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Active channel systems in the middle Indus fan: results from high-resolution bathymetry surveys

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Multibeam swath bathymetry survey was carried out in the middle Indus fan region in the eastern Arabian Sea. Using high-resolution bathymetry data, major morphological features such as the Raman seamount and the Laxmi ridge have been mapped. This study also reveals the presence of sinuous channel systems, continuing towards the distal fan. Though there are several reports on the presence of channels in different regions of the Indus fan, we report here the presence of active channels to the east of the Laxmi ridge. The total length of all channels along the channel axis is about 915 km. The individual spreads of the channels vary from 189.8 to 1980.5 m. Most of the channels are shallow with the average depth measuring about 60 m. The longest channel is about 256.3 km long, 702 m wide and about 57 m deep. The channels observed are similar to the land-based fluvial channels. The channels identified are highly sinuous in nature, their meanders and cut-off meanders are similar to the characteristics of fluvial channels. In general, average channel course in the study area is more than twice the straight course.

Keywords: Active channel systems, bathymetry survey, morphological features, submarine fan.

THE Indus fan in the Arabian Sea is the second largest submarine fan in the world, next only to the Bengal fan. The Indus fan extends in the Arabian Sea for about 1500 km and is up to 960 km wide, covering an area of ~1.12 million sq. km (refs 1–3). It is relatively young and therefore the surrounding sedimentary basins have moderate sediment thickness, usually not exceeding 3 km, with the exception of those off the Pakistan shelf and Surat, where sediments are >6 km thick[4]. The upper Indus fan extends from the foot of the continental slope at about 1000 m water depth to about 3300 m water depth, the middle fan extends up to about 3900 m and the lower fan up to a depth of 4600 m (refs 5–7).

Swath bathymetry surveys in the eastern Arabian Sea were carried out during the 26 days scientific cruise onboard *ORV Sagar Kanya* (SK-306) in October–November 2013 to obtain high-resolution bathymetric data towards preparatory site surveys for the proposed scientific drilling of International Ocean Discovery Program (IODP) in the Arabian Sea. In this communication we present the salient findings of the survey.

Vessel hull-mounted deep-water SB-3012 Multibeam Echosounder was used to carry out the present survey, which operated at 12 kHz frequency with an effective 150° of swath and provided coverage of five times the water depth. The data were acquired using Hydrostar software, whereas EIVA Navipac and ArcGIS 10.2 were used for processing and interpretation. A total of 27 coast-parallel traverses were made during the survey. The survey was carried out from 16°00′00″N to 18°12′10″N lat. and 67°53′27″E to 69°49′01″E long. A total of around 7740 line km data were collected along the charted track lines, covering an area of 54,253 sq. km. The location map and survey area are shown in Figure 1. The overall bathymetry map from the survey area is shown in Figure 2.

The general topography is quite smooth and non-undulating with depths varying from 3000 to 3600 m. The data provide clear dimensions and images of the Laxmi ridge and the Raman seamount – the most significant features in the area. The Raman seamount extends from 17°20′25″N to 16°53′43″N and 68°56′20″E to 69°07′10″E; it is about 49 km long and 23 km wide, N–S elongated with a height

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of about 1371 m, covering the basal area of around 772 sq. km. The NW–SE elongated Laxmi ridge is clearly seen in the data; it extends from 17°45′54″N to 16°00′56″N and 67°10′09″E to 68°09′47″E, with the areal extent of about 246 km long, 86.5 km wide and 835 m in height, covering the basal area of about 10,640 sq. km.

The bathymetry data also exhibit presence of submarine channels in the area. A total of five new channels are reported in this study (Figure 3). Channels 1–3 have mixed orientations. Channel 4A appears to be connected with channel 4B. However, the missing part in between is likely due to the gap in the data. The total length of all channels along the channel axis is about 915 km, whereas the straight downstream length is about 364 km. The longest channel 4A is about 256.3 km long and 702 m wide and about 57 m deep. Channels are either oriented towards the Indus canyon in the NE–SW direction, indicating them to be higher-order channels, or orientated along the Laxmi ridge in NW–SE direction, perhaps because of the impact of the ridge.

