~120 ka eccentricity cycle, its verification requires a high-resolution study because strength of monsoon is strongly affected by the precession (23 ka) and obliquity (41 ka) cycles[30] than the eccentricity cycle (100 ka, range ~95–135 ka). Our results of ~120 ka orbital eccentricity cycles related monsoonal oscillation in the 10°S hydrographic front open an unorthodox view that even though the amplitude of insolation related to the orbital eccentricity cycles (~100 ka) may be low <0.1%), compared to precession (23 ka) and the obliquity (41 ka) cycles[31], its modulating effect on the Asian monsoon system cannot be denied and ignored.

1. Carroll, J., Falker, K. F., Brown, E. T. and Moore, W. S., *Geochim. Cosmochim. Acta*, 1993, **57**, 2981–2990.
2. Oberhuber, J. M., Max Plank Institut fur Metereologie Report, 1988, p. 15.
3. Wyrtki, K., *The Oceanographic Atlas of the International Indian Ocean Expedition*, NSF, Washington DC, 1971, p. 531.
4. Wyrtki, K., in *The Biology of the Indian Ocean* (ed. Zietschel, B.), Springer-Verlag, New York, 1973, pp. 18–36.
5. Dworetzky, B. A. and Morley, J. J., *Mar. Micropaleontol.*, 1987, **12**, 1–19.
6. Gupta, S. M., Ph D thesis, Goa University, 1991, p. 338.
7. Gupta, S. M., *J. Geol. Soc. India*, 1996, **47**, 339–354.
8. Gupta, S. M. and Srinivasan, M. S., *Micropaleontology*, 1992, **38**, 209–236.
9. Johnson, D. A., Schneider, D. A., Nigrini, C. A., Caulet, J. P. and Kent, D. V., *Mar. Micropaleontol.*, 1989, **14**, 33–66.
10. Moore, T. C., *J. Sediment. Petrol.*, 1973, 43, 904–906.
11. Imbrie, J. and Kipp, N. G., in *The Late Cenozoic Glacial Ages* (ed Turekian, K. K.), Yale Univ., New Haven, Conn., 1971, pp. 71–181.
12. Imbrie, J., Donk, J. V. and Kipp, N. G., *Quat. Res.*, 1973, 3, 10–38.
13. Levitus, S., *Climatic Atlas of the World Ocean*, Washington DC, 1982, pp. 173.
14. Shyamprasad, M. and Sudhakar, M., *Meteoritics Planet. Sci.*, 1996, **31**, 46–49.
15. Schneider, D. A., Kent, D. V. and Mellow, G. A., *Earth Planet. Sci. Lett.*, 1992, **111**, 395–405.
16. Baksi, A. K., Hsu, V. McWilliams, M. O. and Farrar, E., *Science*, 1992, **256**, 356–357.
17. Hays, J. D. and Shackelton, N. J., *Geology*, 1976, **4**, 649–652.
18. Crowley, T. J., Kim, K-Y., Mengel, J. G. and Short, D. A., *Science*, 1992, **255**, 705–707.
19. Hays, J. D., Imbrie, J. and Shackelton, N. J., *Science*, 1976, **194**, 1121–1132.
20. Imbrie, J. *et al.*, *Paleoceanography*, 1993, **8**, 699–735.
21. Berger, A. L. and Loutre, M. F., *Quat. Sci. Rev.*, 1991, **10**, 297–317.
22. Gupta, S. M., Fernandes, A. A. and Mohan, R., *Geophys. Res. Lett.*, 1996, **23**, 3159–3162.
23. Miyama, T., Awaji, T., Akitomo, K. and Imasato, N., *J. Geophys. Res.*, 1995, **100**, C10, 20517–20541.
24. *Climate Diagnostic Bull.*, 1995, **95**, T24.
25. Wyrtki, K., *J. Geophys. Res.*, 1987, **92**, C12, 12941–12946.
26. Fine, R. A., *Nature*, 1985, **315**, 478–480.
27. Wang, L., Sarnethein, M., Duplessy, J. C., Erlenkeuser, H. and Jung, S., *Paleoceanography*, 1995, **10**, 749–761.
28. Gupta, S. M. and Fernandes, A. A., *Bull. Indian Geologists Assoc.*, 1995, **18**, 29–51.
29. Shimmield, G. B., Mowbray, S. R. and Weeden, G. P., *Trans. R. Soc. Edinburgh, Earth Sci.*, 1992, **81**, 289–299.
30. Clemens, S. C., Murray, D. W. and Prell, W. R., *Nature*, 1996, **274**, 943–948.
31. Clemens, S. C. and Tiedemann, R., *Nature*, 1997, **385**, 301–304.

