Atypical ferromanganese micronodules from middle fan-valley system, Bay of Bengal

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Ferromanganese micronodules having botryoidal and spheroidal morphogroups have been observed over a 0.22 million km^2 area from the middle fan region of the Bay of Bengal. The bulk micronodules have 26.26% Mn, 1.02% Fe, 1.82% Ca, 0.12% Ni, 0.14% Zn and 0.08% Cu. Their Mn/Fe ratio (25.74) is much higher than the world average. Based on the results of the present study, we suggest that early diagenesis *may be the contributory process for their formation.*

THE occurrence of ferromanganese micronodules has been reported from the area having a low sedimentation rate[1-11], and based upon mass balance equations, a negative correlation between rate of sedimentation and formation, and abundance of these nodules have been reported[1-4]. The formation and occurrence of ferromanganese micronodules from a high sedimentation site, particularly from a fan-valley system characterized by a high terrigenous sediment input, are, so far, unknown.

Here we report the occurrence of ferromanganese micronodules from the middle fan region of the Bay of Bengal. The region is characterized by channel and levees and has sedimentation rates[12,13] ranging from 4 to 20 cm ky^{-1}. We also report the spatial distribution of the micronodules, their morphogroups, bulk mineralogy and elemental contents, within the study area.

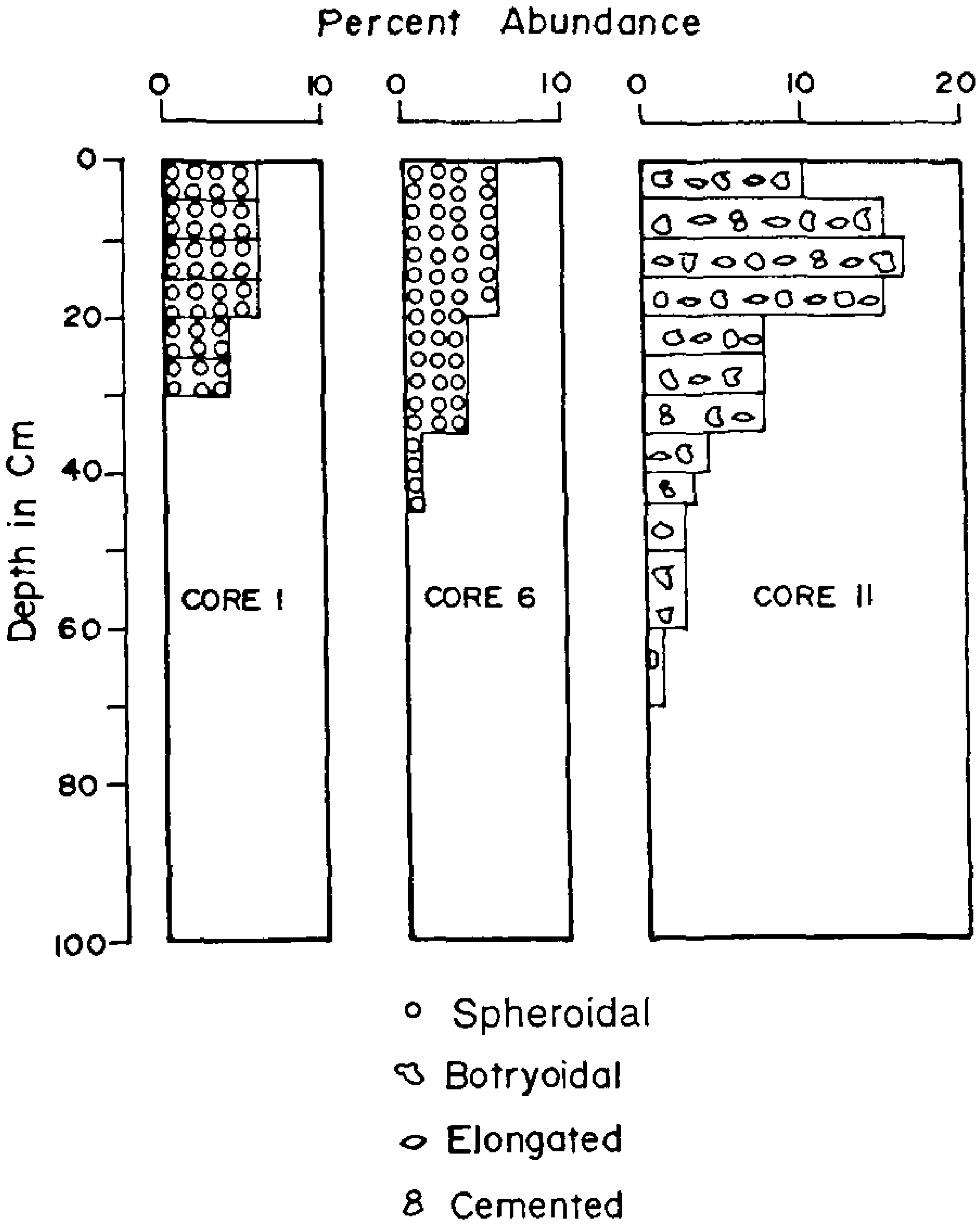

Figure 2. Subsurface abundance of micronodules in the cores 1, 6 and 11. Note an enrichment of micronodules in the upper surfaces of the cores. For the location of the cores, refer Figure 1.