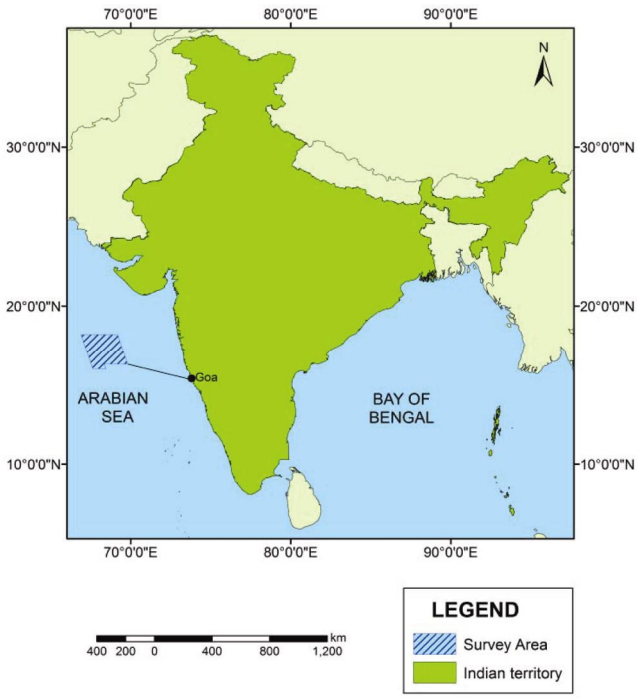

Figure 1. Location map and survey area.

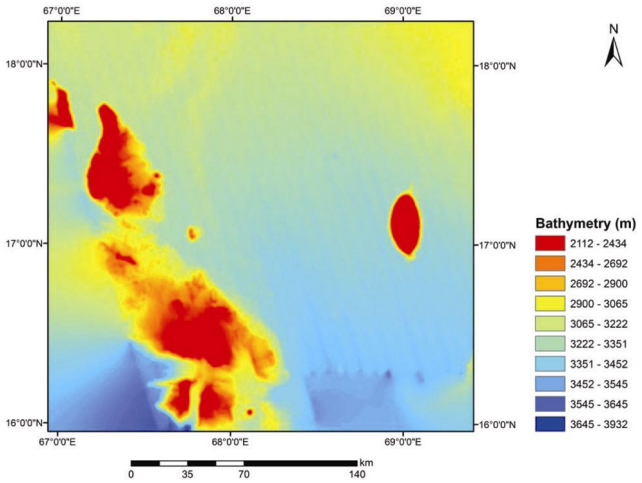

Figure 2. Bathymetry map part of the Arabian Sea generated from SB 3012 multibeam data.

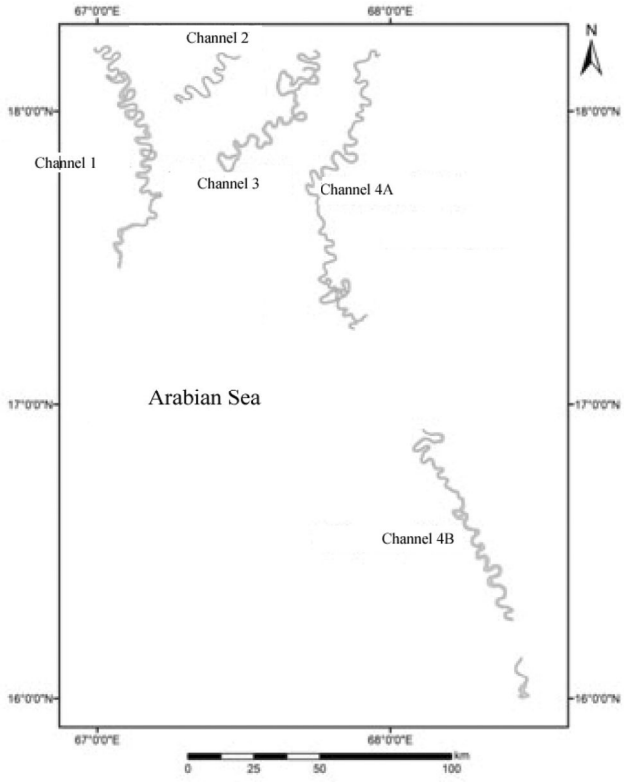

Figure 3. Channel systems mapped in the eastern Arabian Sea during the present survey.