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Occurrence of Fe, Mn-rich layer in the distal Bengal fan

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Dark tan-coloured Fe, Mn-rich stiff layer was observed at 45–50 cm and 40–42 cm levels in the Sagar Kanya 72/1 and 100/6 sediment cores respectively, which were collected from distal Bengal fan under BOBCRUST programme. SK 72/1 and SK 100/6 cores were analysed for Fe, Mn, Ni, Co, Cr, $CaCO_3$ and organic carbon (OC) contents. A remarkable increase in Fe, Mn and drastic decrease in $CaCO_3$, OC, compared to overlying and underlying sediment layers was observed at this stiff layer. Change of these elements concentration correlates with the change of fauna from the cold assemblage to warm assemblage. Increase of Fe, Mn, Ni, Co and decrease of Cr, $CaCO_3$, OC indicate that this layer is formed due to post-depositional migration of these elements during the Pleistocene/Holocene transitional period, because of emasculated influence of terrestrial input into these sites.

BENGAL fan is the world's largest submarine fan, which is positioned under the highest run-off receiving bay, and it is built of terrigenous sediments carried from the Himalayan region by the Ganges, Brahmaputra, Irrawaddy and Salween river systems[1,2]. Variations in the run-off are dependent on the monsoons and the waning and waxing of glaciers in the catchment region. The sediment input is mainly controlled by a number of factors such as turbidity currents, sediment flow or fluvial input to the sea, giving rise to these thick fan sediments. Geochemical character of the sediment column reveals such variations and helps in identifying metal sources apart from providing a clue to their removal mechanism from the overlying water column[3,4]. Studies on Bengal fan deep sea cores are very few[5–10], published geochemical