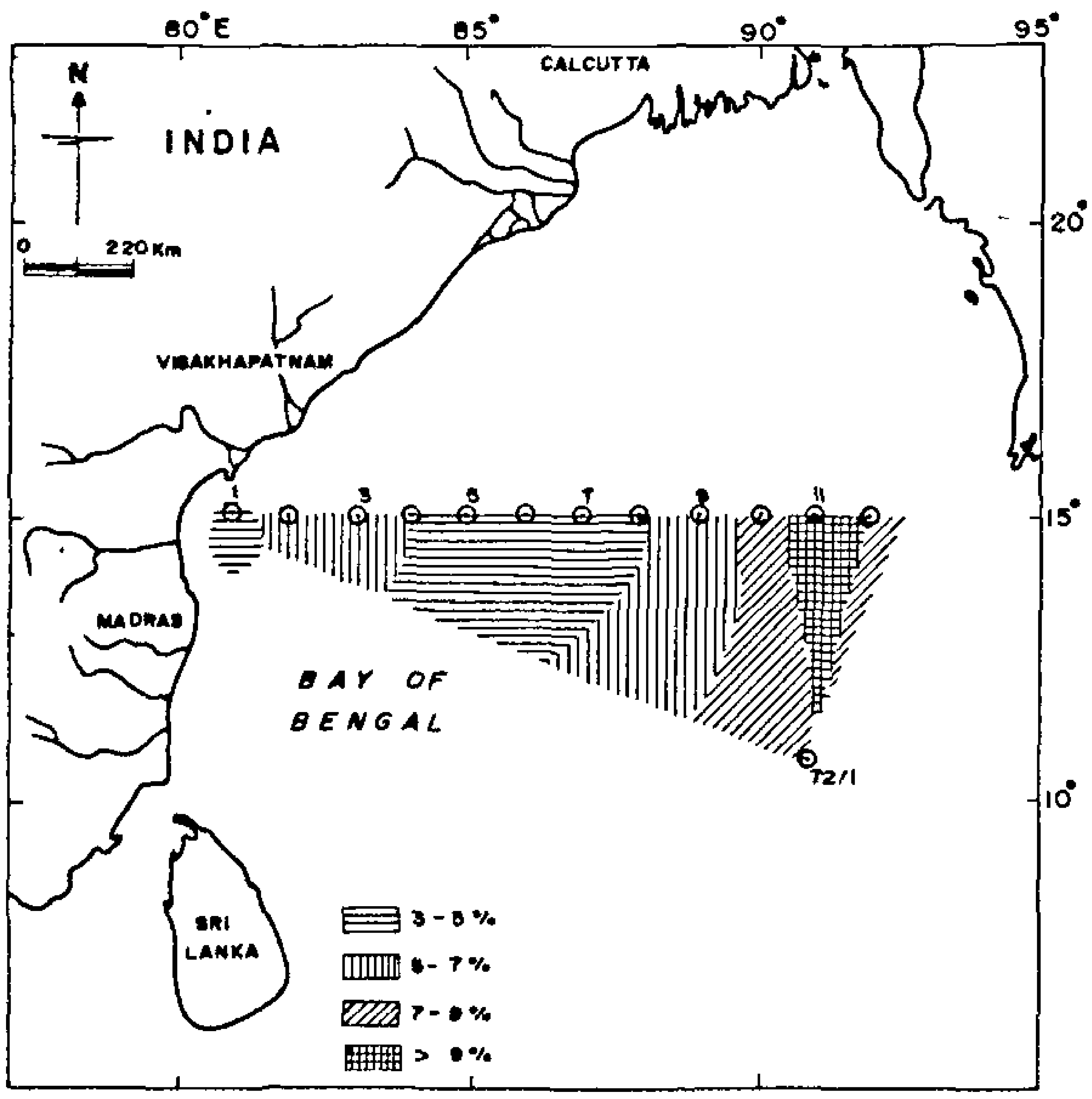

Figure 1. Spatial distribution of micronodules in the study area. The locations of the cores are also shown

During the 31st and 72nd cruises of the ORV *Sagar Kanya*, 13 box cores (30 cm × 30 cm × 6 m) were retrieved from the middle fan region of the Bay of Bengal (Figure 1). The surfaces of the ten cores (upper 10 cm) and subsamples (at 5 cm intervals down to 1 m of core depth) of 3 box cores from the east, west and the central bay were examined under a binocular microscope for component analysis. Micronodules in > 45 µm fraction of 10 g dried samples were obtained. A minimum of 300 grains was counted in each sample.

Due to limitation of sample quantity, the bulk chemical analysis of the micronodules was obtained by boiling 25 mg of micronodules in 10% hydroxylamine hydrochloride following the methods of Sharma and Somayajulu[14]. The leach was analysed on an AAS model Perkin Elmer 2380. The residue left after this leach was about 8%. The accuracy of the analysis was checked against the standard SDO 1–3 and was found to be better than 5%.

To obtain detailed morphology, about 100 micronodules were mounted on aluminium stub, coated with