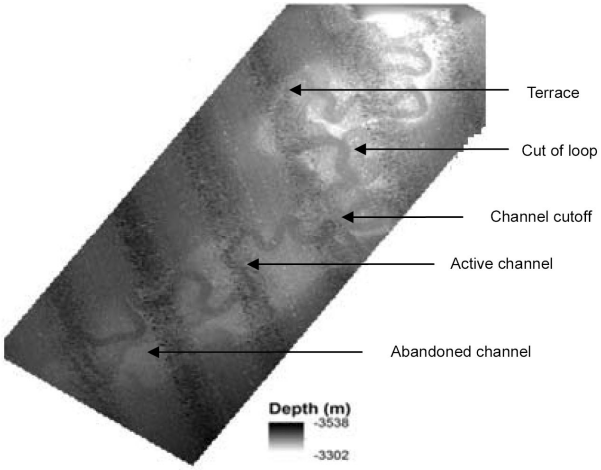

Figure 4. Channel characteristics of channel 2 generated from SB 3012 multibeam data.

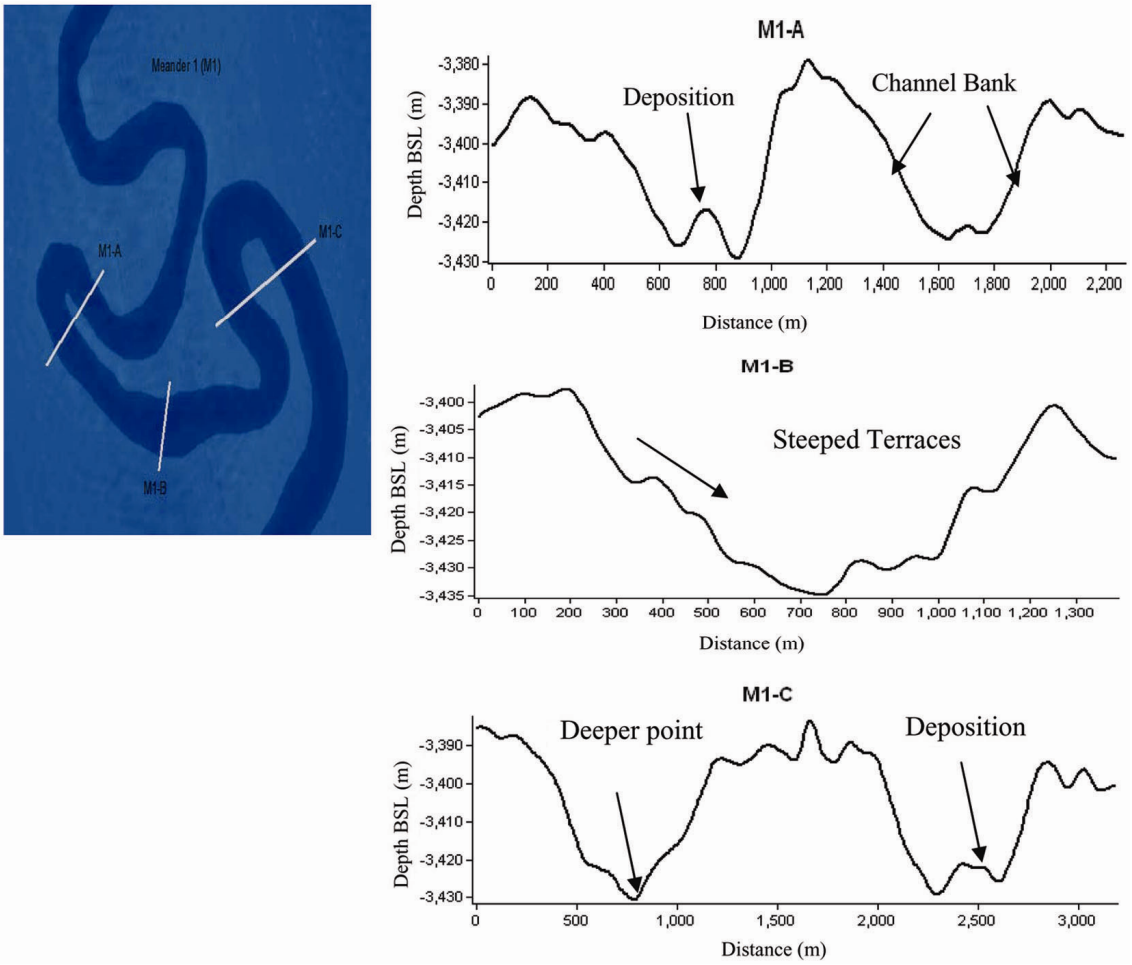

Figure 5. Channel profiles.