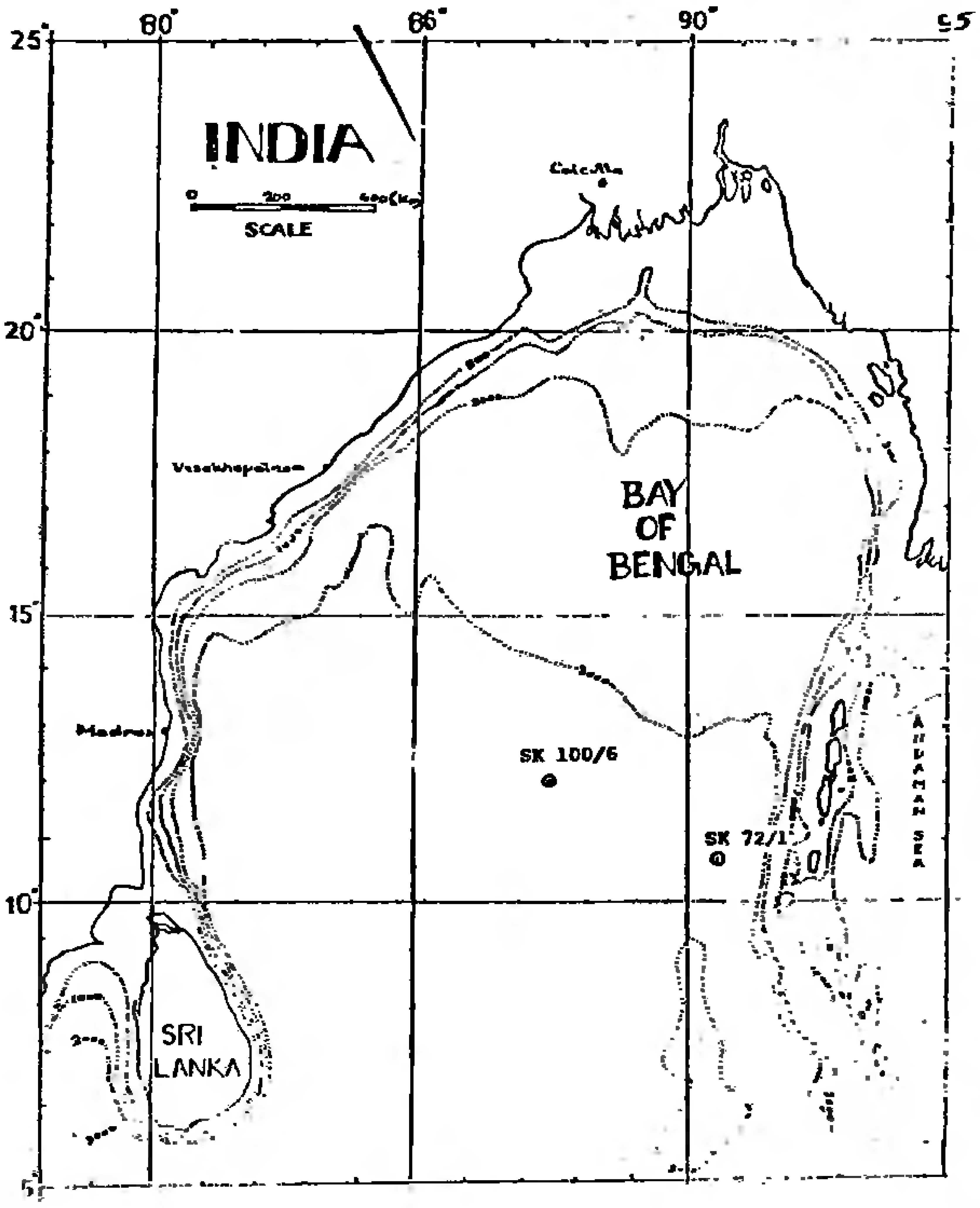

Figure 1. Core location map.

