

## Grain-size & Coarse-fraction Studies of Sediments between Vengurla & Mangalore on the Western Continental Shelf of India

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Grain size analysis reveals that except for distinguishing inner shelf and outer shelf environments no further division of the environment is possible. Coarse-fraction of sediments ranges from 0.1 to 99%. In general, inner shelf sediments are dominated by rock fragments and minerals (9-89%) while in outer shelf and slope sediments skeletal components constitute 15 to 100%. Non-skeletal components on outer shelf consist of ooids, grapestones and pelletoids (0.25 to 30%) in addition to rock fragments and minerals (3 to 68%). Skeletal components of inner shelf and outer shelf are dominantly foraminifers and molluscs while on slope they largely consist of foraminifers. Comparison of the carbonate assemblage of these sediments with those of the northern part shows minor differences in the non-skeletal components. A comparison of this area with the other continental shelves of the world indicates a general similarity in the assemblage.

**D**URING the 17th and 18th cruises of *RV Gaveshani* in March/April 1977, 183 grab samples of sediments were collected over an area of approximately 45000 sq. km of the western continental margin of India between Vengurla and Mangalore (Fig. 1). The samples were spaced at about 10 km along the transects which were 20 km apart. Topography, sediment distribution and related aspects based on the study of 130 of the above samples<sup>1</sup> showed that as elsewhere on the north-western shelf the inner shelf consists of modern silts and clays and that the outer shelf has relict, probably partly reworked quartz and calcareous sands. The upper continental slope was shown to consist of silts and clays. The samples chosen for the present study were, therefore, governed by this sediment distribution. Sixty-three samples were selected in such a manner that the maximum number (45) were from the outer continental shelf and upper slope where the sediment distribution map showed the greatest variation in the texture and least from the inner shelf muds which appeared to be uniform over a large area.

Results of grain-size analysis and distribution of coarse-fraction components based on these selected samples are reported in this paper.

### Methods

Size analyses were carried out by the standard sieve and pipette techniques<sup>2</sup>. Individual size fractions were reconstituted for the coarse-fraction studies<sup>3,4</sup>. Sub-samples were taken after coning and quartering and spread over a gridded tray. In each case about 300 grains were counted and the number percentage of the following components were determined: (1) foraminifers, (2) pelecypods, (3) gastropods, (4) pteropods, (5) others (including bryozoans, echinoids and their spines, ostracods, sponge spicules, algal fragments, etc.), (6) ooids,

grapestones and pelletoids, (7) rock fragments, (8) light minerals, and (9) dark minerals.

Graphic measures<sup>5</sup>: mean size, standard deviation, skewness and kurtosis were computed for each set of textural data on DCM Micro-system 1101<sup>6</sup>.

### Bottom Topography and Sediments

Nature of bottom topography and general distribution of sediments have been reported by Nair *et al.*<sup>1</sup>. The continental shelf in the study area has an average width of 80 km and the depth of the shelf break varies between 90 and 120 m. To a depth of 50 m the shelf is smooth featureless and covered dominantly by the fine sediments (clayey silt/silty clay). Beyond the depth of 50 m, small scale (<5 m) prominences and undulations appear and sediments also become coarse (silty/clayey sand to sand). Beyond the shelf edge the fall in the sea floor is sharp and fine grained sediments are present.

Taking into consideration the topographic features and the sediments, we have made the following divisions: (1) inner shelf (<50 m), (2) outer shelf (50-100 m), and (3) upper slope (>100 m).

### Results and Discussion

#### Colour of Sediment

The colour is shades of olive grey (Fig. 2). It is clear from the distribution of the colour that olive grey (5Y 3/2 and 5Y 4/2) sediments are common. Between Karwar and Malpe the light olive grey (5Y 5/2) sediment is found. Two small patches of yellowish grey (5Y 6/2) are also present on the outer shelf.

