

A Note on Geochemistry of Surface Sediments from Krishna-Godavari Basin, East Coast of India

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Abstract: A closely spaced 75 surface sediments drawn from "Gas Hydrate" Project taken up by National Institute of Oceanography on a regional scale from the Krishna-Godavari Basin (Latitude 15°35' to 16°20' N; Longitude 81°40' to 82°30'E) are analysed for texture, major, and some trace and rare earth elements to understand their source and provenance. Water depth in the study area varies between 300 to 2000 m and there is a WNW-ESE trending sedimentary ridge in the southwestern part of basin. Sediments are mostly silty clay in nature. Ti-bearing minerals such as titanite and pyrophanite are evident by the strong positive correlation between Ti and Ca ($r = 0.89$) and Ti and Mn ($r = 0.67$) respectively. An independent behaviour of Zr suggests occurrence of zircon mineral. The strong positive correlation among Al, Fe, Mg and K ($r = 0.68$ to 0.90) suggests their association with clay. The average total REE ($\Sigma\text{REE } 176 \pm 13$ ppm) abundance is similar to that of average shale with a flat shale-normalized REE pattern suggest a terrigenous source. High concentration of Fe ($6.45 \pm 0.43\%$), Ti ($0.82 \pm 0.07\%$), V (192 ± 23 ppm), Cr (128 ± 13 ppm) and Zr (159 ± 19 ppm) and presence of smectite as a major clay mineral suggest that Peninsular Godavari River has sediment influx from source rocks of Eastern India mainly Deccan Trap, Precambrian and Dharwar formation. Further, it confirms that the role of Ganges-Brahmaputra River sediments to the basin appears to be small compared to the Peninsular rivers.

Keywords: Surface sediments, Geochemistry, Silty clay, Smectite, Titanite, Pyrophanite, Zircon, Bathymetry, Krishna-Godavari Basin, East Coast of India.

INTRODUCTION

The discovery of large hydrocarbons reserves and gas hydrates in the Krishna-Godavari (KG) Basin, East Coast of India has attracted global attention and provided further impetus for intensified exploration and basic scientific studies. The Krishna and Godavari Rivers originate in the Eastern Ghats and traverse across the Peninsular shield comprising various geological units along their drainage basins such as Deccan Traps, Precambrians and Dharwar formations, and have contributed considerably to the sedimentation in the offshore domains along Central East Coast of India. Suspended fluxes of Krishna and Godavari Rivers are low during non-monsoon period (2.5×10^{10} g/y; 4.3×10^{10} g/y) compared to monsoon period (3×10^{13} g/y; 2.1×10^{14} g/y) respectively (Sarin et al. 1985). Although Ganges-Brahmaputra River system by and large is the single largest source contributing denuded Himalayan sediments (~1.06 billion tons/y) into Bay of Bengal (Milliman and Syvitski, 1992), the Peninsular rivers such as Krishna,

Godavari and Mahanadi also discharge considerable amount of sediment load in to the offshore areas along East Coast of India. Detailed bulk and partition studies of Al, Fe, Ti, Mn, Zn and Cu in the water depth from 30 to 500 m from the Eastern Continental margin sediments suggest that Al and Ti have highest (> 95 %) terrigenous source and Mn (~ 60%) has least terrigenous source and Zn and Cu have intermediate terrigenous source between Al and Mn (Mascarenhas et al. 1985). Based on the study of fourteen surface sediments from water depths ranging from 36 m to 1912 m in the Krishna-Godavari delta region, Narsayya, (2002) suggested that Si, Al, Fe, Ti and Mn were all of terrigenous origin. The elemental composition of Krishna and Godavari River bed sediments were carried out in detail earlier (Subramanian et al. 1985; Sarin et al. 1985; Ramesh et al. 1989; Biksham and Subramanian, 1988). During 2002-2003, National Institute of Oceanography, Goa has conducted detailed investigations involving multibeam bathymetry, side scan sonar and sub-bottom profiling and

collected closely spaced 75 gravity cores of ~6 m length for methane extraction, microbiological investigations, sediment texture and geochemical analysis under the Gas Hydrate Project. In the present investigation, surface sediments (0-5 cm) are selected from all the 75 sediment cores and analysed for major, and some trace and rare earth elements to understand their source and provenance.

