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Distribution of Indus born Mica along Gulf of Kachchh Coast: Implications in Understanding Current Dynamics

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Abstract: Indus is one of the major sources of sediments to the Gulf of Kachchh. Yet only its <63 micron fraction is studied in detail with regards to the offshore current dynamics. Hence here we present our study on characteristic signature of the Indus sediment load (i.e. mica minerals) in >63 micron size fraction along the coast of Gulf of Kachchh. The spatial distribution of mica minerals along the Gulf of Kachchh coast was studied which showed in general decreasing trend as we move along the northern and southern coast of the Gulf of Kachchh but, an increase in amount near the southern mouth at Okha. The study shows that the earlier proposed tidal barrier is ineffective in restricting movement of mica across the mouth of the gulf due to its characteristic transport mechanism. Also the presence of mudflats along the gulf of Kachchh coast plays a vital role as sediment receptors in the active sediment transport processes and mica minerals prove to be a promising simple tracer in studying the Indus born sediments in the region.

Keywords: Mica minerals, Sediment pathways, River Indus, Gulf of Kachchh

INTRODUCTION

The coastal geomorphic landforms are signatures of active offshore dynamics and sediment influx (Pethick, 2000). The knowledge of sediment transport and pathways is of very primary importance in coastal engineering and coastal management. Sediment transport processes are quite complex in macrotidal regimes due to high tidal range (Alexander et al. 1991; Kuehl et al. 1996; Hequette et al. 2008; Webster and Ford, 2010). The Gulf of Kachchh- one of the largest macrotidal regime in Asia has been studied extensively for its offshore dynamics and suspended sediment concentration (Nair et al. 1982; Chauhan, 1994; Kunte et al. 2003; Vethamony et al. 2005; Chauhan et al. 2006; Ramaswamy et al. 2007). Due to the absence of any other perennial river in the region, River Indus situated 100km north of the mouth of Gulf of Kachchh is considered to be the major source of suspended sediments to the gulf (Chauhan 1994; Chauhan et al. 2006; Ramaswamy et al. 2007). These studies are mostly concentrated on current measurements, suspended sediment concentration and its mineralogy. Hence the >63 μ size fraction of sediments has been neglected in study so far, although, studies on this coarser fraction of sediments are highly warranted for a better understanding of the transport mechanism and pathway in this unique macrotidal environment (Chauhan, 1994). The study of both, >63μ and < 63μ fraction is very much significant so as to better understand the sediment transport pathways in this macrotidal environment and in turn understand the complex interplay between sediment flux, sources and offshore dynamics. Study of such nature is very much warranted as the Gulf of Kachchh hosts variety of marine national parks, some endangered coral species along its southern coast (Ramaswamy et al. 2007).

Here we present our study on >63μ fraction of sediments from the entire Gulf of Kachchh coast, with special emphasis on distribution of mica minerals, as their presence along the coast has a special significance. The major objective of the study is to ascertain the use of mica minerals as tracers of River Indus load and understand the offshore current dynamics in light of mica mineral distribution along the Gulf of Kachchh coast.

STUDY AREA: GEOLOGY A ND OFFSHORE DYNAMICS

The Gulf of Kachchh (Fig. 1) is situated in western most part of India and is bounded by Kachchh in the north, Saurashtra in the south and Little Rann of Kachchh to its east and the Arabian Sea to its west. It is a semi enclosed basin with high tidal range of about 4m at its mouth and 7 m at its head, which increases to about 11 m in intrinsic creeks. The geological setup of Kachchh mainland is well