Olive grey coloured sediments may reflect high values of the organic matter<sup>7</sup> (up to 5%) while the light olive grey sediments may be due to the

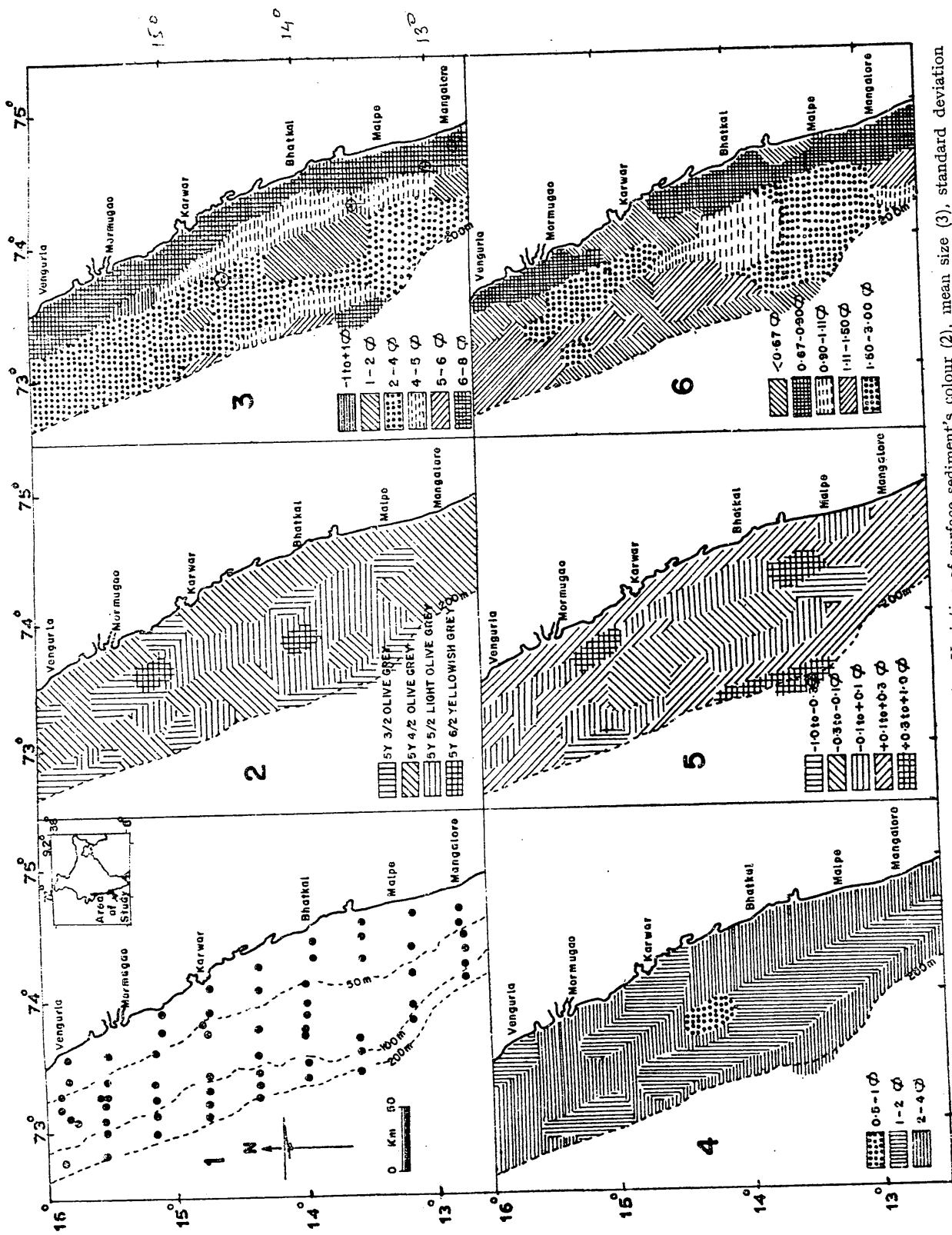


Fig. 1 — Sample location and general bathymetry. Figs. 2 to 6 — Variation of surface sediment's colour (2), mean size (3), standard deviation (4), skewness (5), and kurtosis (6)

low values of the same (<1%). Hence the organic matter may be one of the reasons for change in colour. Yellowish grey colour is a reflection of the iron staining on the quartz grains which are found on the outer shelf.