MATERIALS AND METHODS

During *ORV Sagar Kanya* cruise 176 (May to June 2002), multibeam swath bathymetry system has been used to obtain swath bathymetry in the Krishna-Godavari offshore along East Coast of India. The cruise tracks are aligned ~NE-SW direction to achieve best possible coverage of multibeam swath. 75 long sediment gravity cores of ~6 m length were retrieved on board *Akademic Alexander Sidorenko (AAS-4)* cruise – 4 under Gas Hydrate Project during Dec.2002 to Jan.2003 (Fig.1). In the present investigation, only sediment core tops (0-5 cm) are used for textural and chemical analysis. Textural analysis of the sediment was carried out following the standard procedures of Folk (1968). Dried and finely powdered sediments are digested in an acid mixture of HF, HClO₄ and HNO₃ and made into clear solutions. The major elements were analysed on Inductively Coupled Plasma-Optical Emission Spectrometry at the National Institute of Oceanography, Goa and few trace and rare earth elements on Inductively Coupled Plasma-Mass Spectrometry following the

procedure of Balaram and Rao, (2003) at National Geophysical Research Institute, Hyderabad. Accuracy is checked by international reference materials (MESS, BCSS) and precision by analyzing duplicate samples and which are found to be within the acceptable limit ($\pm 5\%$). Representative sediments were analysed for mineralogy by X-ray diffraction. Glass slides of < 2 micron were prepared and run on Phillips X-ray diffractometer with Cu K α radiation with 2 θ from 3° to 30°. The mineral identification has been done according to Carroll (1970).

RESULTS AND DISCUSSION

Bathymetry

The water depth in the study area varies from 300 to 2,000 m. The swath bathymetry map generated from Hydrosweep shows a WNW-ESE trending sedimentary ridge in the southwestern part of study area (Fig.2). The crest of the ridge rises from 1,200 m to 1,800 m suggesting height of 600 m, and width of ~10 km. The central part of the study area has a gentle smooth topography and water depth gradually increases from 650 m to 1,500 m towards deep-sea side. In the northeastern part of study area a fault controlled fan like geomorphic province is present (Pateria et al. 1992). About 200 m height an elevated tongue shaped plateau with steep fall on either side is noticed. A regional multichannel seismic line E-W shot off ~1 degree south of Godavari Basin shows presence of four seismic sequences (Pateria et al. 1992). The section also shows a marginal fault towards west, perhaps corresponding to the continental margin and/or rise along the east coast of India. A part of the section ~81° E and 82° E longitude is characterized by two fault systems with flower geometry having horst structure and another fault system on east having graben character. Presence of two mounts in southern portion of the present area perhaps displays positive features of two horsts and a depression on eastern side representing a negative feature of graben like structure. Thus, the surface expression of two horsts invariably looks like a ridge in the study area. These bathymetric features control the sedimentation in the study area.

Sediment Texture and Clay Mineralogy

The KG Basin surface sediment's clay, silt and sand content varies from 51% to 84%, 16% to 49% and 0.01 to 3% with an average of 75%, 24.6% and 0.4% respectively. This suggests that sediment texture is mainly silty clay similar to the Krishna-Godavari River mouth sediment (Rao, 1991). Clay minerals have been used to determine

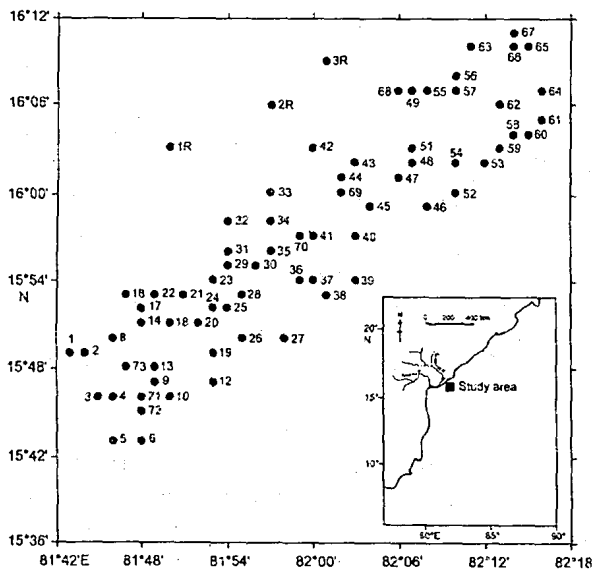


Fig.1. Map showing the study area (inset) and location of sediment cores in the Krishna-Godavari Basin, East Coast of India.

