

Partition Patterns of Iron in the Recent Sediments of the Northern Half of the Western Continental Shelf of India

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Iron has both a lithogenous and non-lithogenous component in the recent shelf sediments of the region between Ratnagiri in the south and Indus Canyon in the north. Overall distribution pattern of iron and its partition between the two components of the sediments are described and the possible factors and processes of its incorporation into the sediments are indicated.

DURING the cruises (Dec. 1973 to May 1974) of *INS Darshak* in the north-eastern Arabian Sea, seafloor sediment samples were obtained from the continental shelf region off the west coast of India, along a number of sections approximately normal to the coast, between Ratnagiri in the south and Indus Canyon in the north. The samples were obtained using various types of samplers such as gravity corer, dredge, snapper and grab. A comprehensive programme of study of these samples, covering all the important aspects was drawn up by the participating organizations in these cruises. As a part of this programme, the present study was undertaken on the elemental geochemistry of the sediments. These studies are aimed at understanding (i) general distribution patterns of various major and trace elements in the shelf region in relation to the distribution patterns of sediments and environmental conditions responsible for their deposition, (ii) partition of elements among different components of sediments and (iii) factors and processes by which various elements are incorporated in the sediments.

Under such a broad outline of the programme, the distribution pattern of iron and its partition among different components of the sediments were carried out and the results obtained are reported in this paper. Except for the brief investigations¹⁻³ there is practically no information is available on the distribution of iron and its partition patterns from this part of the Arabian Sea.

The area from which the sediment samples were collected is shown in Fig. 1. Immediately to the north of the study area is the large Indus River (not shown in the figure) whose influence on the shelf under study is profound. This river drains a large portion of the Indo-Gangetic plain and extends upstream well into the Himalayas. In the south, the Narmada and Tapti rivers of India are smaller than Indus and empty into the Gulf of Cambay. These rivers drain the mountainous regions of Central India including the Vindhya and Satpura ranges. South of the Gulf of Cambay, the drainage is eastward and no important rivers reach the sea.

The geology of the area was discussed by Wadia⁴. The regional geology from the standpoint of potential

sediment sources consists of volcanics, metamorphics and minor amount of sedimentaries in the southern portion of the study area, while in the northern portion, the sediment sources are principally the sedimentary rocks.

In this region, the continental shelf is characterized by certain well defined features in regard to its bottom topography, sediment distribution and clay mineralogy. Topographically, the inner shelf (up to 60 m depth) is largely smooth except at places where the submerged rocks give rugged appearance. Towards seaward is the area of an uneven topography in which the range in unevenness is up to 5 m. This area is followed by a region characterized by rugged topography, further west, where the amplitude of variations is greater than 5 m and goes up to 20 m. While this is so, particularly with the shelf region between Ratnagiri and Daman, the