#### Variation in Textural Parameters

**Mean size ( $M_z$ )**—Variation of mean size in the study area is shown in Fig. 3. The major portion of the area has mean size between 2 and 4  $\phi$ , the range corresponds to fine sand size. The dominating mean size range on the inner shelf is between 4 and 8  $\phi$  corresponding to the silt size. In between these 2 zones a narrow zone of 4-5  $\phi$  (coarse silt) is also encountered along with few localized zones of coarse to medium sand (-1 to +2  $\phi$ ). Besides these, 2 small patches of medium silt (5-6  $\phi$ ) off Karwar and Bhatkal are also present on the slope.

This distribution of mean size does not show any relationship with the present day river mouths on the coast. If it had been so the coarse material would be expected on the inner shelf but such is not the case. Therefore, the absence of any relation may be attributed to the fact that either (i) these rivers do not have the capacity to transport large quantities of coarse material or (ii) whatever coarse material is carried by these rivers is trapped in the estuaries so that only the fine materials get accumulated on the inner shelf.

**Standard deviation ( $\sigma_1$ )**—Areal variation in the  $\phi$ ,  $\sigma_1$  values is shown in Fig. 4. Sediments ranged from 1-2  $\phi$  (poorly sorted) to 2-4  $\phi$  (very poorly sorted) with a patch of 0.5-1  $\phi$  (moderately sorted). Poor to very poor sorting implies that the transportation agencies are incapable of separating the sediments into different size classes.

**Skewness ( $Sk_1$ )**—Variation in the  $\phi$ ,  $Sk_1$  values are shown in Fig. 5. It ranges widely from -0.48 to +0.55  $\phi$ . However, 3 well defined zones in the area can be demarcated: (i) inner shelf with positively skewed sediments which have  $Sk_1$  between +0.03 and +0.25  $\phi$ , (ii) outer shelf sands which are generally negatively skewed and have  $Sk_1$  ranging from +0.3 to -0.3  $\phi$ , and (iii) shelf edge sediments which are dominantly positively skewed (+0.55 to -0.3  $\phi$ ).

It has been observed<sup>8</sup> that positively skewed sediments indicate accumulation of fine and negatively skewed sediments indicate winnowing of sediments. Relating the skewness of the sediment to the processes that are operating on the sediments in this area results in the following inferences: The positively skewed sediments on the inner shelf and the shelf edge means that these are regions where 'low energy' conditions prevail such that the fine sediments accumulate. It implies the absence of physical processes capable of removing the fine fraction. It has been reported earlier<sup>1</sup> that the occurrence of the fine sediments on the shelf edge is an anomalous feature since the shelf edge is supposed to be a region of high energy condition. The fact that the sediments are positively skewed on the shelf edge is further evidence in support of the low energy conditions on the shelf

TABLE 1 — SUMMARY OF STATISTICAL PARAMETERS

| Parameter          | Region (m) | Range ( $\phi$ ) | Average ( $\phi$ ) |
|--------------------|------------|------------------|--------------------|
| Mean-size          | <50        | 4.3-8            | 6.67               |
|                    | 50-100     | 0.49-7.34        | 3.17               |
|                    | >100       | 2.01-6.59        | 4.04               |
| Standard deviation | <50        | 1.76-2.37        | 2.07               |
|                    | 50-100     | 0.80-3.56        | 2.09               |
|                    | >100       | 1.12-2.81        | 2.01               |
| Skewness           | <50        | +0.03-+0.35      | 0.20               |
|                    | 50-100     | +0.30-0.48       | 0.08               |
|                    | >100       | +0.55-0.34       | 0.15               |
| Kurtosis           | <50        | 0.54-1.50        | 0.79               |
|                    | 50-100     | 0.59-2           | 1.36               |
|                    | >100       | 0.53-2.81        | 1.38               |

edge. The negatively skewed sediments on the outer shelf means that the fine fraction is winnowed away. The agents responsible may be currents or waves.

**Kurtosis ( $K_G$ )**—Distribution of  $\phi$ ,  $K_G$  values is illustrated in Fig. 6. The variation ranges widely from 0.53 to 2.81  $\phi$ , i.e. from very platykurtic to very leptokurtic. Very platykurtic and platykurtic zones are dominantly restricted to the inner shelf and slope areas. While the very leptokurtic and leptokurtic zones by and large are on the outer shelf with 2 patches of mesokurtic sediments (0.90 to 1.11  $\phi$ ), one off Bhatkal and other off Mangalore.

