamorphic rocks such as quartzites, phyllites, schists and gneisses.

✓ All these rivers are largely estuarine in character such that most of the sediment transported by them is apparently deposited within the estuaries or on the shallow portion of the shelf.

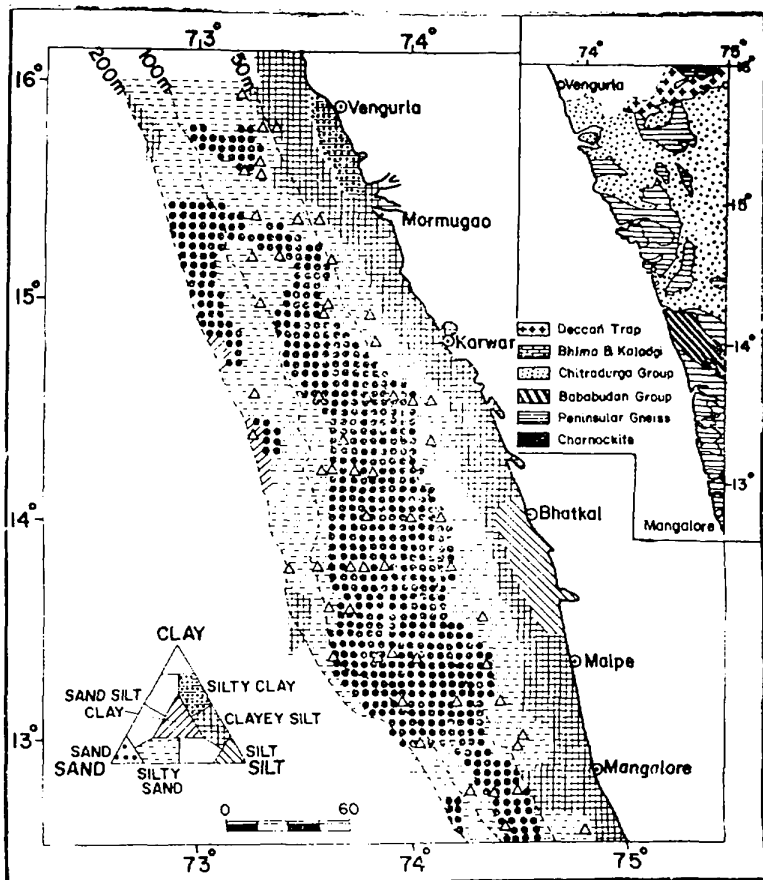


Figure 1. Surface sediment map (Nair *et al.*, 1978); triangles show location of samples used in the report. Inset shows the geology of the coast bordering the study area (After Radhakrishna and Vasudev, 1977).

The surface current direction off the West Coast of India is variable in different parts of the year. Between November and January, the current is from south to north and during the monsoon months the direction is southerly. No information is available on the magnitude and direction of the bottom current in the area.

#### PROCEDURE

129 sediment samples were collected from the continental shelf by a grab during the 18th Cruise of *R/V Gaveshani* out of which 58 samples were selected for the

present study (Fig. 1) as they had significant amount of heavy minerals. Sand size fraction ( $> 62 \mu$ ) was separated from the silts and clays by wet sieving and then treated with 10% HCl to remove carbonate components. Heavy and light minerals were separated with bromoform (sp. gr. 2.89); 300 heavy mineral grains were identified and counted under a petrological microscope. The heavy minerals were divided into three groups, (1) opaque minerals (2) non-opaque minerals and (3) altered minerals.

## RESULTS

### Heavy Minerals

The principal heavy minerals in the area are opaques, bluish green hornblende, epidote, garnet, sillimanite, hypersthene and zircon with minor amounts of andalusite, kyanite, monazite, muscovite, tremolite-actinolite, staurolite and collophane. These minor minerals rarely constitute 1% of heavy fraction but have some local concentrations of 2 to 5% (Table I). The heavy minerals are patchily distributed and vary from less than 1 per cent to more than 5 per cent by weight in the sand size fraction (Fig. 1). The more than 4 per cent zones are found in patches off Mormugao and Karwar, but off Karwar the zone is better defined and extends up to 100 m and even more. The sediments in general are more enriched in heavy minerals on the shelf between Vengurla to Malpe while the sediments on the shelf off Mangalore are relatively impoverished and vary from less than 1 per cent to 2-3 per cent. Some anomalous high concentrations of heavy minerals (more than 4 per cent) are found at about 100 m on the shelf between Karwar and South of Malpe.

The distribution pattern and characteristic of the principal heavy minerals are described below:

*Opaques:* Opaques are most abundant minerals in the area and range from 20 to 90 per cent. The grains are subangular to sub-rounded.