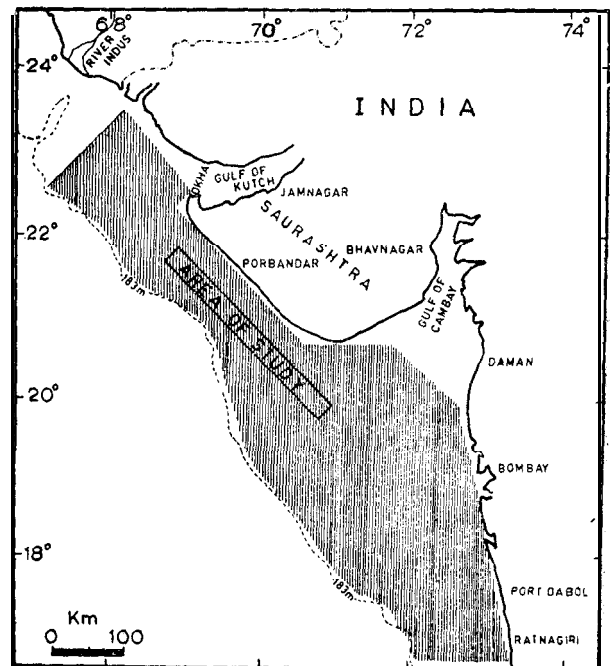


Fig. 1 — Area of study

outer shelf off Kathiawar is largely smooth⁵. In general, texturally, the innershelf (up to 60 m) is carpeted by silty clays or clayey silts and this is followed seaward by a zone of silty or clayey sand. The sediments in the outershelf region (>60 m) are characterized by a higher content of calcium carbonate^{6,7} and these have been described by these authors and by Nair⁸ as relict sediments. According to Stewart *et al.*⁷ the continental shelf in this area exhibits the often observed sediment distribution pattern of fine sediments nearshore and coarse material on the central and outershelf. The clay minerals present in the area are montmorillonite, illite, chlorite and kaolinite^{7,9,10}. In the area south of Gulf of Kutch, the general order of concentration of clay minerals is montmorillonite (50-70%), illite (0-20%), chlorite (0-10%) and kaolinite (0-10%) whereas in the Gulf of Kutch region and the region north of it, the general order of clay mineral concentration* is illite (40-50%), montmorillonite (30-50%), chlorite (20-30%) and kaolinite (0-10%).

Materials and Methods

Representative samples were obtained from the collections made at each station and a suitable amount of each representative sample was leached with the acid reducing agent as described by Chester and Hughes¹¹. Estimations of iron were carried out (i) in the bulk sample with a view to understanding the concentrations of iron associated with the total sediment samples (TSS) and its overall distribution pattern and (ii) in the leach of the acid reducing agent solution, with a view to obtaining an idea of the contributions made by the non-lithogenous and lithogenous fractions (NLF and LF) to the concentrations in the TSS. The bulk samples were digested with a mixture of perchloric and sulphuric acids and the iron estimations were made colorimetrically in the bulk samples as well as in the acid soluble fractions using 2,2'-dipyridyl¹². Since the quantity of acid soluble and insoluble fractions vary from sample to sample, for purposes of comparison, concentrations in the lithogenous and non-lithogenous fractions have been computed to 100% of each fraction from the contributions made by LF and NLF. Further, the percentage of acid soluble fraction in each sample was also computed.

Results

Distribution pattern of iron in TSS, contribution made by LF and NLF to the concentrations in TSS and concentrations of iron associated with LF and NLF of the sediments are shown in Figs. 2-7. Further, the relationship between the percentage of acid solubles and the iron concentrations in NLF is shown in Fig. 8. From the distribution patterns obtained, the following conclusions can be drawn on the general distribution pattern of iron and its partition patterns in the sediments:

(1) General distribution pattern (Fig. 2) of iron (on the total sample basis) indicates that the fine-grained sediments of the innershelf region are characterized by higher concentrations of iron than the coarse sediments of the outershelf. Even among the fine-grained sediments, the sediments in the

region, south of the Gulf of Kutch, are characterized by higher concentrations of iron than the sediments in the region north of it.

(2) Contributions made by LF of the fine-grained sediments in the innershelf region to the concentrations in TSS are relatively higher than the contributions made by the corresponding fractions of the outershelf sediments (Fig. 3). However, it could be seen from Figs. 2 and 3, in terms of percentage contributions, the contribution made by this fraction to the concentrations in TSS is more than 90% all over the shelf region. While this is so, the concentrations of iron associated with LF of the sediments (Fig. 4) do not show any decreasing trend away from the coast in any conspicuous manner. On the other hand, one feature noticed is that the sediments collected from the depths 60-95 m from the outershelf region have concentrations of iron similar to and sometimes even higher than the concentrations associated with LF of the sediments of the innershelf region.

(3) NLF of the sediments of the innershelf region is characterized by higher concentrations of iron than that of the outershelf (Fig. 5). The contributions made by NLF of these sediments to the concentrations in the TSS also exhibit a similar pattern (Fig. 6).