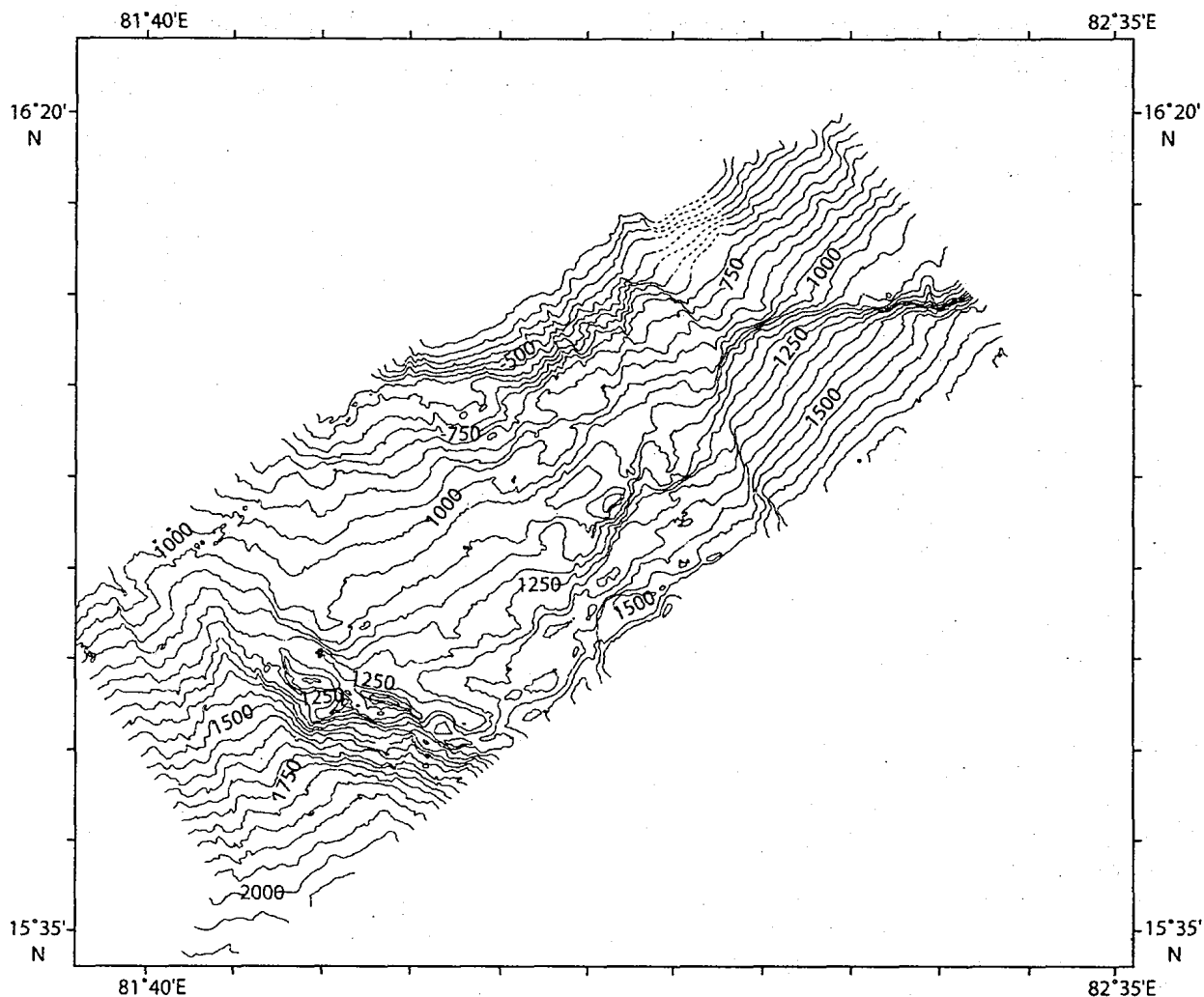


Fig.2. Multibeam bathymetry map of the study area.