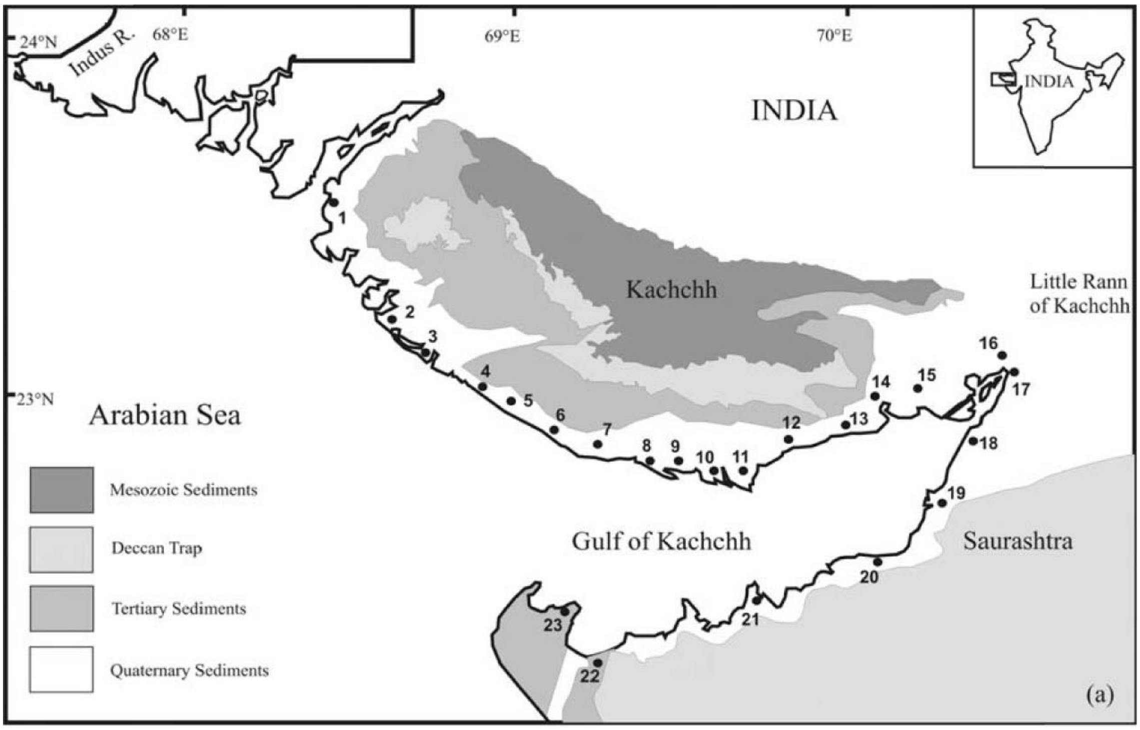

Fig.1. Geological map showing locations of sampling stations in the study area.

documented (Biswas, 1987, 1993). It comprises of sandstone, shale and limestone of Jurassic, Cretaceous and Tertiary age; basalts of late Cretaceous age (Deccan Trap) overlain by the laterite of Palaeocene age and semi consolidated to unconsolidated sediments of Quaternary age. On south of the Gulf of Kachchh, Saurashtra coast consists of dominantly basalts and laterite of late Cretaceous to Palaeocene age as well as limestone and shale of Mio-Pliocene age along with patches of miliolite limestone of Quaternary age (Bhatt, 2000).

Studies have revealed that the currents enter the mouth of Gulf of Kachchh from north and travel towards east to southeasterly direction all along the northern coast and get reversed at the head of the gulf, and travel all along the southern coast of Gulf of Kachchh to exit at the mouth (Fig.2a; Nair et al. 1982; Chauhan, 1994; Kunte et al. 2003; Chauhan et al. 2006). A noteworthy contribution was made by studying the suspended sediment fluxes using Ocean Colour Monitor (OCM) data in the Gulf of Kachchh (Kunte et al. 2003), which showed a northward movement of currents along southeastern coast of Saurashtra carrying suspended load and entering mouth of Gulf of Kachchh (Fig. 2b).

METHODOLOGY

The intertidal microenvironment is considered as one of the most active landforms in a coastal configuration for accessing sediment pathways. In all 23 major stations were selected along the entire Gulf of Kachchh coast and three samples from each station were collected from the intertidal microenvironment and packed in plastic bags (n = 69). The samples were then taken to laboratory where >63μ fraction and < 63μ fraction were separated following mechanical sieving and pipette analysis following standard procedure (Folk, 1974). About 1 g of >63μ fraction of each sample was separated by coning and quartering method to observed under binocular microscope and the concentration of mineralogical components was estimated by grain count method normalized with the total weight of the sample.

RESULTS AND DISCUSSION

Microscopic studies confirmed the presence of muscovite and biotite as dominant mica minerals in >63μ fraction. The Cretaceous, Tertiary and Quaternary formations of Kachchh have major lithology like basalt, sandstone, shale and limestone whereas, Saurashtra has late Cretaceous basalt and lateritic rocks with a cover of Tertiary shale and limestone (Fig. 1). These are devoid of mica which is a major product of metamorphic terrain. River Indus travels through a varied lithology including high-medium grade metamorphic, igneous and sedimentary rocks of