(4) Percentage of acid solubles associated with the outershelf sediments is relatively higher than the percentage of acid solubles associated with the fine-grained sediments of the innershelf region (Fig. 7). However, the concentrations of iron in NLF of the sediments bear an inverse relationship with the percentage of acid solubles (Fig. 8).

Discussion

Sedimentary geochemistry of iron shows that iron in the minerals of the igneous rocks is partly oxidized during weathering and partly gets dissolved as ferrous ions. These ions can be transported over long distances if the solution remains reducing and slightly acidic and if it is not mixed with the other ions that form insoluble compounds. A great variety of ions may cause precipitation, the most common being carbonate, sulphide and silicate. They may precipitate by oxidation in streams, lakes or swamps, in sea water as oxides when the water is aerated, as carbonate or silicate if the water is mildly reducing as sulphide if the redox potential is low and when sulphur is abundant. If the conditions are favourable for the oxides to precipitate, they often remain in suspension as stable sols and may be carried over long distances in aerated surface waters. These colloids are flocculated where streams enter the sea¹³. Further, in the marine environment, iron may be associated with the sediments in the following ways also: (i) as iron located in the lithogenous minerals such as augite, hornblende, magnetite, ilmenite, etc., (ii) as iron incorporated in the marine sediments directly from sea water¹⁴, (iii) as iron derived through biological processes¹⁵⁻¹⁸ and (iv) as iron associated with the clay minerals either as an essential constituent or as a minor constituent within the crystal lattice or as iron oxide on the surface of the mineral platelet+*.

