

## Sandwaves of the Gulf of Khambhat

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In the Gulf of Khambhat the best formed sandwaves are seen in the west close to the Eastern Sand Bank. With increasing clay content and clay cover of the sea bed, the sandwaves become poorly formed. In the southern part of the Gulf the sandwaves are nearly symmetrical, <2 m height and 100-200 m wavelength. In the northern part of Gulf the sandwaves are asymmetrical, 3-4 m high and 300-400 m wavelength. The sediments in the crest are finer than those in the troughs. The extensive development of the sandwaves in the Gulf is related to the abundant coarse sediment from the rivers Narmada and Tapti. High energy hydrodynamic conditions primarily, due to large tidal range in the funnel shaped Gulf appear to be responsible for the formation of these sandwaves.

Flow-generated bedforms are an integral part of the process of sediment transport and these are related to flow conditions and quantum and size of the sediment input. Studies on bedforms are useful in interpreting the movement of sediment and bedload and for the suspension of material above the bed. A study of the bedforms, therefore, of present day environments and the simulation of hydrodynamic conditions in the laboratory have proved useful in understanding the origin of primary sedimentary structures in the relict sediments.

Ripples, mega-ripples and sandwaves represent best known flow-generated bedforms on the sea bed. The best known occurrence of sandwaves is in the North Sea<sup>1-4</sup> although sandwaves have also been reported from other areas<sup>5-9</sup>. In India the only reported occurrence of periodic bedforms is from the outer shelf off Bombay<sup>10</sup>. The sandwaves here are in 3 zones, 8 to 15 km in length in 60 to 77 m depth zone. The sandwaves have NNE-SSW orientation; height 1-2 m and wavelength 100 to 700 m, though commonly between 100 and 200 m. These sandwaves possibly represent bedforms generated by very high waves developed later during storms or as a result of fluctuations in deposition of sediments or they may be relict also.

### Description of Area

The Gulf of Khambhat (Cambay) is an inverted funnel shaped (70 km wide, 130 km long) indentation on the western shelf of India between the Saurashtra peninsula and the mainland of Gujarat. It receives drainage from Narmada, Mahi, Tapti, Purna, Ambica and Damanganga rivers. The drainage area of Narmada and Tapti is >150,000 km<sup>2</sup> and the average monthly discharge exceeds 2000 m<sup>3</sup>/sec<sup>11</sup>. These rivers

discharge a large volume of sediments as also suspended load. Concentration of suspended matter in the surface water of the Gulf is >4 mg/litre and at the bottom >8 and even 13 mg/litre<sup>12</sup>.

The important characteristic feature of the Gulf is its high tidal range. At Bhavanagar the tidal range is of the order of 10 m and at Daman it is 5 m<sup>13</sup>. Being influenced by the tides, the direction of currents changes and even reverses from SW to NE and vice versa. Surface current speeds up to 2.5 knots have been recorded.

### Methods

The southern part of the Gulf was surveyed during the 26th cruise of *R V Gaveshani*. The area lies 10 km east of the extensive sand bank, the Eastern Bank<sup>14</sup>. The depths in the area range from 8 to 38 m. Three NE-SW lines at 1.5 and 2 km intervals were surveyed (Fig. 1). The surveys included echosounding, side scan sonar and shallow seismic profiling and the positions were fixed by Shoran. The echosounding was carried out with a Kelvin Hughes MS-45 echosounder (30 kHz), with a basic scale of 0 to 40 m. Side scan sonar surveys were carried out with an EG and G Mark 1 B side scan sonar system. The fish of the side scan sonar was towed with a 600 m armoured cable and the towing depth controlled by increasing and decreasing the length of the wire in relation to the speed of the vessel. The transducer in the fish was operated with 10° beam depressions, 20° beam width at a range recorded at 250 or 500 m. A Huntec Hydrosonde (Frequency 5 kHz) was used for the shallow seismic profiling. Based on echosounding and shallow seismic records, samples were collected from selected locations with Peterson's Grab (area 900 cm<sup>2</sup>) during the 28th Cruise of *R V Gaveshani*. During sampling, the echosounder was