The areas (inner shelf and slope) where the percentage of the 2 main (silt and clay) populations are sub-equal, kurtosis ranges from platykurtic to very platykurtic. However, the area having unequal proportion of the main (sand and silt/clay) population is leptokurtic to very leptokurtic.

Statistical parameters for each region are summarized in Table 1.

#### Environmental Significance of Grain-size Parameters

Numerous attempts have been made<sup>9-14</sup> to demarcate the environment of deposition but the results have been highly variable. In the present study area no distinct environment such as deltas, spits, bars, etc. are found and the samples are entirely from the continental shelf and slope. The 2 basic types of the sediments (sand and mud) have, moreover, been deposited during different geological times, viz. late Pleistocene and Modern and the former probably has undergone reworking by the present hydraulic regime. It is, therefore, difficult to expect that division of the environments can be made on the basis of grain-size parameters. Scatter plots (Fig. 7) show that the values for the inner and outer shelf sediments cluster separately (Fig. 7A-C, E and F).

#### CM Pattern

Passega<sup>15,16</sup> and Passega *et al.*<sup>17</sup> emphasized that the characteristic of a depositional agent are reflected in the texture of the sediment. He has drawn CM (C = one percentile and M = median) pattern which showed that they are generally sharply

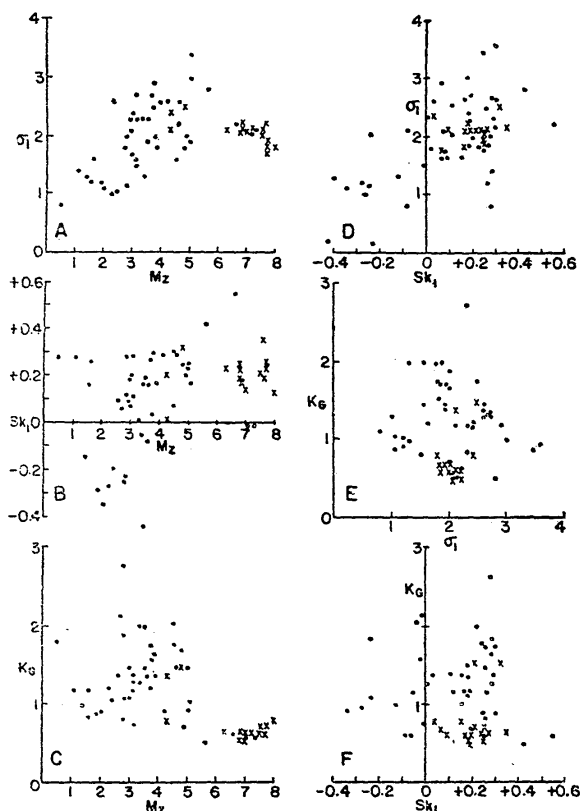


Fig. 7 — Scatter diagrams of various textural parameters [(A) Mean size versus standard deviation; (B) mean size versus skewness; (C) mean size versus kurtosis; (D) skewness versus standard deviation; (E) standard deviation versus kurtosis; and (F) skewness versus kurtosis. x, inner shelf samples and ●, outer shelf and slope samples]

defined and vary considerably with the type of the depositional agent. In the present study CM patterns of Passega were used to study the characteristics of the depositional agent in this area (Fig. 8).

Basic CM pattern reveals that the sediments under study can be grouped into 2 major populations, (i) as suspended load and (ii) as bottom suspension and rollings. It can be seen from Fig. 8 that the sediments under the 1st category are confined to the inner shelf and the sediments of the outer shelf and slope are confined to the 2nd.

The departure of points from the line  $M = C$  shows poor sorting even in the coarser half. This is in accordance with the calculated values of sorting (Fig. 4).