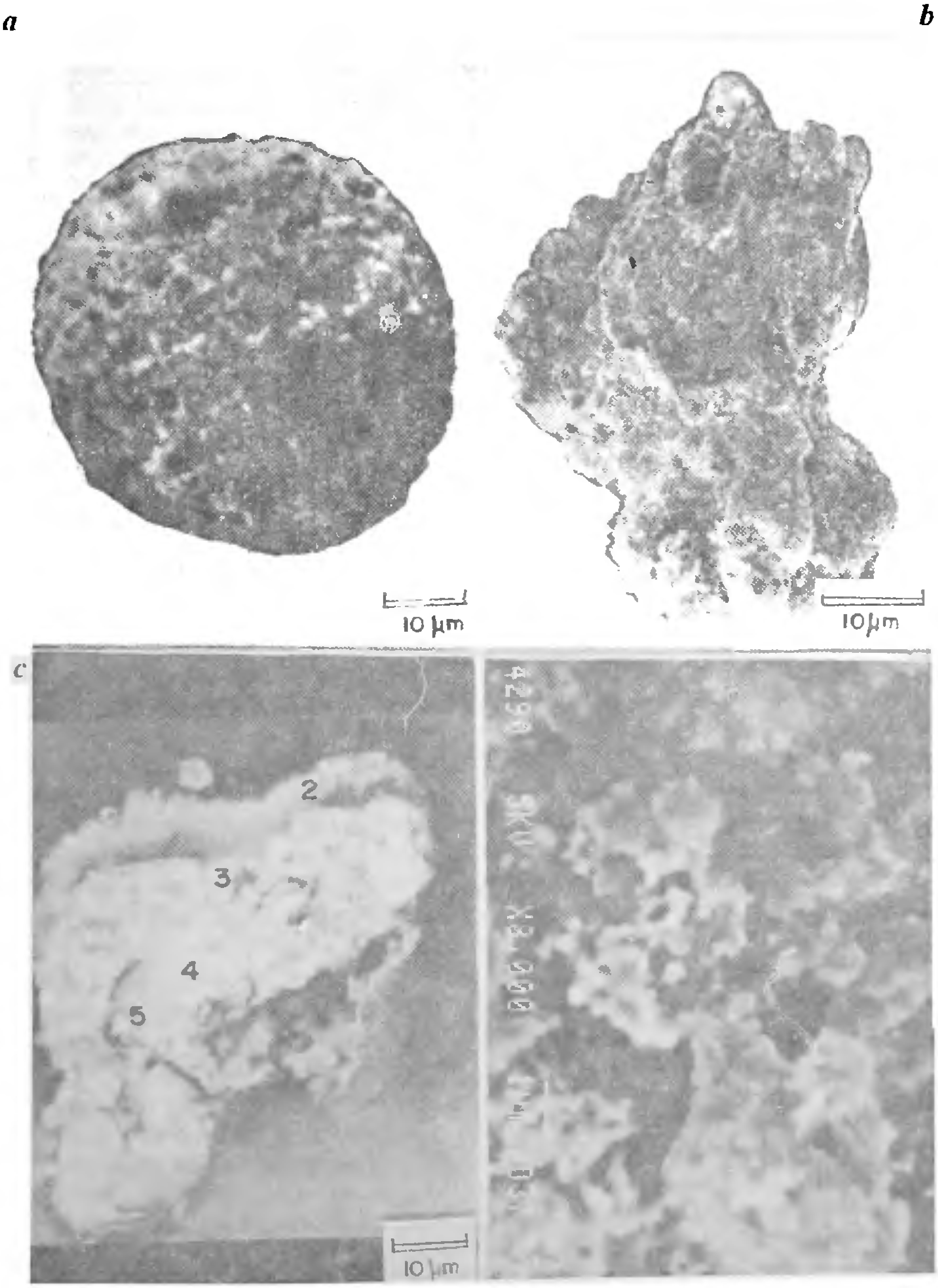

Figure 3. SEM photographs of the micronodules depicting different morphological forms *a*, Spheroidal morphogroups from the western bay, *b*, Spheroidal form from the eastern bay, *c*, Polished sections showing uniform deposition and absence of concentric layers, *d*, enlarged portion of *c* depicting the todorokite deposition. The alphanumericals in the *c* show the locations where electron microprobe analysis for the elemental contents was performed

carbon and gold and studied under a Camebax Scanning Electron Microscope. A few polished sections were also studied to ascertain internal structures. To determine the variations in the elemental distribution within the micronodules, electron microprobe coupled with SEM was used at four locations, on one of the polished sections.

The distribution of the micronodules in the Bay of Bengal is shown in Figure 1. Their occurrence is observed over 0.22 million km^2 area in the middle fan region of the bay. However, their abundances vary widely within the bay. The eastern bay has higher abundance (9%) compared to the central or western bay (3%; Figure 1). The variations are also noticed in the subsurface abundance of these micronodules. They are observed down to 78 cm section in the core from the eastern bay (core 11; Figure 2). In the central and western bay (cores 1 and 6), however, their occurrence

Table 1. Average chemical composition of micronodules obtained from 10% leach of hydroxylamine hydrochloride (1) and EPMA (2–5) analysis (4 spots) from Bay of Bengal, Central Indian Basin and Pacific For the locations of the spots 2–5, refer Figure 3 *d*