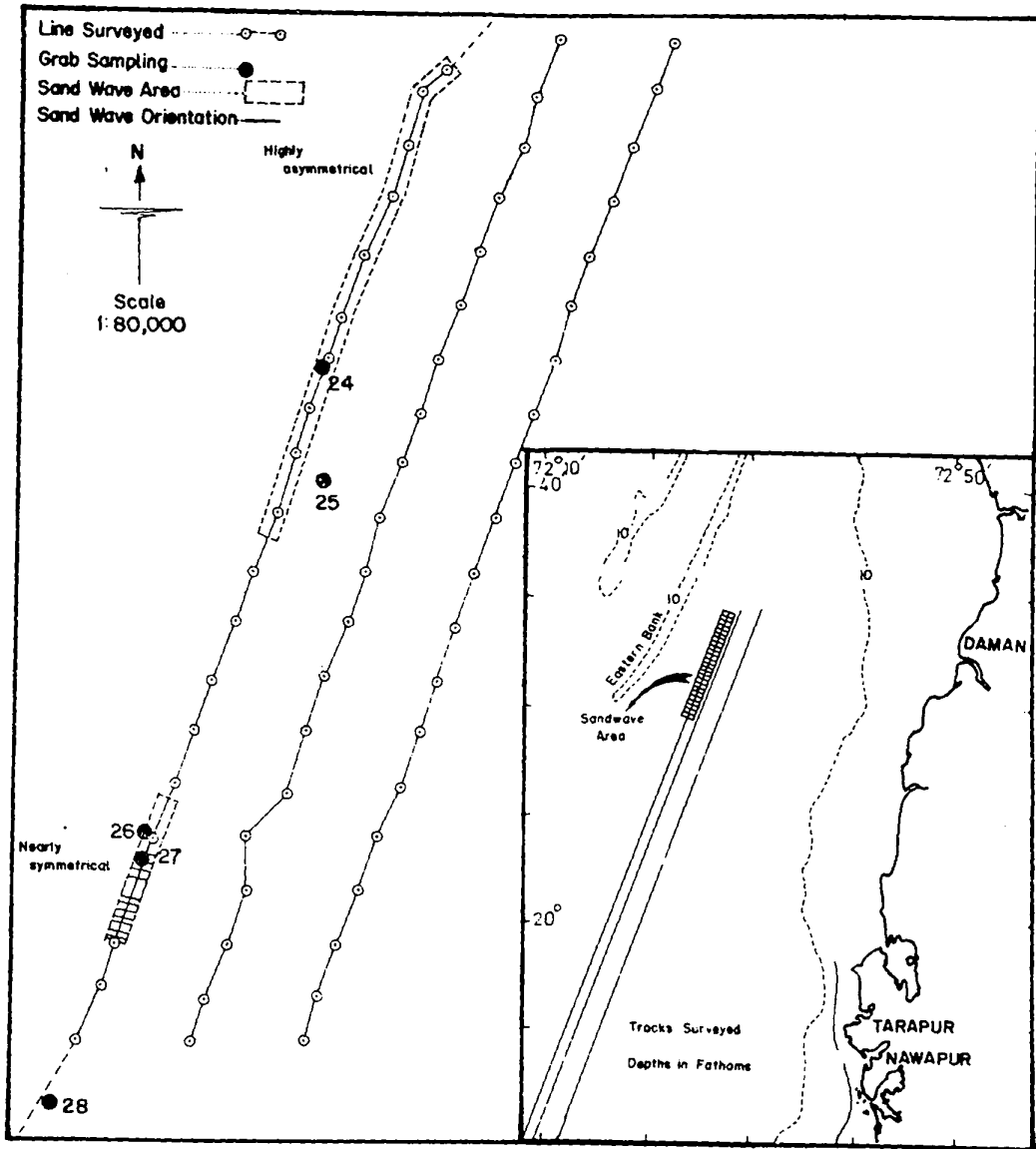


Fig. 1—Lines surveyed and zones of sandwaves [Inset is showing the location of area]

operated continuously to ensure collection of samples from the troughs and crests of the sandwaves.