the provenance, sediment transport pathways and depositional environment. Smectite is the major clay mineral (70%) with minor quantity of kaolinite and illite (Fig.3) and is similar to KG River mouth and shelf sediments (Kolla and Rao, 1990; Rao, 1991). On the other hand, the clay minerals of the Bay of Bengal sediments are mainly illite and small quantity of kaolinite and smectite mainly derived from the weathering of the Himalayan rocks through Ganges-Brahmaputra River system (Siddique, 1967; Goldberg and Griffin, 1970; Roonwal et al. 1997; Faruque et al. 2002). Therefore, presence of abundant smectite in the KG Basin might have been brought by the Peninsular rivers such as Krishna and Godavari Rivers mostly by the chemical weathering of Deccan basalts under humid and warmer climatic conditions. Smectite is a very fine-grained clay mineral deposited in low energy environments. There

is a distinct clay mineralogy variation in sediments brought by Krishna-Godavari and Ganges-Brahmaputra River systems. Therefore, presence of abundant smectite and minor quantity of illite in the KG Basin suggests that Himalayan derived material through Ganges-Brahmaputra River system reaching KG Basin appears to be not very significant.

Geochemistry

The average chemical composition of sediments from the KG Basin along with Ganges, Brahmaputra, Krishna and Godavari River sediment are presented in Table 1. Correlation matrix between the elements analysed are presented in Table 2. Surface distribution of clay content and some representative elements such as Al, Ti, Zr, Sc and Σ REE are shown in Fig.4 to understand the aerial

Table 1. Comparison of average elemental concentration of sediments from KG Basin (n = 75) with that of Ganges, Brahmaputra, Krishna and Godavari River sediments

Element	Krishna-Godavari Basin sediment	Krishna River Basin sediment [#]	Godavari River Basin sediment [#]	Ganges River Basin sediment [#]	Brahmaputra River Basin sediment [#]
Al (%)	8.04 ± 0.43	3.4	4.3	4.6	5.6
Fe	6.35 ± 0.28	4.2	5.7	2.1	2.9
Ti	0.82 ± 0.07	0.55	0.86	0.30	0.31
Mg	1.50 ± 0.09	1.30	1.37	1.30	1.65
K	1.67 ± 0.01	1.07	1.03	1.30	1.20
Mn	0.08 ± 0.01	0.10	0.10	0.04	0.06
Ca	2.03 ± 0.26	5.30	4.50	2.34	1.93
Ba (ppm)	205 ± 3.2	425	495	348	347
V	192 ± 23	203	297	86	137
Cr	129 ± 13	68	126	52	100
Cu	91 ± 20	49	82	21	17
Ni	84 ± 9	30	51	20	47
Zn	151 ± 25	31	54	46	47
Zr	159 ± 19	n.a	n.a	n.a	n.a
Sc	25 ± 3.2	n.a	n.a	n.a	n.a
Rb	99 ± 14	64	62	124	85
Sr	140 ± 43	235	233	116	270
Co	30 ± 3	n.a	n.a	n.a	n.a
ΣREE	176 ± 13	n.a	n.a	n.a	n.a

([#] Subramanian et al. 1985). n.a.-data not available

distribution. Figure 4 shows that major area of study area is occupied by 70–80% clay content. Al dominates the northern part of the study area with 8–9% whereas southern part by 7–8% and distribution of Zr and ΣREE show patchy distribution (Fig. 4). The mean concentration of element are e.g. Al (8.04±0.43%), Fe (6.35±0.28%), Ti (0.82±0.07), V (192±23 ppm), Cr (129 ± 13 ppm) and Zr (159 ± 19 ppm). Al shows strong positive correlation with Fe (0.89), K (0.70) and Mg (0.68) suggesting their association with

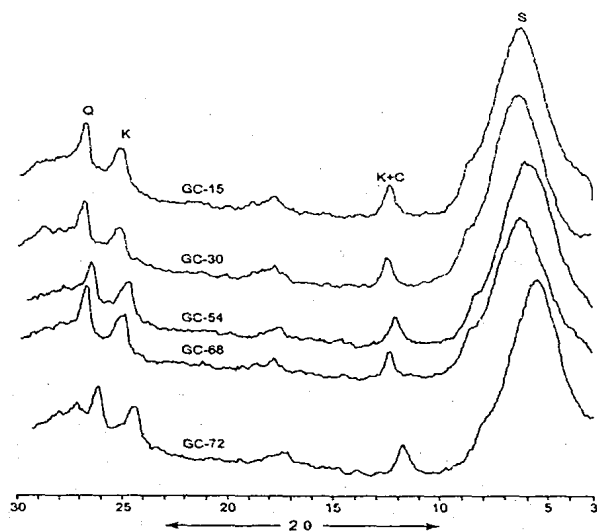


Fig.3. X-ray diffractograms of representative sediments (S - smectite, K = kaolinite, C = chlorite and Q = Quartz).