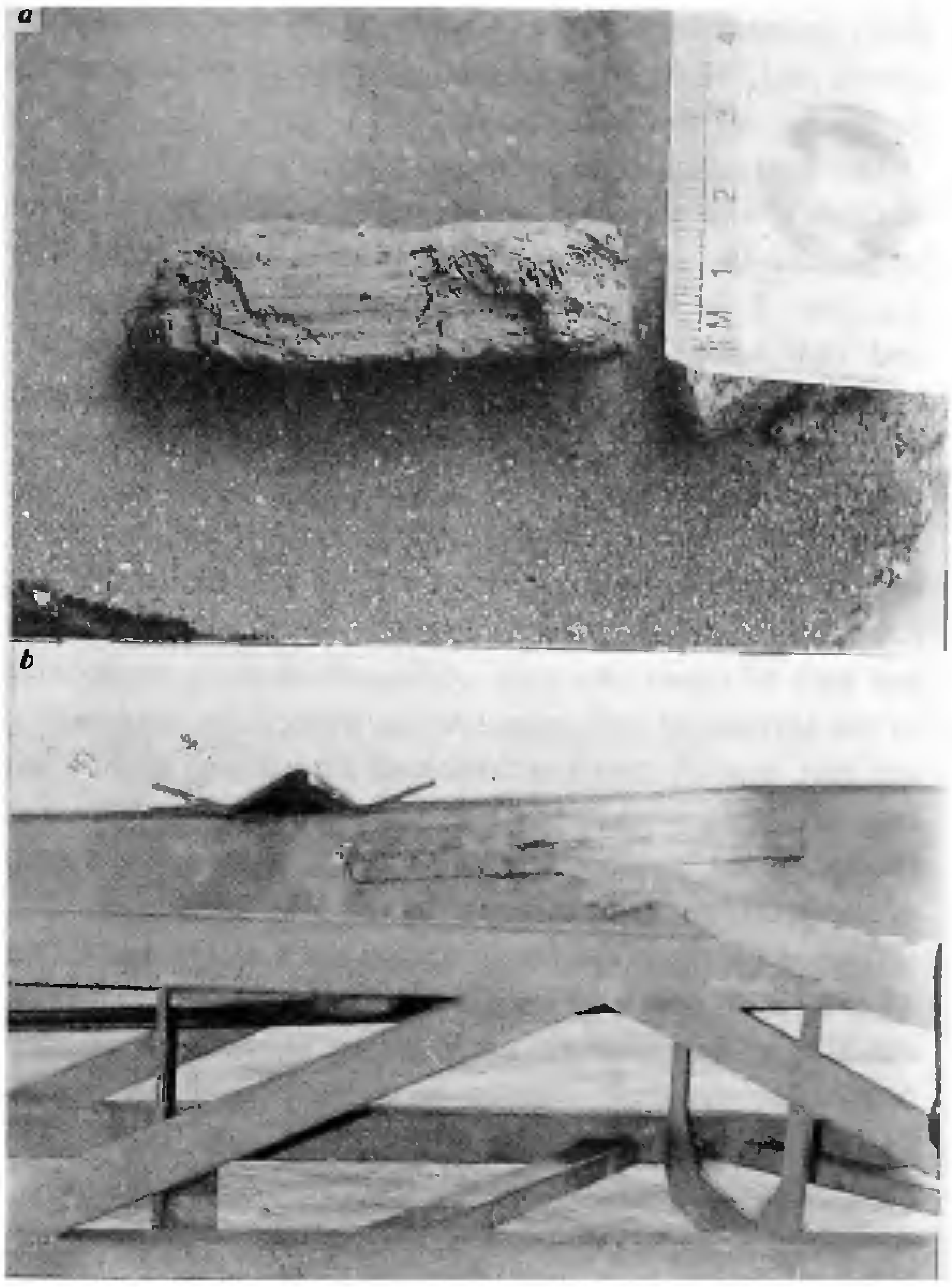

Figure 2. *a*, Stiff layer collected from SK 100/6; *b*, Bend in box corer.

studies are still more scanty. Fe, Mn, enrichment is reported in the Central Indian Ocean[11–14] and surface sediments of the Bengal Fan[5]. The present work describes the occurrence of Fe, Mn-rich layer in two cores collected from distal Bengal fan (Figure 1), with reference to variations in Ni, Co, Cr, $CaCO_3$, OC and the formation of this layer at Pleistocene/Holocene boundary is emphasized.

The concentration of various elements in the bulk sediments was determined by Phillips X-ray fluorescence spectrophotometer, precision and bias (± 5%) were monitored by replicate analyses of selected samples. Organic carbon[15] was estimated to a precision of ± 0.01%. $CaCO_3$ was estimated by standard titration method (± 0.5%)[16]. Colour logs were prepared with Munsell soil colour charts.

Dark tan-coloured, laminated and stiff layer is observed in SK 72/1 and SK 100/6 at 45–50 cm and 40–42 cm levels of the core sediments respectively. The thickness and stiffness of this layer, within the respective sub-sample, vary in both the sites. It is 4 mm in the eastern core (SK 72/1) and 15 mm in the core from Central part of the distal fan (SK 100/6, Figure 2 *a*). The impenetrability and bent of the box corer was thought to be due to this hard layer (on-board) observation SK 100 (Figure 2 *b*). However, this needs to be confirmed after contemplating other mechanical problems involved in it. This hard layer separates the total core mainly into two parts, i.e. light-coloured upper part [yellowish brown (2.5Y/5/4); yellowish gray (5Y 7/2)] and dark-coloured lower part [greenish black (5G/2/1/); olive gray (5Y/5/2)]. It is sandwiched in between these two geochemically different environments.

Iron concentrations in the core sediments vary from 2.5 to 9.9%, 2.78 to 10.27% in SK 72/1 and SK 100/6 respectively. In both the sites, the uppermost part of the core represents lower values, whereas the maximum concentration is encountered at hard layer. Iron values of this layer are 9.9% in SK 72/1, 10.27% in SK 100/6. Along with iron values Mn, Ni and Co, concentrations at these hard layers are conspicuously high. In contrast to this, $CaCO_3$ and OC values are considerably low at this depth. Average concentrations of $CaCO_3$ are 15.46% and 6.27% in the upper and lower parts of the core in SK 72/1 and similarly, 43.33%, 6% in SK 100/6. On an average, organic carbon shows lower values in the upper part and higher values in the lower part in both the cores. Whereas lowest values of $CaCO_3$ (1%; 0.5%) and lowest OC (0.4%; 0.04%) in SK 72/1, SK 100/6 are noticed respectively at the stiff layer. A few centimeters above and below to this layer, abundancy of fragmented foraminiferal shells are noticed.

The antipathetic relationship between $CaCO_3$ and OC indicates that the deposition of these two is not controlled by the same process. It is observed that >63 μm fraction of the sediment consists mainly of foraminiferal and radiolarian shells and their fragments. Hence the coarse fraction is biogenic. It is well established that in marine sediments, $CaCO_3$ being biogenic/authegenic shows an inverse relationship with terreginous material[8,17]. OC in the present site is mainly of terrestrial origin[6], higher concentrations of this terrestrial OC and low $CaCO_3$ indicate the strength of terrestrial input. Upper part of these two core sediments depicts weakening of the terrestrial influence. As an immediate response to the last glacial maxima followed by strong aridity and fast recession of the mouth of the rivers due to retreat of the sea level, the resulting reduction was in the supply of the terrigenous sediments in the Bay of Bengal. It is reflected by the relative change in the $CaCO_3$ and OC at 45–50 cm and 40–42 cm in SK 72/1 and SK 100/6 respectively. Increase in the relative abundance of *Globorotalia menardii*, which is widely used to denote Pleistocene/Holocene boundary, was observed from these depths, substantiating the above argument[18,19]. Similar observations of Mn enrichment at surface and subsurface levels of sediment cores from pelagic environment have been documented earlier[3,20,21]. It has been suggested that in hemipelagic sediments, the onset of green colouration corresponds to the point below which solid phase Fe^{+3} is reduced and pore water Fe^{+2} is present[22]. Depth position of this Fe, Mn-rich layer, clearly indicates that this layer overlies the dark colour reduced sediment column.