Element (%)	Bay of Bengal 1	2	3	4	5	Central Indian Basin[10]	Pacific Ocean[4]	World average[6]
Ti	–	0 01	0 01	0 01	0 01	0 24	–	0 69
Mn	26 26	29 19	29 17	29 31	29 02	36 02	19 81	16 18
Fe	1 02	1 33	1.32	1.34	1 36	1 39	10 97	6.47
Ca	1 82	1 16	1 18	1 17	1 18	2 34	–	2 22
Mg	1 21	–	–	–	–	3 68	–	1 56
Ni	0 12	0 98	0 97	0.99	0 96	1 44	0 42	0 48
Co	0 01	0 01	0 01	0 01	0 01	0 15	0 12	0.30
Cu	0 08	0 92	0 93	0 94	0 92	1 69	0.43	0 25
Zn	0 14	0 29	0.21	0 23	0 22	0.38	0 11	–
Mn/Fe ratio	25 74	21 94	22 09	21 87	21 33	25 99	1.80	2 50

is noticed down to much shallower core depths (about 30 cm, Figure 2).

The micronodules may be grouped into two dominant morphological forms (Figure 3). In the western and the central bay, they are characteristically spheroidal (Figure 3 *a*). Their morphology in the eastern bay, close to Andaman sea region, is however markedly different. These micronodules have botryoidal form (Figure 3 *b*). Occasionally, cemented and mamilliated forms are also observed in this region. The study of the polished section reveals that unlike the micronodules of Central Indian Basin (CIB) or Pacific[4, 10, 11] (MANOP site), the concentric layered structure is conspicuously absent (Figure 3 *c*). In the polished section uniform deposition of todorokite is observed.

The chemical analysis of the bulk micronodules is presented in Table 1. These results suggest that micronodules are enriched in Mn (26.66%) and depleted in Fe (1.02%), Ni (0.12%), Cu (0.08%) and Zn (0.14%). The study of elemental distribution, obtained from the electron microprobe (Table 1; 2–5), in general, agrees with the results obtained through bulk chemical analysis of the micronodules. These results further suggest that the micronodules have a similar elemental distribution within the entire section of the micronodules (Table 1), and Mn is not precipitated as the surface coating. The Mn/Fe ratio at different locations is also similar (Table 1; 2–5). These results confirm that the micronodules lack a layered structure having variable elemental composition, and during the accretion of Mn, no change has taken place in the environment of deposition. Compared to the micronodules of the other region of the world, the micronodules of the Bay of Bengal have similar Mn/Fe ratio to those of Central Indian Basin (CIB). However, compared to Pacific Ocean or world average[4, 6], the micronodules of the Bay of Bengal are much depleted in Fe (Table 1).

The occurrence of micronodules over a sizeable area in the Bay of Bengal is widespread, and therefore, suitable conditions do prevail despite the high terrigenous input and 10-fold higher sedimentation in the study area than either the CIB or the Pacific. These factors suggest that rate of sedimentation is not a limiting factor for the formation of ferromanganese micronodules.

Earlier studies[1–4, 10–12, 15, 16], based upon Mn/Fe ratio, characteristic Mn minerals precipitated in the micronodules and subsurface distribution of micronodules in the sediment column, have identified the processes contributing to the formations of ferromanganese nodules. The micronodules of the Bay of Bengal, when plotted in the ternary diagram of Halbach *et al.*[15], fall in the early diagenesis domain. Other studies[9–11] have also suggested that todorokite in the Mn mineral forms as a result of early diagenesis. There is a surface enrichment of micronodules in all the cores (Figure 2). Similar trend has been observed in the Pacific and Indian Ocean[4, 10, 16], and this trend has been attributed to partial dissolution of micronodules at deeper subsurface level and remobilization of Mn to the top of the sediment column during early diagenesis[10, 16]. Thus, based upon the above results, it is suggested that these micronodules are formed as a result of early diagenesis.