clay derived from the continent. Ti normally shows strong positive correlation with Al or Fe in the marine sediments but in the present study, such a relation is not observed. The enrichment of Ti (0.82 ± 0.07%) could be due to presence of titanium bearing minerals and its content is low compared to KG delta region (1.44%; Narsayya, 2002). The strong positive association of Ti with Ca ($r = 0.88$) suggests presence of titanite mineral (Fig.5). Titanite is a common accessory mineral usually found in igneous and metamorphic rocks. It survives weathering sufficiently and found as a heavy mineral in the sediments. Mislanekar and Gujar (1996) reported a presence of titanite in the surface sediments in a shallow depth from the eastern continental margin of India. This mineral is not traced in < 2-micron clay minerals. Therefore, a bulk sediment slide was made and run for mineralogy by XRD. The maximum intensity peak of titanite coincides with quartz peak and the strong peak (72%) at 29.6 (2θ), is considered to be due to the presence of titanite. Similarly, positive correlation between Ti and Mn ($MnTiO_3$) ($r = 0.67$) suggests possible presence of pyrophanite (Fig.5). This mineral is not reported so far from the eastern continental margin of India. Pyrophanite is a manganese titanium oxide mineral usually found in metamorphosed manganese deposits and less common in the igneous rocks. A close look of the chemical data of Seralathan and Seetaramaswamy (1987) also suggests possible presence of pyrophanite (Mn and Ti, $r = 0.48$, $n = 43$) in the delta sediments of Cauvery River. The

Table 2. Correlation matrix for the elements analysed for the surface sediments from Krishna-Godavari Basin (n=75)

	Al	Fe	Ti	Ca	K	Mg	Mn	Ba	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Zr	Rb	Sr	Y	Tot. REE	
Al	1.00																					
Fe	0.89	1.00																				
Ti	0.01	0.07	1.00																			
Ca	-0.16	-0.10	0.88	1.00																		
K	0.69	0.71	-0.16	-0.22	1.00																	
Mg	0.66	0.76	-0.31	-0.37	0.67	1.00																
Mn	0.22	0.17	0.68	0.64	-0.12	-0.26	1.00															
Ba	0.15	0.11	0.73	0.56	0.06	-0.41	0.58	1.00														
Sc	0.24	0.23	-0.05	-0.09	0.18	0.17	-0.04	-0.01	1.00													
V	-0.07	-0.02	0.35	0.33	-0.04	-0.18	0.16	0.28	0.82	1.00												
Cr	0.11	0.12	0.12	0.05	0.07	-0.02	0.04	0.12	0.88	0.88	1.00											
Co	0.06	0.12	0.20	0.18	0.04	0.01	0.15	0.15	0.89	0.92	0.90	1.00										
Ni	0.17	0.23	-0.13	-0.21	0.24	0.23	-0.15	-0.12	0.82	0.68	0.83	0.78	1.00									
Cu	0.26	0.30	0.27	0.17	0.15	0.15	0.13	0.20	0.73	0.66	0.66	0.69	0.70	1.00								
Zn	-0.17	-0.10	0.37	0.25	-0.18	-0.32	0.18	0.31	0.29	0.52	0.38	0.40	0.39	0.44	1.00							
Ga	0.17	0.16	0.05	0.03	0.13	0.07	0.04	0.07	0.95	0.89	0.93	0.95	0.81	0.67	0.36	1.00						
Zr	0.04	0.09	0.18	0.22	-0.03	-0.12	0.18	0.13	0.23	0.30	0.30	0.28	0.20	0.26	0.22	0.28	1.00					
Rb	0.09	0.14	-0.18	-0.05	0.21	0.28	-0.13	-0.20	0.05	0.01	-0.04	0.05	-0.08	-0.27	-0.17	0.08	0.22	1.00				
Sr	0.06	0.02	-0.20	-0.16	0.22	0.09	-0.25	-0.05	0.08	0.03	0.00	0.00	-0.06	-0.08	-0.15	0.06	-0.11	0.32	1.00			
Y	0.07	0.10	0.33	0.38	-0.02	-0.19	0.34	0.24	0.25	0.35	0.29	0.32	0.15	0.29	0.26	0.31	0.62	0.00	-0.13	1.00		
Tot. REE	0.07	0.03	0.04	0.10	0.14	0.07	0.10	0.12	-0.07	-0.04	-0.11	-0.02	-0.10	-0.10	-0.10	-0.02	-0.07	0.06	0.02	0.05	1.00	