As early as 1895, it was suggested that post-depositional remobilization and reprecipitation were responsible for the higher values of Mn in deep sea sediments[23]. Diagenetic processes, such as the post depositional migration of Fe, Mn and other trace elements as a result of a moving redox front, are well known[24–28]. Mn is highly insoluble in oxic environments and is buried as oxyhydroxide particles and coatings in the sediment. In hemipelagic environments, oxidation of labile organic matter causes the sediment to become anoxic at depths and Mn^{++} is mobilized either by the reduction of manganese hydroxides or as a result of solubility equilibria. Manganese then diffuses along a pore water concentration gradient from anoxic to oxic conditions and is immobilized by the oxidation of Mn^{++} and the precipitation of the manganese oxyhydroxides[24,25]. This process can produce near-surface diagenetic manganese contents of several weight percent[29–31]. The behaviour of Fe in marine sediments is similar to that of Mn, with iron hydroxides being mobilized as Fe^{++}, following the utilization of labile manganese oxides[24,25]. Mn responds sensitively to paleo-oceanographic changes. Mn enrichment due to changes in the concentration of the overlying water column mainly because of paleoclimatic events like changes associated with phases of transition from glacial to interglacial periods have been reported for the sediments of the Atlantic and Pacific regions.

The behaviour of Co and Ni, during remobilization, is closely related to that of Mn[25,30,32–34]. Pore water data from hemipelagic sediments[35] indicate that both Co and Ni reach dissolved maxima in the Mn reduced zone and are precipitated along with manganese oxide zone[26–29]. Chromium is definitely depleted in the upper oxidized section of the core, contrary to the case of Mn, Ni, and Co. Cr probably exists in the oxidized mud prevalently as CrO_4^{-2}, which is highly soluble[36]. In the reduced down section of the core, Cr^{6+} will be reduced to Cr^{4+} and Cr^{3+} and precipitated.

Geochemical nature of the sediments in terms of the above described elements clearly envisages (Figures 3, 4) that in the present study, the stiff layer is positioned in between reduced dark colour and oxidized light colour sections of the core sediments.

Organic carbon minima is correlated with Mn maxima, this inverse relationship in deep sea is well established especially at glacial ends, where oxidation is the main process responsible for this lower OC and higher Mn concentrations. Oxidation of organic carbon results in the dissolution of foraminifera[24]. In agreement to this, lowest values of $CaCO_3$ at this stiff layer are due to $CaCO_3$ dissolution at this depth. Fragmentation of foraminiferal shells, slightly above and below this depth, indicates the influence of the dissolution and complete absence of foraminiferal shells at stiff layer is an indication of the intensified dissolution, presence of silicious fauna such as radiolarians confirm the dissolution of $CaCO_3$. However, such enrichment of metals can also be possible in volcanogenic sediments, but absence of volcanic shards rules out the intuition of volcanic origin of this layer and supports the dissolution phenomena. In general, lamination is one of the sedimentary structures indicating the sedimentation pattern, while laminae in the stiff layer could be considered as micro-level sedimentation during the formation of the stiff layer.

Petrological and XRD investigations were conducted to identify minerals of the above-said metals. As these studies do not show any mineralogical form, this sample is further subjected to SEM studies. These studies indicate that the above-discussed metal concentrations in the stiff layer are not in well-defined crystalline form, they are either in cryptocrystalline form or in the oxide coatings on the sediment particles, which are deposited earlier to the formation of this stiff layer.