**Size Characteristics of Sediment**

Grain-size distribution of only 4 transects are reproduced in Fig. 9 to show the distinct bimodal and polymodal nature of sediment. They are off (1) Vengurla, (2) Karwar, (3) Bhatkal and (4) Mangalore. The degree of polymodality varies in different parts of the continental margin. Polymodality is due to the presence of heterogenous skeletal material and reflects the immaturity of these sediments. In some samples even 4 modes are present. Samples from inner shelf and slope mostly have values on the finer end while the outer shelf sediments are shifted towards the coarser

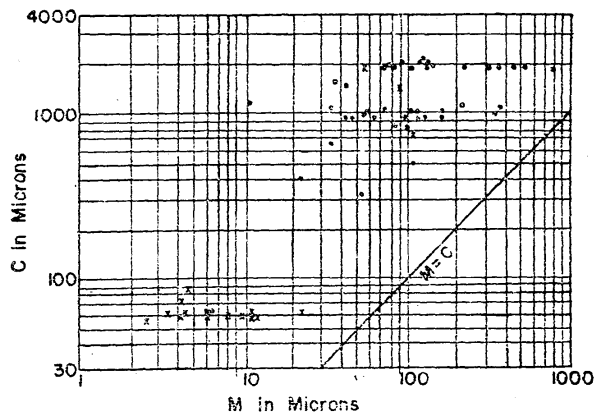


Fig. 8 — CM pattern [x, inner shelf samples and ●, outer shelf and slope samples]

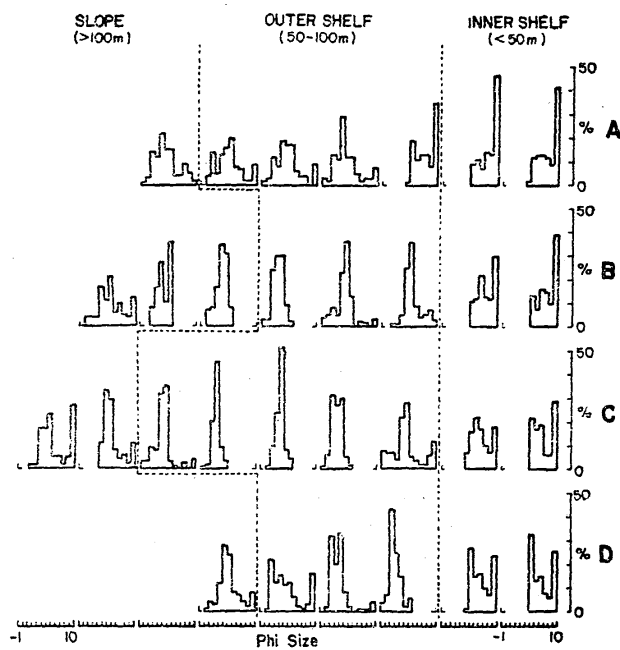


Fig. 9 — Size distribution histograms [Transects are off (A) Vengurla, (B) Karwar, (C) Bhatkal and (D) Mangalore]