independent behaviour of Zr in the sediment probably suggests presence of heavy mineral such as zircon. Zircon is one of the common heavy minerals reported from the East Coast of India. The elemental concentrations such as Fe, Ti, V, Cr and Zr and ratios of Fe/Al (0.79) and Ti/Al (0.10) closely match with the Godavari River sediment than the Krishna River sediment (Subramanian et al. 1985). This further suggests that sediment contributed by Ganges-Brahmaputra River system appears to be very insignificant in this basin. This is supported by the presence of smectite as a dominant clay minerals. Al and Fe concentration is low in the sediments derived from the Himalayas through Ganges-Brahmaputra River system compared to Krishna-Godavari Rivers (Wijayananda and Cronan, 1994). Krishna-Godavari River basins have different rock types of different ages, hence it is difficult to assign the sources for each element. Trace elements such as Cu, Ni and Zn have nearly 30 to 50 % non-terrigenous source (elemental excess) compared to their bulk content. Based on the partition geochemistry of eastern continental shelf sediments, Mascarenhas et al. (1985) found that Fe, Mn, Cu and Zn have ~ 25 to 60 % non-terrigenous source compared to their bulk content and suggested that Fe-Mn hydroxides adsorb these trace metals. In the present study Fe and Mn do not have non-terrigenous source suggesting their sole supply from the continent (Subba Rao, 1962) and they do not show any correlation with Cu, Ni and Zn content. The Middle Bengal Fan, which is further east of KG Basin, is dominated by Illite as a clay mineral and low content of Ca (1.4%), Mg

(1.5%), Na (0.2%), V (100 ppm) (Chowdary et al. 1992). This further suggests that these sediments are dominantly derived from Himalayas. This shows that Godavari River sediment supply is essentially restricted to only KG Basin and its contribution to the middle Bengal Fan appears to be minimum.

Rare earth elements concentrations vary from 151 to 215 ppm with an average of 176 ± 13 ppm which is comparable to average shale values (Taylor and McLennen, 1985). The shale-normalized REE (Fig.6) show a flat pattern with sample/shale values very close to 1 suggesting their continental nature (Piper, 1974). There is no significant correlation between REE and major elements analysed (Table.2). Shale-normalized REE patterns exhibit a small positive Eu-anomaly (Fig.6) in all the sediments. The presence of Eu-anomaly could be due to hydrothermal input or aeolian dust (Elderfield, 1988) or presence of sodium feldspar (Murray et al. 1991). The absence of negative Ce-anomaly suggestive of no hydrothermal input and the presence of high sodium content (Chowdary et al., 1992) in the KG Basin indicates the presence of sodium feldspar, which is responsible for the small positive Eu-anomaly in these sediments.

Sediment Dispersal

The shelf is rather wider in the north than the south and is narrowest off Godavari and Krishna Rivers (Venkateswarlu et al. 1992). Sediment derived from various sources influence the geochemistry of an area and therefore