Published results of textural and geochemical studies on SK 31/11 core sediments indicate the Pleistocene/Holocene Boundary at 40–45 cm bsf of the core[8]. In the

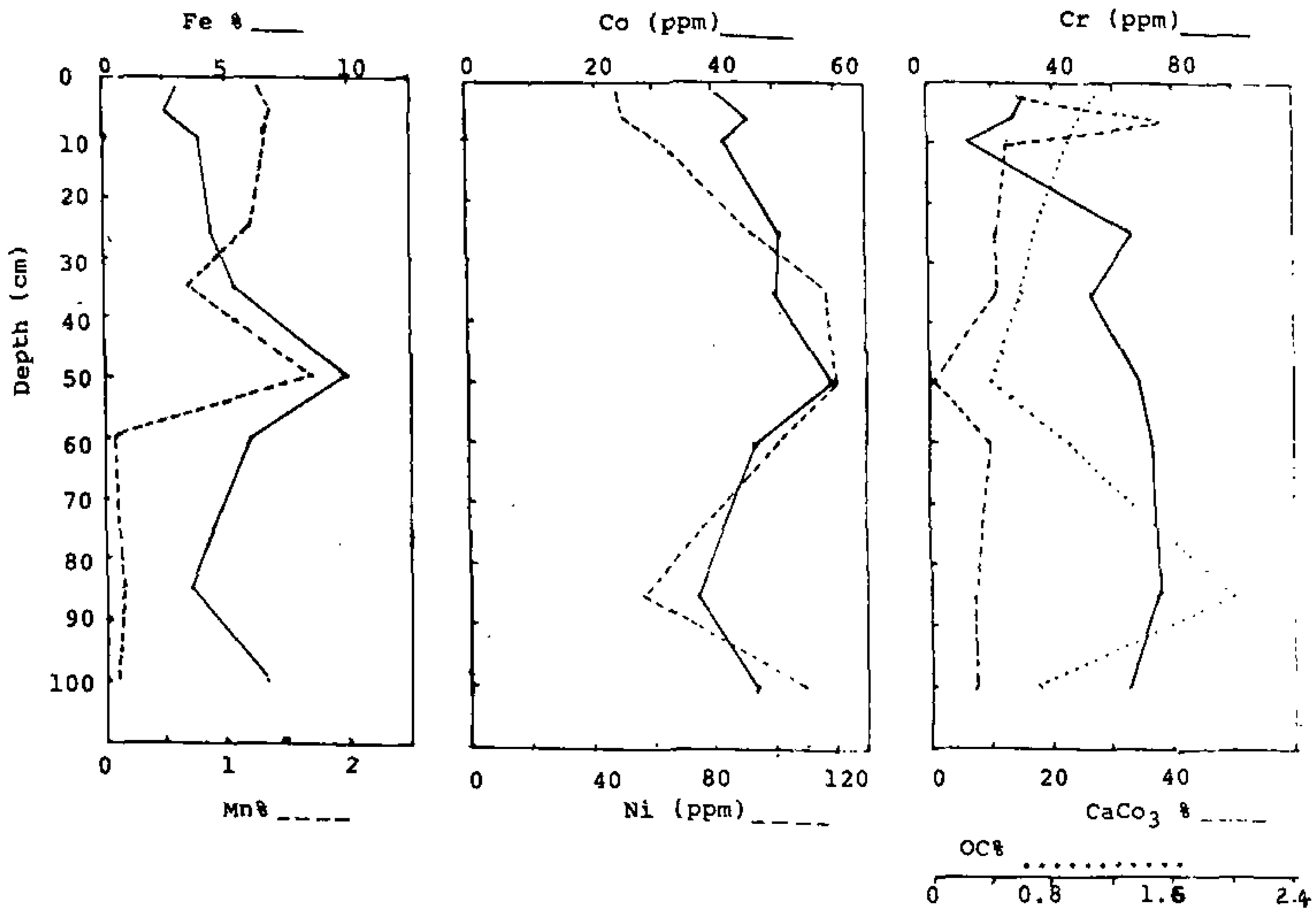

Figure 3. Vertical geochemical variations of SK 72/1.