Side scan sonar records were interpreted and corrected following the procedures given by Belderson *et al.*<sup>15</sup> and Flemming<sup>16</sup>. The height of the sandwaves were calculated from the echograms while the length along the crest and the wavelengths were estimated from the records of side scan sonar as suggested by Allen<sup>17</sup>.

Size analysis was done using standard procedures<sup>18</sup>. For the study of angularity, the sample was treated with dilute HCl to remove carbonate encrustation and

grains, and compared with Power's scale of angularity<sup>19</sup>.

### Results and Discussion

The records indicate a series of well-defined periodic bedforms. These are clear both in the records of echosounder and side scan sonar. The records indicate that sandwaves are better defined on the westernmost line and become gradually obscure and indistinct, towards the east because of a greater clay admixture in the sediments as the sand banks themselves get covered by clays. The present communication, therefore, is

based on the features recorded on the westernmost line surveyed and possibly these features extend further west and may be better developed because of their proximity to a sand bank.

The sandwaves in the area occur in 2 distinct zones about 4 km apart. The sandwaves which are < 1 m in height are not recorded properly on the sonographs but are clearly seen in the echograms. The southern group, extending over a length of 3 km, comprises nearly symmetrical sandwaves of about 1-2 m height and the wavelengths of 75 to 165 m (Pl. I, Fig. 1). The sandwaves extend 200 to 400 m along the crest (Pl. I, Fig. 2). The northern group extends over a length of 10 km and probably further north beyond the survey area. The sandwaves are asymmetric, the lee-side being almost vertical with height 2 to 4 m and wavelength 200-470 m (Pl. I, Fig. 3).

The classification of the sandwaves has not yet attained universal accord. The bedforms with a ripple-height of > 4 cm and up to a 'several decimeter' has been described by Allen<sup>17</sup> as 'large scale asymmetrical ripples' whereas McCave<sup>20</sup> considers ripples with length > 30 m and height > 1.5 m as 'sandwaves'.

Reineck and Singh<sup>21</sup> classify the ripples into 5 basic classes and accordingly the bedforms in the area under investigation are considered as giant current ripples. The presence of sandwaves supported by high energy hydrodynamic conditions prevailing in the Gulf and high suspended load confirms that the sediments at the seabed in the region are probably mobile.

Langhorne<sup>22</sup>, Bokuniewicz<sup>23</sup>, Jones *et al.*<sup>24</sup> have correlated the steep side of the ripple points with the direction of migration of the sandwaves. In the present study, the steep direction of the sandwaves points towards the south. It is, therefore, reasonable to deduce that the sandwaves in the Gulf are migrating towards south. McCave<sup>20</sup> and Stride<sup>1</sup> have reported that the height of the sandwaves decreases in the direction of migration. In the Gulf this has been confirmed.

Fleming<sup>5</sup> plotted the height versus wavelength of the sandwaves which confirms that the waves follow a well defined trend. A similar plot (Fig. 2) for the Gulf of Khambhat shows that the sandwaves of the northern and southern area fall in 2 different groups. The water depths in the northern and southern area are almost similar and as per Allen's<sup>17</sup> formula, for a depth of