A detailed study of oxic–suboxic environment within the sediment column from the eastern, central and western Bay of Bengal, elemental variations in the micronodules from the different subsamples of cores, and in the sediments of the cores is underway to further elaborate the formation of micronodules in one of the highest terrigenous sedimentation regions of the world.

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Vesicular–arbuscular mycorrhiza in an alkaline *usar* land ecosystem

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Vesicular–arbuscular mycorrhization was observed on plants growing in an alkaline *usar* land ecosystem that supported only scanty vegetation. Six plant species, four belonging to the pioneer vegetation and two introduced in the *usar* land were examined. VAM colonization was observed on all the six plant species and the greatest colonization was on introduced bamboo (81.2%). Rhizosphere soil of the plants harboured a significant population of VAM fungi belonging to three genera, *Glomus*, *Acaulospora* and *Entrophospora*. The results indicated abundant occurrence of VA-mycorrhizae on root systems of plant species of pioneer vegetation as well as introduced plants in the alkaline *usar* land ecosystem. Native VAM fungi of *usar* land ecosystem appear to be tolerant to soil alkalinity. The results suggest potential use of the native VAM fungi for the revegetation and reclamation of alkaline *usar* lands.

USAR is a term collectively used for all kinds of alkaline and saline waste lands in northern parts of India. It is estimated that about 7 million hectares of *usar* land unfit for agriculture is present in India[1]. A major part of this type of waste land is spread in the plains of Uttar Pradesh (1.29 million hectares). The soil in this area is highly alkaline and supports only marginal and scanty vegetation. Vesicular–arbuscular mycorrhizae (VAM) are the most common of all mycorrhizae and are widely recognized as components of all terrestrial ecosystems[2]. VA-mycorrhizal fungi are ubiquitous and occur in nearly all natural soils[3,4] from arctic to tropics in a wide range of niches[5,6]. There has been hardly any study of VA-mycorrhizal associations of *usar* land vegetation and distribution of VA-mycorrhizal fungi in the *usar* land ecosystem. In this communication we report the VA-mycorrhizal association of plant species of an alkaline *usar* land ecosystem in the North Indian plains.

This investigation was carried out in a selected site in and around the Anwari Research Station of Kaul Science Foundation approximately 20 km away from Lucknow city (Figure 1). *Sporobolus diander* (Rets) P. Beauv, *Desmostachya* sp., *Dendrocalamus strictus* (Roxb.) Nees (Bamboo), *Adhatoda vasica* Nees and *Solanum xanthocarpum* Schrad & Wendl. formed the pioneer vegetation in this site, *S. diander* and *Desmostachya* sp. being dominant. VA-mycorrhizal association of the pioneer vegetation and two introduced plants, bamboo seedlings (*D. strictus*) and chamomile plants (*Matricaria chamomilla* L.) were examined during this study.

A number of soil samples from the root zone of each plant species growing in different locations of the site were randomly collected. Physical and chemical properties of the soil such as texture, pH, electrical conductivity, available nitrogen, phosphorus and potassium were determined by the standard analytical methods[7].

Rhizosphere soil samples along with fine roots of each plant species were collected randomly from a number of plants growing in the site. The first sampling was done in August 1989 and the second in February 1990. Roots were separated, washed, chopped into 2–4 cm segments, cleared with KOH and stained with trypan blue as described by Phillips and Hayman[8]. VA-mycorrhization of each plant species was determined by estimating the per cent root colonization according to the method of Biermann and Lindermann[9]. At least 50 root segments were examined for each estimation. The extent of VA-mycorrhization was calculated from the per cent root length colonized. Population of VA-mycorrhizal fungi in the rhizosphere soil of each plant species was determined by the wet sieving and decanting method of Gerdemann and Nicolson[10]. The VA-mycorrhizal fungi isolated from the rhizosphere soil were identified with the help of the *Manual for the Identification of VA-mycorrhizal Fungi*[11]. Data were statistically analysed by adopting the appropriate method of 'Analysis of variance'. Statistically significant difference among the data was tested by critical difference (C.D) test at 1 and 5 per cent level of probability.