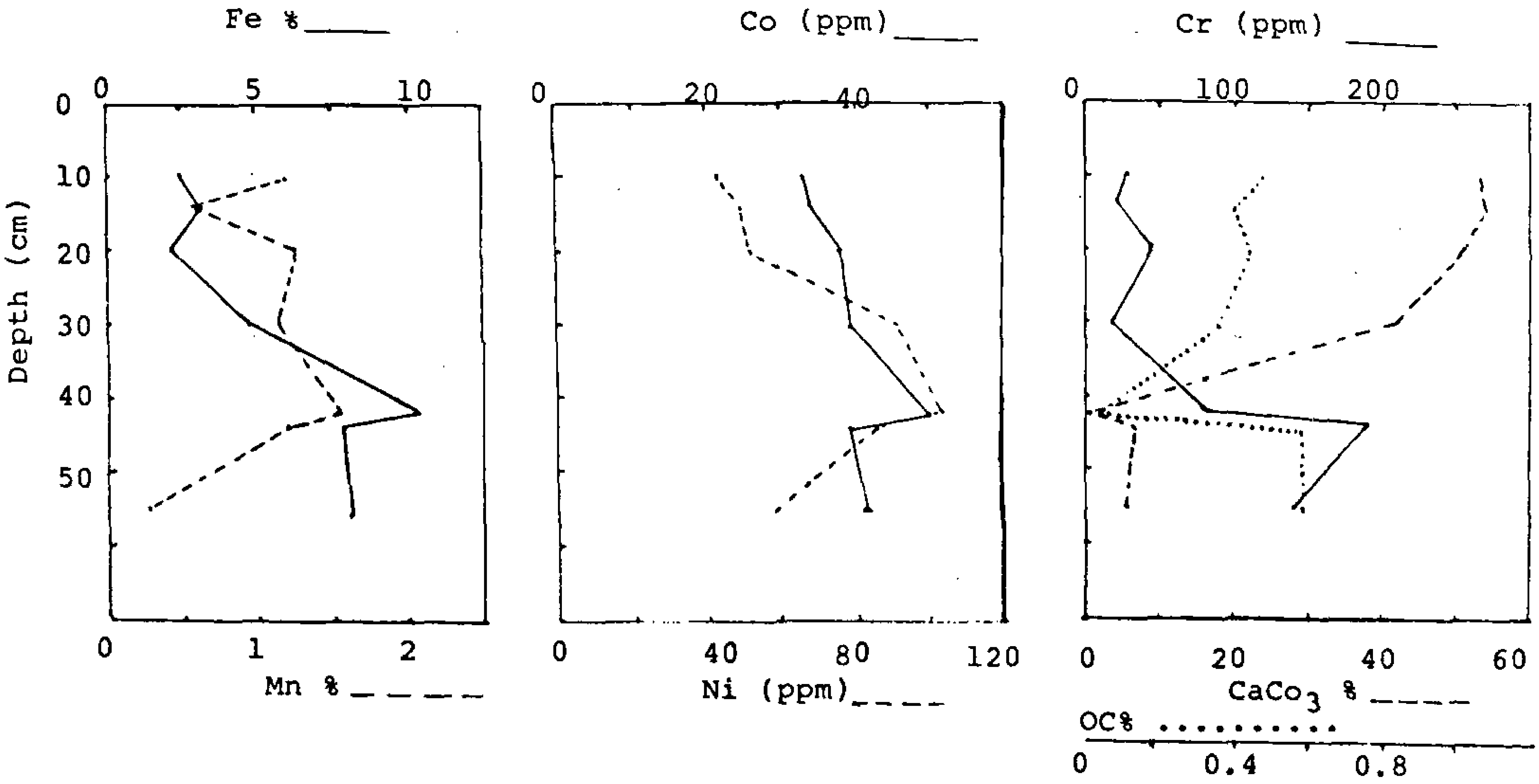

Figure 4. Vertical geochemical variations of SK 100/6.

present study a 7 mm thick Fe, Mn-rich layer is observed in this core also, at the above boundary level. Distributional pattern of geochemical elements in the Holocene and Pleistocene parts of the above core sediments, coincides with our data. It is observed that the thickness of stiff layer increases in SK 100/6 (15 mm) from SK 31/11 (7 mm) and SK 72 (4 mm), indicating the prominence of metal concentration in the central part compared to two other sites which are relatively near the continental input.

Thus the conclusion is that the Fe, Mn-rich layer is formed due to post-depositional migration of these elements during the Pliestocene/Holocene transitional periods because of emasculated influence of terrestrial input into these sites. Oxidation of labile organic matter provides the mechanism for the redox-related mobilization in the distal Bengal Fan.

1. Curray, J. R. and Moore, D. G., *Geol. Soc. Am. Bull.*, 1971, **82**, 563–572.
2. Gold-berg, E. D. and Griffin, J. J., *Deep-Sea Res. Oceanogr. Abstr.*, 1970, **17**, 513–537.
3. Chester, R., *Marine Geochem.*, Academic Division of Unwin Hyman Ltd, London, 1990, p. 698.
4. Broecker, W. S. and Peng, T. H., in *Tracers in the Sea*, Lamont Dohert Geological Observatory Press, Columbia University, New York, 1982, p. 690.