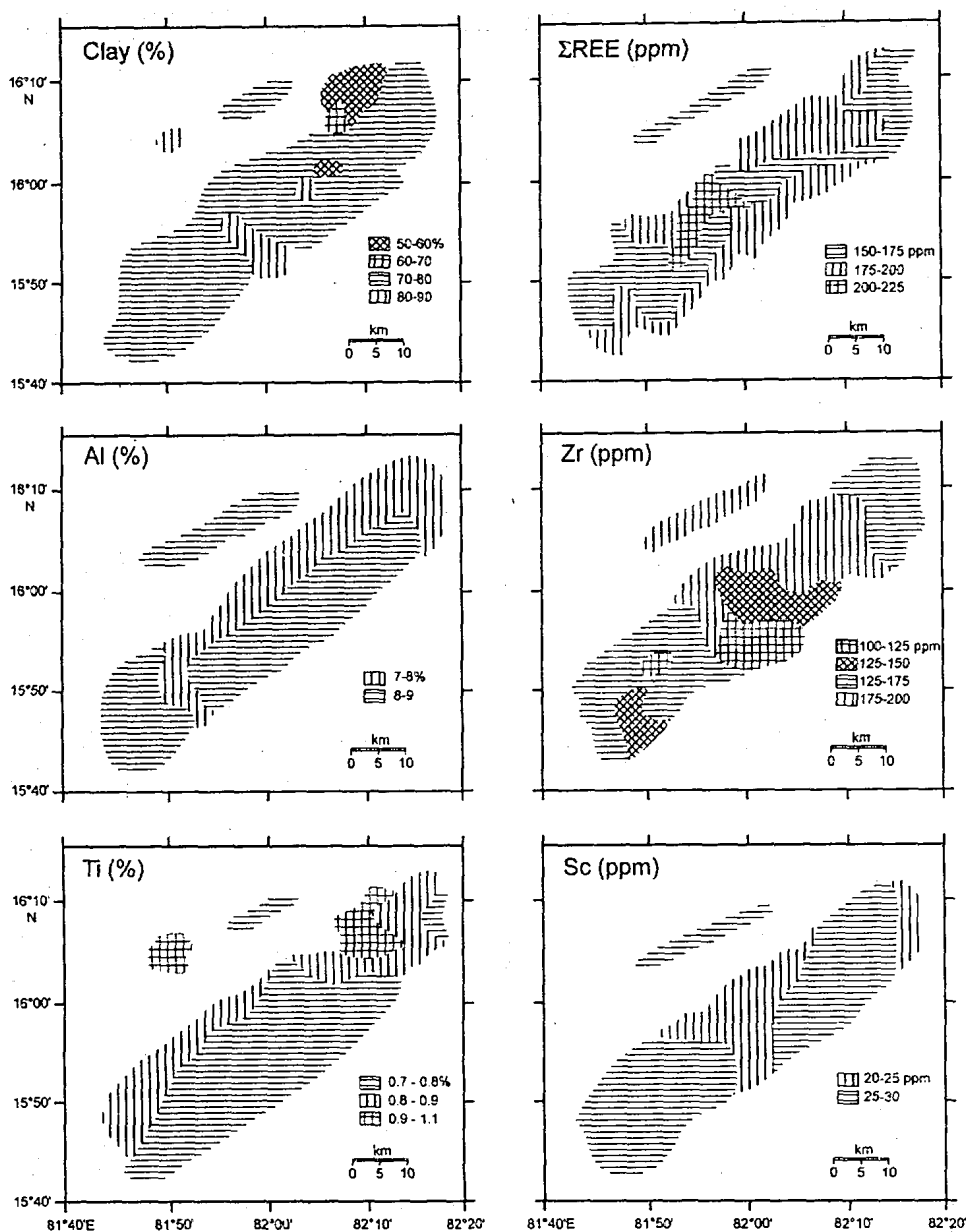


Fig.4. Distribution of clay (%), Al(%), Ti(%), Σ REE (ppm), Zr (ppm) and Sc (ppm) in the surface sediments.

sediment provenance forms an important component of geochemical investigations. Coastal circulation along the eastern coast of India is largely governed by the seasonally reversing current pattern associated with the monsoon phenomenon and by the river runoff (Varkey et al. 1996). During SW monsoon, strong poleward currents prevail along the coast as a result of anticyclonic gyre and current pattern reverses wherein weak equatorward current pattern is established during NE monsoonal cyclonic gyre (Varkey et al. 1996; Shetye et al. 1991, 1993). The current patterns,

which are responsible for the sediment dispersal, can be established using clay minerals as proxies, since these are carried in suspension and their fluvial sources are well established in the Bay of Bengal. Two clay mineral suites representing two dominant fluvial sources are known i.e. dominant illite + chlorite and minor kaolinite represent Himalayan (Ganges-Brahmaputra Rivers, Konta, 1985) provenance whereas dominant smectite, minor kaolinite and traces of illite point towards peninsular river source (mainly Krishna and Godavari Rivers; Subramanian 1987). Based