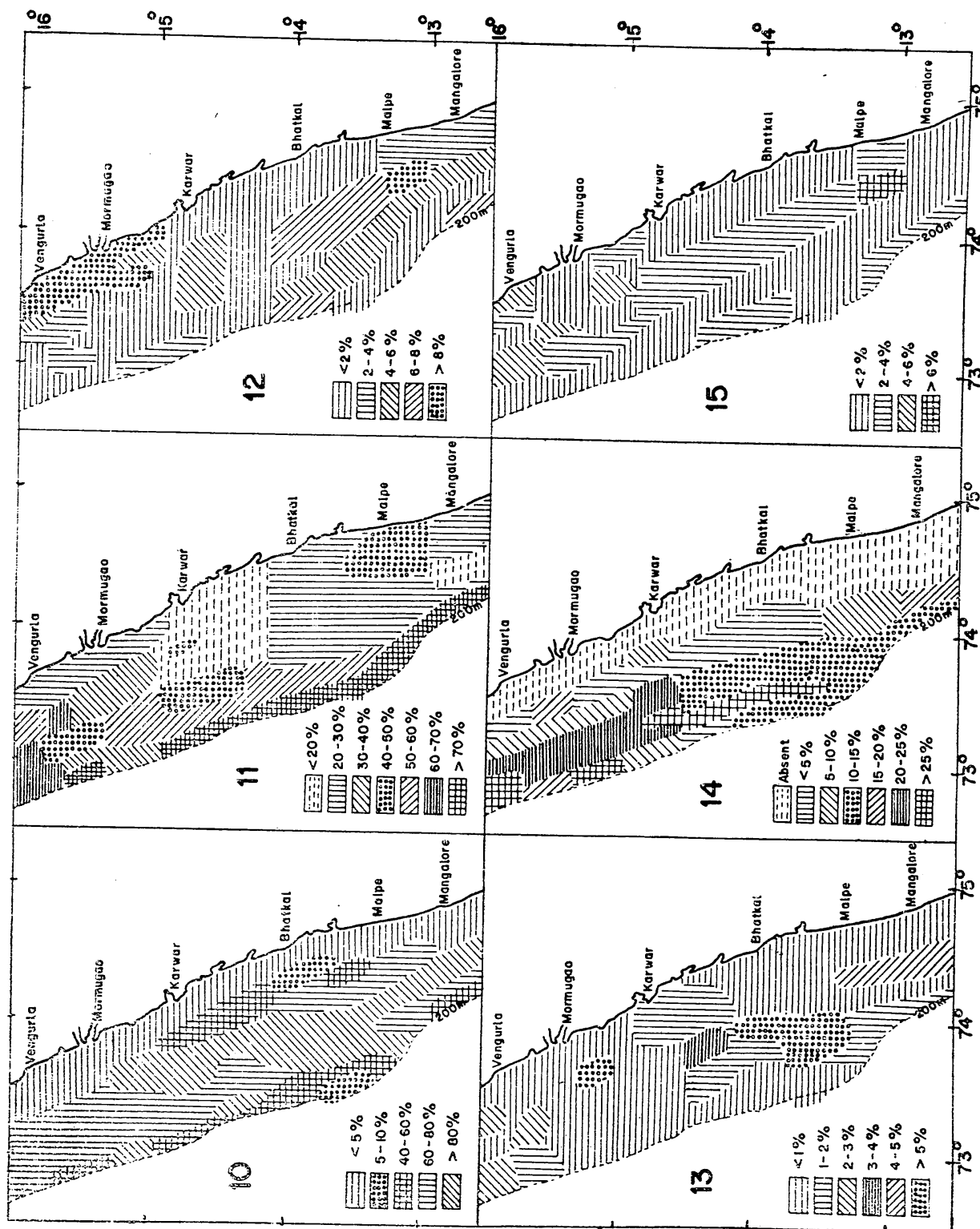
end or have a uniform distribution. It is interesting to observe that the modal classes (Fig. 9) of the sediment persist largely unchanged between the transects over a north to south distance of about 300 km. One possible agent that may give rise to this uniformity may be the south flowing monsoon current.