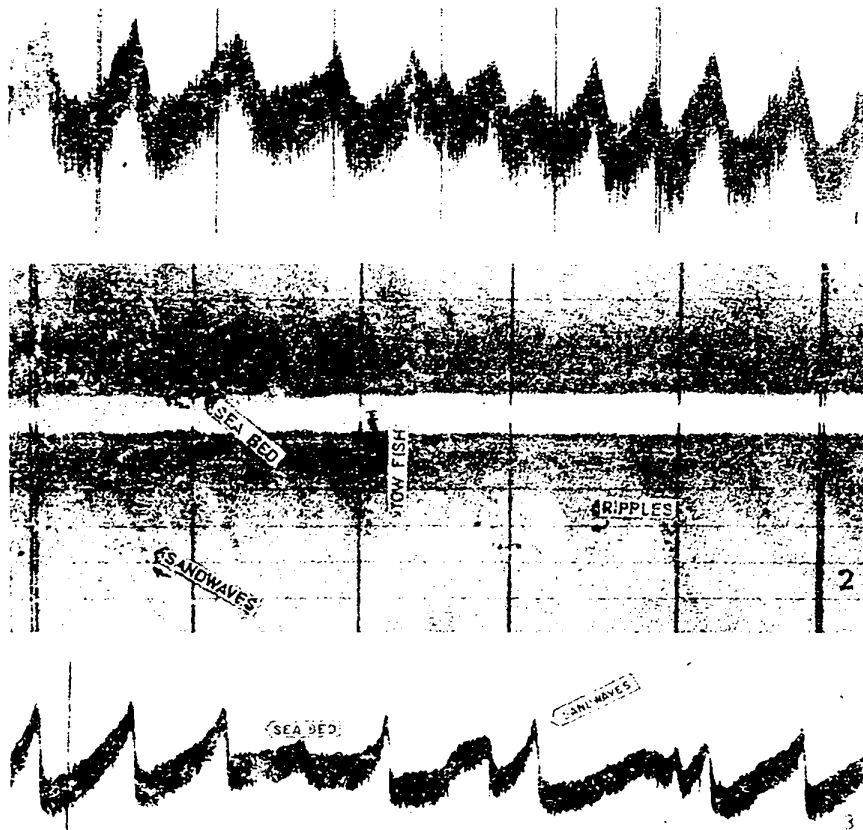


Plate I--Sandwave patterns [Fig. 1: Echogram showing nearly symmetrical sandwaves from southern group. Fig. 2: Sonograph showing sandwaves extension. Fig. 3: Echogram showing highly asymmetrical sandwaves from northern group]

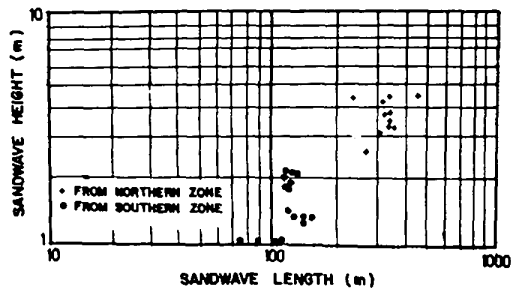


Fig. 2—Sandwave height as a function of wavelength

35 m, the wave height should be 5.9 m and wavelength 287 m. The observed parameter of sandwaves in the northern area are nearer to the theoretical value than in the southern area. According to McCave<sup>20</sup>, the lack of agreement between theoretical calculations and observed values may be due to a fall in the effective current speed or because of the decrease in the quantum of sediment transport at the bottom as compared to the total discharge. The latter in turn depends on the size and density of grains.

The occurrence of symmetric and asymmetric sandwaves may also be due to the quantum of sediment transport during the ebb and flood tide varying with the distance from the shore. The areas where it is nearly the same, almost symmetrical sandwaves may be formed.

The relation between the grain size and various parameters of the sandwaves has been widely discussed<sup>2,3,5,25</sup>. Field studies have been followed by model studies to correlate the grain size with the stream power, shear stress, stress, threshold friction velocity, orbital diameter of the wave motion, etc. with the formation of sandwaves. Even with these extensive studies the factors affecting grain size distribution between the trough and crest are poorly known. This may be because of the complication introduced by the reversal of strong currents in a tidal zone.

From the sandwaves of the Gulf of Khambhat, 5 samples were collected from the crests and troughs for the study of grain size and angularity. Though the number of samples analysed is too small to make any generalisation, it is observed that the sediments in the crests are fine-grained moderate to well-sorted and sub-angular while in the trough, these are coarse-grained poor to moderately-sorted and angular (Table 1). These observations are similar to those reported earlier by Harvey<sup>3</sup>.

Table 1—Grain Size and Shape of Sediments from Sandwaves

| Sample No. | Location | Mean size Mz (Phi) | Standard deviation | Skewness Sk (z) | Angularity |
|------------|----------|--------------------|--------------------|-----------------|------------|
| 24         | Trough   | 1.7                | 1.7                | -0.4            | A          |
| 25         | Crest    | 0.8                | 0.8                | -0.04           | SA         |
| 26         | Crest    | 0.48               | 0.48               | 0.24            | SA         |
| 27         | Trough   | 0.65               | 0.65               | 0.12            | A          |
| 28         | Even     | 0.58               | 0.58               | 0.28            | SA         |

A = angular; SA = subangular

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