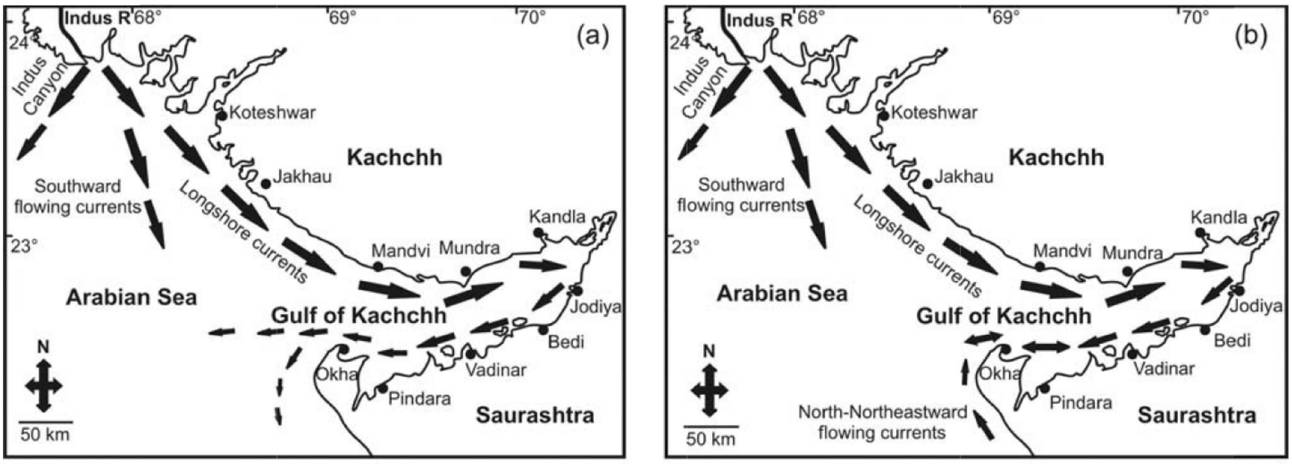

Fig.2. Dominant current direction in the Gulf of Kachchh during **(a)** summer months and **(b)** winter months (modified after Nair et al. 1982; Chauhan, 1994; Kunte et al. 2003).

Himalaya and debouches about 50 x 10^6 tonnes of sediments annually into the Arabian Sea (Chauhan, 1994; Garzanti et al. 2005). Part of these sediments travels under the influence of long-shore currents to enter the mouth of Gulf of Kachchh and moves eastwards. River Indus is known to have a significant amount of mica in its sediment load (Mallik, 1976; Garzanti et al. 2005; Chauhan et al. 2006). The mica minerals being flaky in nature are capable of being transported for longer distances in suspension due to their shape. It is estimated that >63μ size of mica grain has similar transit mechanism as of silt size quartz being transported by suspension making them hydraulically equivalent (Doyle et al. 1983).

The Gulf of Kachchh coast as classified by Prizomwala et al. (2010), exhibits four major segments on the basis of landforms and textural attributes of sediments. Table 1 shows compositional attributes of >63μ fraction of all stations along the Gulf of Kachchh coast, while Fig. 3 depicts variation in the concentration of mica along different parts of the Gulf of Kachchh coast.

Outer Sub-sink between Jakhau and Layza Nana

This straight coastal segment is consisting of sandy landforms like beaches and dunes, and exhibits higher concentrations of mica minerals (Fig. 3). Koteshwar is the most proximal station to mouth of River Indus and is situated near Kori creek. It has highest concentration of mica (24%). This higher concentration of mica minerals is linked with its proximity to the River Indus mouth. The lithoclasts concentration varies from 2-8%. This is due the coastal rivers which debouch their load with increasing lithoclast proportion mostly derived from basalt and sandstone country. The sediments of this segment have provenance signatures from Kachchh mainland in the form of increase in lithoclast percentage and from the River Indus as mica minerals.

Transition Zone from Layza Nana to Mundra

This segment hosts both, sandy landforms like wide beaches and dunes as well as muddy landforms like mudflats. The >63μ fraction of the mudflats exhibit a comparatively higher concentration of mica minerals (14-15%) than the sandy landforms (12-13%). The concentration of lithoclasts is low to about 2-4%. Studies on mudflats worldwide have

Table 1. Compositional attributes of >63 micron fraction from intertidal microenvironment of the Gulf of Kachchh coast