5. Sarin, U. M., Borole, D. V. and Krishnaswami, S., *Proc. Indian Acad. Sci.*, 1979, **88**, 131–154.
6. Fontugne, M. R. and Duplessy, J. C., *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1986, **56**, 69–88.
7. Chauhan, Onkar, S., Borole, D. V., Gujar, A. R., Mascarenhas, Antonio, Mislanker, P. G. and Rao, CH. M., *Curr. Sci.*, 1993, **65**, 558–562.
8. Chauhan, O. S., Mascarenhas, A., Paropkari, A. L. and Rao, CH. M., in *Oceanography of the Indian Ocean* (ed. Desai, B. N.), Oxford, IBH Publ. Co., Bombay, 1992, pp. 479–486.
9. Borole, D. V., *Curr. Sci.*, 1993, **65**, 778–781.
10. Chauhan, Onkar S., Gujar, A. R. and Rao, CH. M., *Earth Planet. Sci. Lett.*, 1994, **128**, 563–573.
11. Nath, B. N., Rao, V. P. and Becker, K. P., *Mar. Geol.*, 1989, **887**, 301–303.
12. Nath, B. N. and Mudholkar, A. V., *Mar. Geol.*, 1989, **86**, 57–66.
13. Roy, S., Dasgupta, S., Mukhopadhyay, S. and Fukuoka, M., *Mar. Geol.*, 1990, **92**, 269–283.
14. Pattan, J. N. and Mudholkar, A. V., *Chem. Geol.*, 1990, **85**, 171–181.
15. El Wakeel, S. K. and Riley, J. P., *J. Conseil Int. I Enplor. Mer.*, 1957, **22**, 180–183.
16. Piper, C. S., *Soil and Plant Analysis*, University of Adelaide, 1947, p. 368.
17. Hays, J. D. and Perruzza, A., *Quat. Res.*, 1972, **2**, 355–362.
18. Volat, J. L., Partourat, L. and Vergnaud Grazzini, C., *Rev. Mar. Geol.*, 1980, **34**, 1–28.
19. Divakar Naidu, P., *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1991, **86**, 255–263.
20. Margini, A., Eissenhawer, A. and Walter, P., *Paleoceanography*, 1990, **5**, 811–821.
21. David, F. R., McGeary, J., Damuth, E., *Geol. Soc. Am. Bull.*, 1973, **84**, 1201–1212.
22. Lyle, M., *Limnol. Oceanogr.*, 1983, **28**, 1026–1033.
23. Murray, J. and Irvine, R., *Trans. R. Soc. Edinburgh*, 1987, **37**, 721–742.
24. Froelitch, P. N., Klinkhammer, G. P., Bender, G. R., *et al.*, *Geochim. Cosmochim. Acta*, 1979, **43**, 1075–1090.
25. Klinkhammer, G. P., *Earth Planet. Sci. Lett.*, 1980, **49**, 81–101.
26. Colley, S., Thomson, J., Wilson, T. R. S. and Higgs, N. C., *Geochim. Cosmochim. Acta*, 1984, **48**, 1223–1235.
27. Wilson, T. R. S., Thomson, J., Colley, S., Hydes, D. J., Higges, N. C. and Sorensen, J., *Geochim. Cosmochim. Acta*, 1985, **49**, 811–822.
28. Thamson, J., Higgs, N. C. and Colley, S., *Mar. Geol.*, 1989, **89**, 315–330.
29. Bonatti, E., Fisher, D. E., Joensuu, O. and Rydell, H. S., *Geochim. Cosmochim. Acta*, 1971, **35**, 189–201.
30. Sawlan, J. J. and Murray, J. W., *Earth Planet. Sci. Lett.*, 1983, **64**, 213–230.
31. Kadko, D. and Heath, G. R., in *Fine Grained Sediment, Deep Water Processes and Facies* (eds Stow, D. A. V. and Piper, D. J. W.), Geol. Soc. Spl. Publ., 1984, vol. 15, pp. 145–151.
32. Hem, J. D., *Chem. Geol.*, 1978, **21**, 199–218.
33. Callender, E. and Bowser, C. J., *Am. J. Sci.*, 1980, **280**, 1063–1096.
34. Klinkhammer, G. P, Heggie, D. T. and Graham, D. W., *Earth Planet. Sci. Lett.*, 1982, **61**, 211–219.
35. Higgie, D. and Lewis, T., *Nature*, 1984, **311**, 453–455.
36. Elderfield, H., *Anal. Chem.*, 1970, **42**, 414–415.

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Erratum

Satellite data reveals pre-earthquake thermal anomalies in Killari area, Maharashtra

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Figures 2 and 3 on pages 882 and 883 have been interchanged though not the captions. We regret the error.