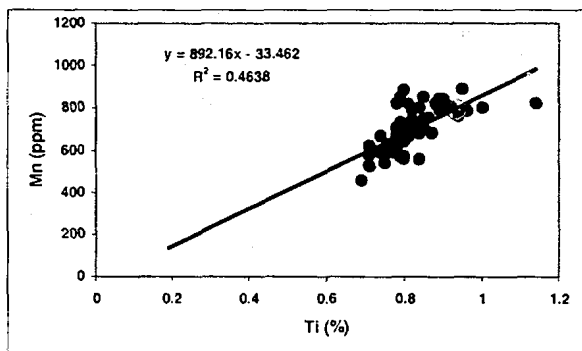
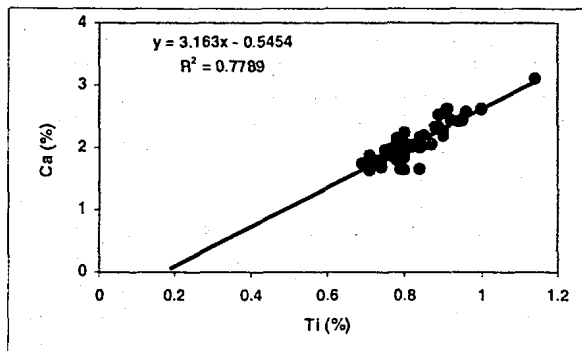


Fig.5. Scatter plot of Ti and Ca (top) and Ti with Mn (bottom) in the sediments suggesting presence of titanite and pyrophanite minerals respectively.

on the dominance of smectite (along with sillimanite and garnet) in the study area, the major source of sediments has been assigned to Krishna and Godavari Rivers by Kolla and Rao (1990). Chauhan and Vogelsang (2006) also detected dominance of smectite in this area, which they attributed to dispersal of sediments derived from Krishna-Godavari Rivers to adjacent deep region by across-shelf component of strong poleward current during prevailing SW hydrography. Magnetic susceptibility was used as a proxy by Sangode et al. (2001) to understand the provenance of sediments from this region. They found that the susceptibility was higher in top 100 cm of this region implying Godavari River as a principal source of sediments during Late Quaternary. Similar to our finding, little kaolinite was also found by Chauhan and Vogelsang (2006), which they attributed to small contribution of sediments from Ganges-Brahmaputra Rivers by equatorward dispersal. Nevertheless,

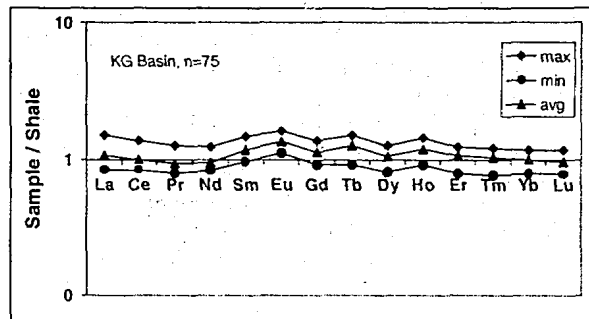


Fig.6. Shale normalized rare earth elements (REE) pattern of sediments (n = 75).

these studies (Sangode et al. 2001; Chauhan and Vogelsang, 2006) have also shown that the Ganges-Brahmaputra derived sediments were the main source (as suggested by predominance of illite and chlorite) prior to Last Glacial Maximum (LGM) when equatorward NE monsoon currents were very strong.

CONCLUSIONS

Sediments from Krishna-Godavari Basin suggest presence of heavy minerals such as titanite, pyrophanite and zircon. The geochemical signatures explicitly indicate that the Krishna-Godavari Basin sediments are dominated by the supply of Godavari River sediment compared to Krishna river sediment. Godavari River sediment discharge is confined mostly to KG Basin with little or no further lateral dispersal to the Middle Bengal Fan. It appears that the supply of sediments by Ganges-Brahmaputra River system derived from the Himalays to the Krishan Godavari Basin appears to be insignificant. The data generated during this present study will aid in a better understanding of the delta building processes, dispersal of sediments and palaeoenvironmental conditions.

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