*Hornblende:* It is a very common mineral in the area and ranges from 1 to 30 per cent. It occurs mainly as green to bluish green prismatic grains which may indicate its derivation mainly from metamorphic rocks (Pettijohn, 1956). Many grains are nearly opaque and appear translucent only at the edges. Highest concentration of more than 15 per cent are found on the shelf off Mangalore, on the outer shelf at water depths of 80 to 100 m and more between Mormugao and south of Bhatkal. The mineral is present in high concentrations locally at water depths of 50 to 65 m off Mormugao and Karwar.

*Epidote:* It is a common mineral in the mapped area. It occurs in the range of 1-20 per cent and the typical grains are green and greenish yellow with characteristic ringed interference colours. Its distribution pattern is very similar to hornblende inasmuch as, in general, it is more concentrated in the sediments on the outermost

TABLE I. Percentage ranges of the different heavy minerals in the sand size fraction of the sediments

Mineral	Percentage
Opaque	26-93
Hornblende	1-32
Epidote	0-32
Garnet	0-8
Sillimanite	0-21
Tremolite Actinolite	0-20
Orthopyroxene	0-9
Zircon	0-4
Andalusite	0-3
Kyanite	0-1
Collophane	0-14
Monazite	0-1
Muscovite	0-5
Chlorite	0-3
Staurolite	0-3
Tourmaline	0-2
Altered minerals	0-14

part of shelf between Mormugao and Bhatkal. Off Mangalore episode is generally present in high amounts of 10-15 per cent at depths of 50 to 100 m.

*Garnet*: The mineral occurs in the range of 0-8 per cent and is typically irregular, angular, colourless to pink grains. The mineral is widely distributed in the range of 2-4 per cent on the shelf between Vengurla to Karwar and locally enriched in sediments to more than 8 per cent on the shelf off Mormugao. South of Karwar to Mangalore, the mineral is scarcely and patchily distributed.

*Sillimanite*: The mineral ranges from 1-20% and occurs in the sediments as long slender prisms and also as fibres. Sillimanite occurs in concentrations of 5-10 and 10-15 per cent on the shelf off Mormugao and Karwar and occurs up to water depth of 70 m. South of Karwar the mineral is either absent or present in amounts of 1-5 per cent.

*Orthopyroxene*: The orthopyroxene identified is mainly hypersthene which occurs in irregular grains with characteristic pleochroism. The mineral occurs in the range of 0-11 per cent and is relatively more common in the sediments on the shelf between Vengurla and Karwar. Relatively higher percentages of more than 4 and 2-4 are found at depths of 100 m off Mormugao and 100-200 m off Bhatkal respectively.

*Zircon*: Zircon occurs in the range of 0-5 per cent and the typical grain is colourless, euhedral and zoned. Zircon is sparsely distributed on the shelf between Vengurla to Bhatkal, but is found in the range of 2-4 per cent on the shelf south off Mangalore.

*Altered minerals*: In this category are included those minerals which could not be identified because of their highly altered appearance. Most altered minerals appear to be hypersthene, epidote and hornblende on the basis of their shape and colour. These minerals are relatively unstable minerals (Krumbein and Pettijohn, 1938). The abundance of the altered minerals is most prominent on the outershelf at water depths of 80-100 m particularly, between Mormugao and Karwar.

#### HEAVY MINERAL ASSEMBLAGE AND MINERAL PROVINCES

The distribution pattern and abundance of heavy minerals has been used to map heavy mineral assemblages and demarcate mineralogical provinces. Examination of the percentages of the individual minerals within and outside the assemblage reveals variation which is related partly to the variation in the composition of the source rocks and partly on the reworking by currents and waves on the basis of specific gravity, size and shape. Further, the current direction in the area is variable during different parts of the year. It is from south to north between November and January and north to south during the monsoon months. Such reversing currents may also lead to the mixing of the various minerals.

On the basis of the heavy mineral distribution pattern the area has been divided into four heavy minerals provinces (Fig. 2). (1) Mandovi-Zuari Province (2) Kalinadi Province (3) Netravati Province and (4) Offshore shelf Relict Province.

#### Mandovi-Zuari Province

This province represents the northern most part of the area, off the Mandovi and Zuari rivers and extends up to water depth of about 80 m. It consists of opaques, hornblende, epidote, garnet sillimanite and hypersthene. Opaques are the most abundant minerals and greatly dominate all other minerals. Hornblende and epidote are widely distributed in the range of 1-5 per cent but hornblende occurs in very high concentrations of more than 20 per cent in some samples off the Zuari river.

Garnet is also wide spread but sillimanite and hypersthene are restricted to north of the Mandovi river. Among the minor minerals tremolite-actinolite and chlorite are present and form locally more than 5 per cent.

The mineral assemblage in this province indicates predominant metamorphic source rocks with minor contribution from Deccan Traps. Precambrian quartzites, banded hematite-quartzite and phylites, gneises, hornblende-epidote-chlorite schists are the major rock types drained by the Mandovi and Zuari rivers. This mineral assemblage can be traced back to the drainage basins of Mandovi-Zuari rivers.