Sample Station	Quartz-Feldspar (%)	Mica (%)	Litho-clasts (%)	Carbonate (%)
Koteshwar	74	24	2	-
Jakhau	77	21	2	-
Pingleshwar	77	19	4	-
Khuada	78	17	5	-
Chachi	77	15	8	-
Layza Nana	80	14	6	-
Mandvi Palace	80	13	7	-
Rawal Pir	81	12	8	-
Modwa	83	12	6	-
Navinal	86	14	5	-
Mundra	81	15	4	-
Bhadreshwar	84	12	4	-
Jogni Mata	88	10	2	-
Gandhidham	84	14	2	-
Kandla	83	13	4	-
Surajbari A	89	10	1	-
Surajbari B	91	8	1	-
Navlakhi	80	3	9	8
Jodiya	78	5	8	9
Bedi	80	4	8	8
Vadinar	77	5	4	14
Pindara	76	10	8	12
Okha	70	12	8	10

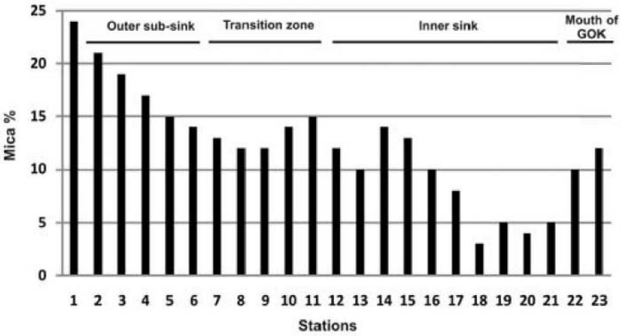

Fig.3. Distribution of mica along the Gulf of Kachchh coast, (1) Koteshwar, (2) Jakhau, (3) Pingleshwar, (4) Khuada, (5) Chachi, (6) Layza Nana, (7) Mandvi Palace, (8) Rawal Pir, (9) Modwa, (10) Navinal, (11) Mundra, (12) Bhadreshwar, (13) Jogni mata, (14) Gandhidham, (15) Kandla (16) Surajbari A, (17) Surajbari B, (18) Navlakhi, (19) Jodiya, (20) Bedi, (21) Vadinar, (22) Pindara and (23) Okha.

shown that mudflats act as major receptors of suspension load (Allison et al. 1996; Kuehl et al. 1996) and are potentially good archives to palaeo-environmental changes. Due to longer residence time of sediments in mudflats the relative concentration of mica minerals in mudflats is more than sandy landforms.

Inner Sink from Mundra to Vadinar

This segment is predominantly composed of monotonous mud bearing landforms i.e. mudflats. The mica mineral concentration is varying along the northern and southern coast of Gulf of Kachchh. Higher concentration of mica minerals is seen in mudflats of the Gulf of Kachchh coast i.e. Mundra (15%), Bhadreshwar (12%), Jognimata (10%), Gandhidham (14%) and Kandla (13%).These stations being distal ones compared to the stations of previous segments should continue a decreasing trend of mica concentration. However, a slight increase in mica concentration is seen at stations 10 and 11 that supplement the fact that mudflats act as ‘sub-sinks’ for the sediments being transported as suspension load in a sediment transit system. The southern coast having wide mudflats shows lesser concentrations of mica minerals with increased lithoclast and carbonate proportion as seen at stations 18 to 20 (Navlakhi, Jodiya, Bedi and Vadinar). The reason for this drop could be an increase in locally available sediments from the Saurashtra being transported by the rivers like Machchhu, Aji, Rangmati, Ghi, etc. These largely basalt derived sands suppress the relative proportion of mica in the >63μ sediment fraction in the mudflats.

Mouth of Southern Coast between Vadinar and Okha

The southern coast of Gulf of Kachchh hosts narrow mudflats and sandflats along with cliffs of Tertiary rocks. This part of coastline shows an increase in mica mineral concentration in comparision with the other stations of this coast. Mica concentration increases from 5% at Vadinar to 10% at Pindara and 12% at Okha Rann. A little increase in locally derived -lithoclasts and carbonate could also be seen.