**Areal Distribution of Coarse-fraction Components**

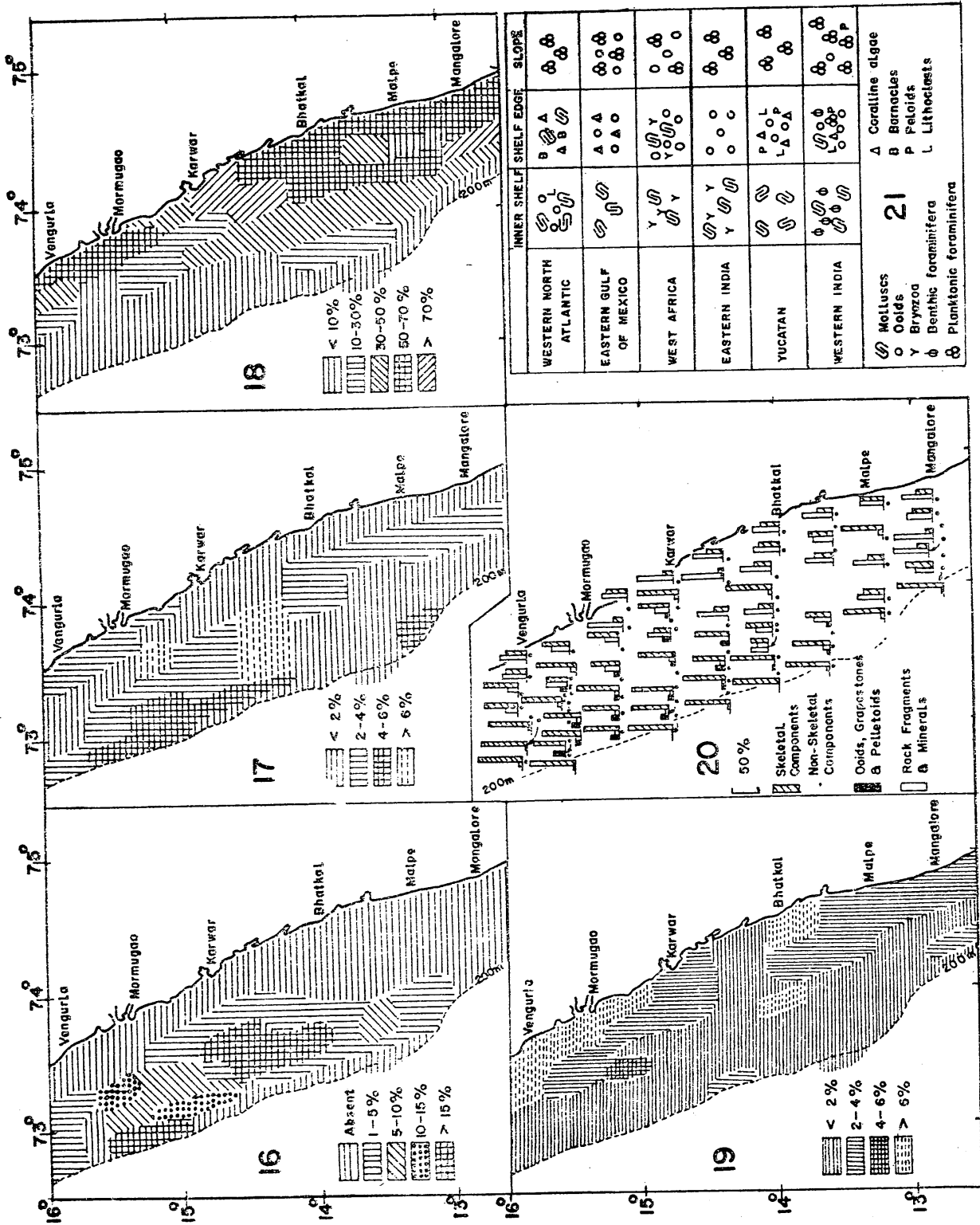
Fig. 10 shows the abundance of the coarse-fraction  $\mu(>62 \mu\text{m})$  in the study area. The inner shelf has low percentage of coarse-fraction (<5%), while in the outer shelf it is more than 80%. On the upper continental slope (>100 m) the coarse-fraction average is about 58%.

**Skeletal Components**

*Foraminifers* — Percentage of foraminifers in the coarse-fraction of the surface sediment is shown



Figs 10 to 15 — Areal distribution of (10) coarse-fraction (>62 μm) foraminifers, (11) pelecypods, (12) gastropods, (13) gastropods, (14) prteropods and (15) others in coarse-fraction



Figs 16 to 19 — Areal distribution of (16) ooids, grapestones and pellets, (17) rock fragments, (18) light minerals and (19) dark minerals in the coarse-fraction. Fig. 20 — Relative distribution of skeletal and non-skeletal components. Fig. 21 — Zonation of predominant grain types in carbonate sediments on open shelves<sup>23</sup> [Carbonate assemblages on western continental shelf of India shown for comparison]

in Fig. 11. On the inner shelf the foraminifera percentage does not exceed 50 except near Maple. On the outer shelf its range is between 40 and 70%. However, beyond the shelf edge the percentage reaches >70. High percentage of foraminifera beyond shelf may be attributed to the low percentage of terrigenous/detrital material on the slope coupled with high biological productivity.

**Pelecypods** — In general, distribution of pelecypods is highly variable (Fig. 12). A high percentage (>8%) zone is found extending from Vengurla to north of Karwar on the inner shelf while over the greater part of the shelf the percentage ranges from 2 to 8.