Table 1. Morphological characteristics of the channel systems in the area

Parameters	Measured values
Channel axis length (km)	914.88
Downstream straight distance (km)	364.24
Sinuosity	2.51
Downstream slope gradient	1 : 658
Maximum width (m)	1889.49
Minimum width (m)	189.81
Average depth of channel (m)	60

The channel characteristics and morphology vary in different parts of the fan. The channel systems of the Indus fan are part of the Indus river deep-sea routing system. The Indus fan is mostly fed by the Himalayan sediments carried by the River Indus. The river originates from the Tibetan Himalaya and flow W–S–W through the alluvial plains covering an area of approximately 1.12 million sq. km and finally reaches its delta, the Arabian Sea[8,9]. Within the sea, Indus canyon-channel systems provide the route for transport and deposition of sediment discharged to the deep sea. The Indus canyon-channel system of the Arabian Sea and Ganga–Brahmaputra canyon-channel system in the Bay of Bengal are the two largest canyon-channel systems of world. Similar to the Indus canyon-deep-sea channel system, about 31 deep-water canyon-channel systems were identified in various geographic contexts, but their extents in the sea are limited within a few hundred kilometres from the shelf and only a few are more than 1000 km.

The Indus canyon (swatch) originates in the shallow water of 20–30 m depth and cuts across ~100 km wide continental self. Its average width is ~8 km and depth is ~800 m. At 1400 m water depth, the canyon widens to 20 km and is 325 m deep[7]. In all fan systems, channel widths and depths decrease downstream[10], and it is also true for the Indus channel system. In the upper fan channels are up to 10 km wide and 200 m deep, whereas in the middle fan, channels are smaller and up to 30–40 m deep. In the lower fan, numerous small channels (<1.5 km wide and <5 m deep) with or without small levees are identified[7]. The channels observed in the present study are shallow channels averaging about 60 m deep, with their widths varying from 189.8 to 1980.5 m. Typically, they

exhibit characteristics of the middle Indus fan. The channel dimensions are computed and listed in Table 1.

The channels observed are similar to the land-based fluvial channels. The channels are highly meandered and their degree of meandering is represented by sinuosity. The sinuosity value of 1 represents a straight channel. The average sinuosity as calculated ~2.5 indicates high meandering and the channel travels more than twice its straight course. It is also observed that channels close to the Laxmi ridge are low in sinuosity compared to the other channels. Similarity between the fluvial and submarine channel is reported by various workers and the same has also been observed here[11–14]. The flow channels, meanders and meander cut-off appearances are similar to the characteristics of active fluvial channels (Figure 4). The channel profiles are shown in Figure 5. All channels are gently sloping and the small heights, undulations observed in the channel floor are perhaps due to the formation of various depositional features such as point bars on the channel floor. The deepest point in the channel moves towards the concave side of the channel bank and forms small valleys (V-shaped) in the channel floor.

The middle and lower Indus channel systems have been mapped by previous studies. As mapped by the Geological Long Range Inclined Asdic (GLORIA) side scan sonar[15,16], the middle Indus channel system is confined to the west of the Laxmi ridge. However, mapping by multibeam bathymetry has shown that meandering channels are present in the lower fan area between 120–13°N lat. and 67–68°30′E long. (ref. 17). Our present data, in addition, report the presence of active channels in the east of the Laxmi ridge.

This study brings out new images of channel systems in the eastern Arabian Sea in the middle Indus fan. Their appearances are possibly influenced by morphological expressions such as the Laxmi ridge and the feeder systems through the shelf region to the middle fan area. The channels observed are in active stage and are attributed as part of the currently active Indus canyon-channel complex system.

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