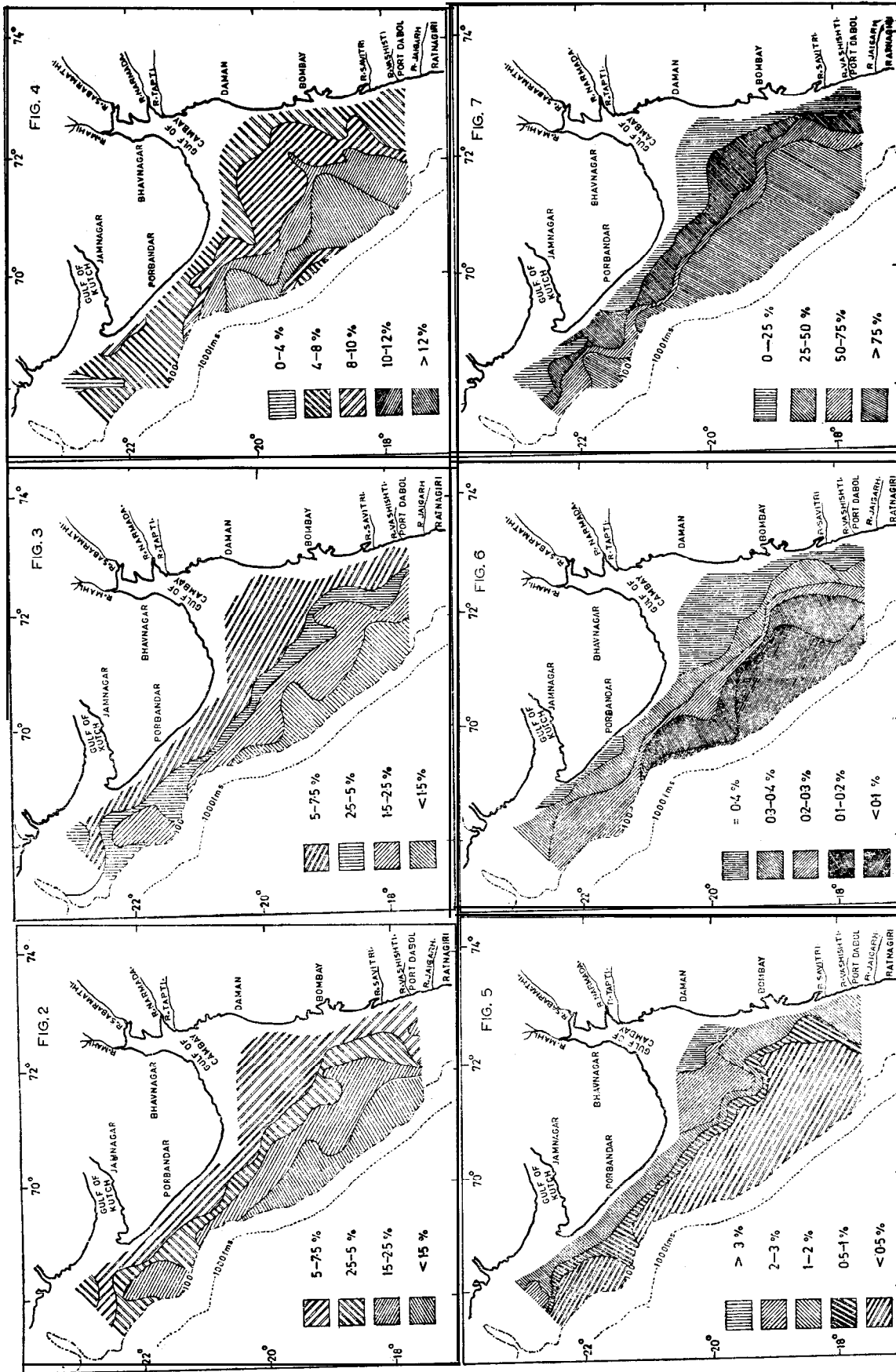


Fig. 2 — Distribution pattern of concentrations of iron in the total sediment samples. Fig. 3 — Distribution pattern of concentrations of iron associated with lithogenic fraction of the sediments. Fig. 4 — Distribution pattern of concentrations of iron associated with non-lithogenic fraction of the sediments. Fig. 5 — Distribution pattern of concentrations of iron in total sediment samples. Fig. 6 — Distribution pattern of contributions made by non-lithigenous fraction of the sediments to the concentration of iron in total sediment samples. Fig. 7 — Percentage distributions of acid solubles in the sediments

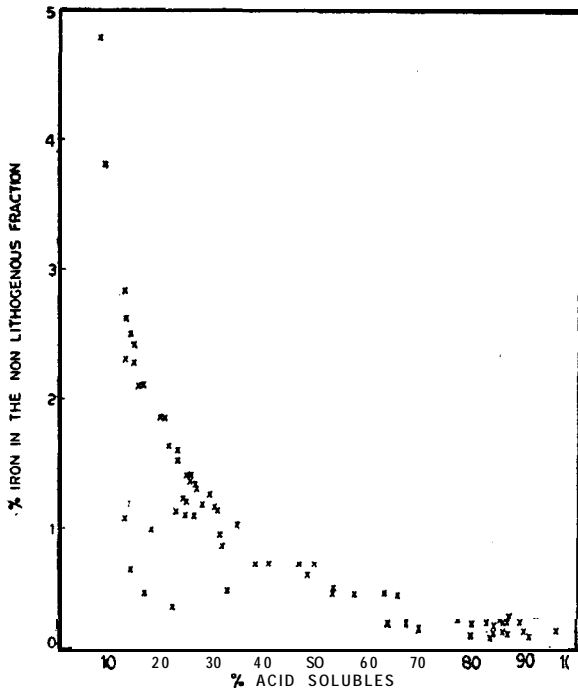


Fig. 8 -Relationship between the percentage of acid solubles and percentage of iron in non-lithogenous fraction of the sediments