Implications in Current Understandings

As per the current understanding (Nair et al. 1982) a tidal barrier exists across the Gulf of Kachchh that prevents Indus load from reaching directly southward to the Arabian Sea and diverts that towards the Gulf of Kachchh. The longshore currents move eastward along the northern flank of Gulf of Kachchh till they reach to the head of the Gulf of Kachchh, and continues to flow along the southern flank to finally exit the mouth at Okha from where they are throwing the sediments at depths of >200m into the Arabian Sea. A small portion of it is transported southward along the Saurashtra coast. This inferred sediment transport model was proposed on basis of mica and clay mineral distribution in and off the mouth of Gulf of Kachchh that has shown reduction in amount of mica and lack of variation in amount of clay minerals south of the tidal barrier. The presence of tidal barrier has been attributed to the higher amount of Indus sediments off the mouth of Gulf of Kachchh and dominance of characteristic peninsular load off the Saurashtra coast (Nair et al. 1982). However, this variation can also be explained on simple basis of ‘vicinity and proximity of sources’ off the Gulf of Kachchh mouth and Saurashtra. The smectite in <63μ fraction and bioclasts in >63μ fractions are considered as the characteristic peninsular load off the Saurashtra coast (Chauhan, 1994). As suggested by Chauhan (1994) the dominant current directions influencing the sediment distribution in and off the mouth of Gulf of Kachchh are northwest, southeast and east-west. Whereas, Kunte et al. (2003) presented a new finding of previously unnoticed seasonally northward and northeastward moving currents along the Saurashtra coast during the months of December to March.

Note the trend of mica distribution all along the coast of Gulf of Kachchh (Fig. 3). Due to presence of tidal barrier which effectively reduces the movement of mica across the gulf mouth, the amount of mica should subsequently reduce all along the coast and it should become negligible at the southern mouth of Gulf of Kachchh. However, an anomalous increase at southern mouth of the gulf has been noticed in our study (i.e. stations 22-Pindara and 23-Okha). This implies that there exists a very complex movement of currents in and off the mouth of Gulf of Kachchh, which are seasonally dynamic as supported by study of suspended sediment transport using OCM satellite imagery by Kunte et al. (2003). During summer the dominant currents in and adjacent to the gulf are southward, southeastward and east-west which controls the movement of Indus sediments and makes them to enter the mouth of Gulf of Kachchh and travel all along the northern flank, up till they reach the head of the gulf and then travel along the southern flank to finally exit the mouth (Fig. 2a). During winter months dominant current direction along the northern coast of Gulf of Kachchh remains southeastward and eastward whereas, currents move northward along the Saurashtra coast and partly enter in to the mouth of the gulf (Fig. 2b). On account of this, the increase of mica at southern mouth of the gulf can be explained by two ways;

1 The tidal barrier is ineffective in restricting the movement of mica across gulf mouth, due to transit mechanism of mica minerals being in suspension.
2 The southern flank of mouth of gulf receives mica from the seasonally northward and northeastward currents.

As stated earlier, fine to very fine mica grains behave hydraulically identical to silt size quartz (Doyle et al. 1983). Therefore, an anomalous increase of mica mineral concentration in >63µ sediment fraction from 5% at Vadinar to 10-12% at Pindara and Okha points more likely towards direct transport of mica from north as River Indus is well know rich fluvial source of it (Mallik, 1976; Garzanti et al. 2005; Chauhan et al. 2006). In absence of this possibility the increase in mica mineral concentration would not be of considerable amount, due to the lack of mica minerals in the country rocks of northern Saurashtra and near shore currents of the Arabian Sea in this part of the region. The second possible mechanism requires enough proportion of mica in the Arabian Sea near to Okha. Moreover, if it is true then seasonal variation in the concentration of mica should be there. In absence of such study we refrain from concluding a total rule out of this possibility too.

CONCLUSION

The mineralogical attributes of the >63µ fraction of the sediments from Gulf of Kachchh coastline suggest that the Kachchh coast receives sediments from the River Indus and Kachchh mainland, whereas along the Saurashtra coast the provenance signatures of River Indus gets subdued due to the sediment inputs from Saurashtra hinterland. Hence, (1) River Indus, (2) Kachchh mainland and (3) Saurashtra peninsula have been identified as the three major sources of sediments to the Gulf of Kachchh coast. Spatial distribution of mica minerals along the Gulf of Kachchh coast has a special significance as it indicates that the tidal barrier seems ineffective in obstructing the transport of mica minerals across the Gulf of Kachchh mouth and more importantly the mica minerals proves to be simple yet significant tracers of River Indus load in the region. The study also documents the role of mudflats as receptors of suspension load and in turn acting as 'sub-sinks' in sediment transport pathways in a coastal configuration.

However, we believe there is need to study the coastal sediments in the Gulf of Kachchh coast so as to unravel the complex sediment pathway and provenance discrimination within different size fractions to better understand the present day erosional engine acting in vicinity and distal catchments to highlight the seasonal as well as temporal variations.

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