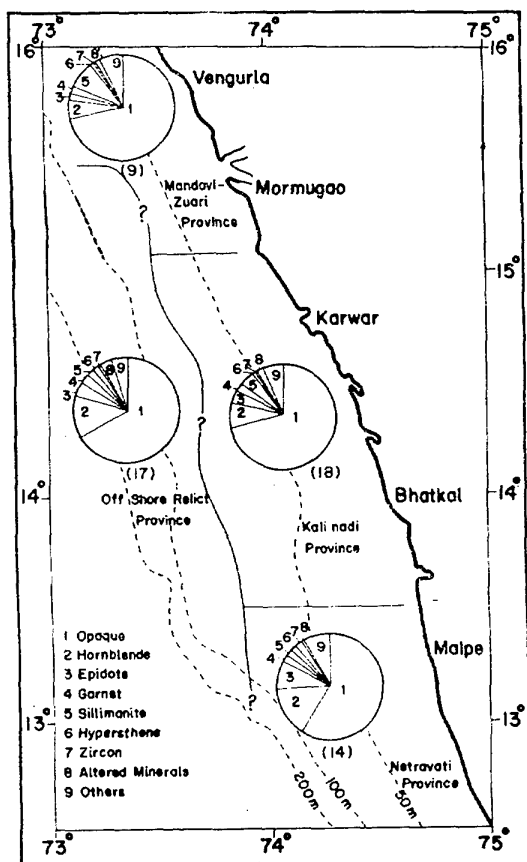


Figure 2. Heavy mineral provinces. (The number below the circle represent the total number of samples).

### Kalinadi Province

This province appears to occupy the largest area on the shelf, extending from south of Mormugao to as far south as Malpe. The province is very similar to Mandovi-Zuari Province in its mineral assemblage, but has higher amount of sillimanite, hornblende, epidote and garnet. The higher concentration of these minerals are found only on the shelf off Karwar, up to a water depth of about 50 m. Southward from Karwar to Malpe, the province is mainly characterised by abundant opaques

and lower amounts of hornblende and epidote. Among the minor minerals, tremolite-actinolite and staurolite are found in many samples forming as high as 5 per cent.

The mineral assemblage in the province is also indicative of predominantly metamorphic source rocks. The principal rock types found in the drainage basin of Kalinadi are pre-Cambrian gneisses, granites, granite gneisses, schists and some charnockites. The principal rock types found along the coast are hornblende schist and banded hematite quartzite (Fig. 1).

### Netravati Province

This province represents the southern most area and extends from Malpe southward to Mangalore at water depths less than 50 m to about 100 m. This province differs from the other two provinces, in its much higher concentration of hornblende, epidote and zircon. Garnet and hypersthene though present, are found only in depths less than 50 m between Mangalore and Malpe. Sillimanite is largely absent in this province. Among the minor minerals muscovite and tremolite-actinolite are found in many samples and each forms locally as high as 5 per cent.

The mineral assemblage in this province is in part derived from the drainage basins of the major river Netravati which drains mainly a metamorphic terrain consisting of pre-Cambrian granite gneisses, dolerites, ferruginous quartzites, and charnockite. In the lower reaches the river drains plateaus covered with laterite and Tertiaries.

### Offshore relict Province

This province represents the outer most part of the area at depths of about 80 m to 100 m, and extends from Mormugao to Malpe (Fig. 1). This province is characterised by hornblende, epidote, garnet, hypersthene, altered minerals with variable amounts of other minerals. It is designated as the offshore relict zone because heavy minerals in this province are associated with relict sediment and because this zone contains high concentration of heavy minerals.

### COMPARISON OF HEAVY MINERAL ABUNDANCES IN THE INNER AND OUTER SHELF SEDIMENTS OFF MANGALORE

Detailed studies of the heavy mineral distribution on the inner shelf off Mangalore by Siddiquie and Mallik (1972) permit a comparison with the distribution on the outer shelf off Mangalore. Table II shows the range of values for the heavy minerals from the inner shelf and outer shelf. As expected the outer shelf relict sediments are rather depleted in heavy minerals as compared to the inner shelf sediments. Depletion in the outer shelf sands may arise due to subaerial exposure and weathering during the time of Pleistocene low sea levels. It may also be due to the fact that much of the river-borne sediment is deposited either in the estuaries or within a limited distance (30 km) from the coast, thus depriving the outer shelf of sand sized sediments including heavy minerals.

TABLE II. Heavy mineral abundance of the inner and outer shelf off Mangalore

Minerals	Range (in sand size)	
	Inner shelf <sup>1</sup>	Outer shelf <sup>2</sup>
Hornblende	3-77	0-20
Garnet	0-98	0-4
Sillimanite	0-15.4	0-6.5
Tremolite Actinolite	0-10	0-5.5
Zircon	0-10.6	0-4
Epidote	0-15.1	0-21
Orthopyroxene	0-8.9	0-1

<sup>1</sup> Data from Siddiquie and Mallik (1972).

<sup>2</sup> Data from the present study.

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