The trends (1) and (2) mentioned under Results clearly establish the fact that there is a good supply of the element from the land to the innershelf region through iron held in the lattice structure of the detrital minerals. While this is so, the percentage contribution made by LF to TSS (more than 90%) is substantial all over the shelf region. Absence of any conspicuous decrease in the concentration of iron associated with LF of the sediments along any given section suggests that the nature of the lithogenous material (heavy minerals and or clay minerals) is the same all over the shelf region. This being so along any given section, from the regional point of view, the differences found in the concentrations of iron between the sediments of the region north of the Gulf of Kutch and the region south of it or the TSS basis as well as on the basis of the concentrations associated with LF may perhaps be attributed to the differences in the composition of the source rocks in the 2 regions and the corresponding differences in the mineralogical composition of the sediments of the 2 regions. The differences that can be observed in the heavy minerals reported from the Gulf of Kutch and Gulf of Cambay regions by Stewart *et al.*⁷ and the relatively low values of iron reported by Marchig³ in the sediments of the shelf region around the mouth of Indus river also support this. It may be mentioned here that the concentrations of iron associated with the lithogenous fractions of the sediments in the region south of Gulf of Kutch (when converted to oxide) compare favourably with the values given for Deccan Traps²⁰ indicating thereby that the lithogenous material in this region has been mostly derived from the Deccan Traps.

Nair²¹ reported the occurrence of submarine terraces between 60 and 95 m depth along the northern half of the western continental shelf of India. These were explained to have been formed during the periods of lowered sea levels. High concentrations of iron associated with LF of the sediments collected from these depths may perhaps be due to their association with these terraces.

It is evident from the foregoing account that iron has probably been fixed to a large extent in the sediments in the solid state through the detrital minerals supplied from the land. Apart from this mode of fixation of the element in the sediments, relatively higher concentrations of iron associated with NLF of the fine-grained sediments of the innershelf region indicate that the element is being removed effectively from the overlying waters in the innershelf region and fixed in the sediments through other processes also.

Concentration of iron associated with non-lithogenous fractions of sediments may be of (i) iron associated with the carbonate phase of the sediments, (ii) iron held in the non-lattice position of the clay minerals and (iii) iron of hydrogenous or biogenous origin. Consideration of the distribution pattern of the acid soluble fraction shows that it is relatively higher in the sediments of the outershelf region than in the sediments of the innershelf along any given section. While this is understandable in view of the fact that the sediments of the outershelf region are characterised by higher percentages of calcium carbonate than the sediments of the innershelf region, the inverse relationship obtaining between the concentrations of iron in NLF and the percentage of acid solubles clearly indicates that the non-lithogenous component of iron is not associated with the carbonate phase of the sediments (biogenic or otherwise) to any large extent. This explains why low values of iron are associated with NLF of the outershelf sediments, the bulk of which is composed of calcium carbonate only.

The association of considerable amounts of iron with carbonate phase of the sediments being precluded, higher concentrations of iron associated with NLF of the fine-grained sediments of the innershelf region with low carbonate content may be considered to have been fixed through other processes. One possibility is that non-lithogenous component of iron is held in the non-lattice position of the clay minerals of these sediments. While it is true that part of the iron may be associated in this form, it is quite unlikely that the entire concentrations of iron are associated in this form, in view of the fact that the order of the concentrations obtaining in these sediments cannot be accommodated in the non-lattice position.

The other possibility for higher concentrations of iron observed is the west coast of India being in a zone of intense tropical weathering it is quite likely that iron leached from the rocks as well as their products of weathering such as regur and laterite rich in iron and carried by rivers in the colloidal state to the sea may be getting flocculated in the nearshore regions giving rise to higher concentrations in the non-lithogenous fractions of the sediments

of the innershelf region. The presence of the silts and clays in the inner&elf region quite close to the shore and the relatively higher values of iron associated with the non-lithogenous fraction of the sediments in the vicinity of the river mouths support this assumption.

Thus the presence of favourable conditions in the innershelf region, i.e. the occurrence of fine-grained sediments and the flocculation of the colloidal material by the rivers, may be responsible for higher concentrations associated with non-lithogenous fraction of the fine-grained sediments.

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