**Gastropods** — Gastropods are not as abundant as pelecypods (Fig. 13). Highest percentage (>5%) is found on the outer shelf off Bhatkal and the inner shelf off Mormugao. The <1% zone with a few exceptions is areally the most extensive.

**Pteropods** — Pteropods are absent on the inner shelf (Fig. 14). The zone of higher percentage (>25%) occurs on the upper continental slope between Karwar and Bhatkal and off Vengurla and Mormugao. In general, the abundance increases with increase in water depth.

**Others** — All the minor components are grouped under this head which includes bryozoans, echinoids and their spines, ostracodes, sponge spicules, algal fragments. In general their percentage do not exceed 4 (Fig. 15) except at 4 localized zones where the percentage ranges from 4-6. These zones are off Vengurla (near coast and outer shelf), off south of Mormugao (inner shelf) and off Malpe (inner shelf).

#### Non-skeletal Components

**Ooids, grapestones and pelletoids** — These are mainly found on the outer shelf. On the inner shelf and south of Malpe these are absent. Moreover, on the outer shelf their distribution is patchy with a maximum of 36% (Fig. 16).

#### Detrital Components

**Rock fragments** — Percentage of rock fragments in the coarse-fraction is shown in Fig. 17. Highest concentrations (4-6%) are found on the outer shelf off Mormugao, south of Karwar and on the slope off Maple. Comparatively high values of rock fragments on the inner shelf in the northern part (Vengurla to Bhatkal) may be due to the basaltic terrain, whereas the rock fragments on the inner shelf southward from Mormugao may be derived from the Dharwarian rocks which are probably more resistant to weathering than the basalt. This may also account for their lesser (<2%) percentage in this region. Higher values of the rock fragments on the outer shelf and the upper continental slope especially off Mormugao may be relict.

**Light minerals** — Inner shelf is dominated by these minerals and ranged from 50 to >70% (Fig. 18). On the outer shelf their percentage ranges 10-50 while on the slope the percentage is <10.

**Dark minerals** — Dark minerals are heavy minerals including limonitic infillings of the shells. Their

detailed study is under progress<sup>18</sup>. Their percentage is not very high (2-6%). A zone of comparatively high percentage (>6%) is found on the inner shelf between Vengurla and Karwar, and off Bhatkal (Fig. 19). The abundance on the inner shelf of these areas may reflect the nearness to the source rocks whereas the outer shelf patch off Bhatkal may be relict.

#### Comparison of Carbonate Assemblage of Study Area with the Northern Part

Skeletal and non-skeletal distribution on the northern part<sup>19</sup> and the present study area (Fig. 20) are similar. Of the non-skeletal components the ooids are much less (36%) as compared to the northern part (75%). Moreover, south of Malpe they are absent. The absence may be due to (a) the conditions were not favourable for their formation and (b) after formation those were destroyed because of the high energy conditions that prevail on the narrow shelf.

In general it can be summarized that the inner shelf and slope region of both the areas are dominated by benthic foraminifera and molluscs and planktonic foraminifera respectively. On the outer shelf both types of foraminifera and molluscs along with the ooids are present.

If we compare this open shelf with the Gulf of Kutch it is found that percentage of carbonate is less (10-50%)<sup>20</sup> in the Gulf. Molluscs are more abundant than foraminifera and non-skeletal components like ooids are absent<sup>21</sup>. We believe that the scarcity of the carbonate in the Gulf of Kutch may be due to either the high turbidity which reduces the biological productivity or the high tidal velocities (maximum 5 knots<sup>22</sup>) which may cause physical destruction of the carbonate components.

#### Comparison of Western Continental Shelf of India with Some Other Open Shelves

Comparison of carbonate assemblages on some of the typical carbonate dominated open continental shelves of the world<sup>23</sup> are shown in Fig. 21. The assemblages on the western continental shelf of India are in general similar to those found on the other shelves. Differences in the numbers and variety of the assemblages are minor and may be attributed to climate, variation in physiography of the adjacent coastal rock formation, bathymetry, hydrography and water chemistry.

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