# Calcium carbonate distribution in the Late Quaternary sediments of Bay of Bengal

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**Spatial distribution of calcium carbonate concentration in sixteen core top sediments indicates an increasing trend towards the deep-sea, and suggests that the carbonate concentration in the western Bay of Bengal is mainly controlled by terrigenous dilution. The temporal distribution, in general, shows a higher concentration of biogenic calcium carbonate in the middle segment of the cores (between 80 and 150 cm) compared to upper and lower half segments. The gradual enrichment of *in-situ* biogenic carbonate at this level is probably due to a reduced terrigenous supply by the Ganga–Brahmaputra river system owing either to a weak SW monsoon or tectonic trapping of sediments in the subsiding Indo-Gangetic Foredeep during the Last Glacial Period in late Pleistocene. However, towards the Godavari river mouth (E–W traverse) as the calcium carbonate concentration demonstrates no variation in temporal distribution, this indicates a higher Godavari river influx probably related to a strong NE monsoon during the glacial period. The presence of low-carbonate content in the upper part of the cores is attributed to an increased terrigenous supply in the post-glacial period. The temporal distribution also shows three abrupt increases in calcium carbonate concentration related to transported nature of biogenic and chemogenic (ooids) materials from the shelf regime under turbidity current/gravity flow activity.**

A study of sediments from 16 gravity core samples, 60 cm to 289 cm long, collected from the continental slope off Vishakhapatnam to deep sea Bay of Bengal, shows that these sediments comprise the following depositional facies[1]: (i) Pelagic and hemipelagic clay – with low (5–10%), and high (10–30%) carbonate concentration; (ii) Turbidite/gravity flow deposit – with low (normally < 5%) carbonate concentration (siliceous turbidites) and high (50–75%) carbonate concentration (calcareous turbidites). The turbidite units were identified by visual inspection of core, sedimentary structures and grading, characteristic pattern in grain size and composition[2–4]. These turbidites show a regular decrease in model grain size, and grain size distribution shows large modes of coarse and medium silt. In contrast, hemipelagic sediments show no regular grading, and grain size distribution shows large modes in fine silt and clay grade. Further, these turbidites are either siliceous or calcareous. The siliceous turbidites are characterized by abundant terrigenous materials (quartz, mica, feldspar, heavy minerals, etc.) and are devoid of presence of any fauna. In contrast, the calcareous turbidites consist of abundant calcareous bioclastic materials, particularly shallow-water benthic foraminifera, planktonic foraminifera, shell fragments, bivalves, pteropods and gastropods, followed by detrital minerals (quartz, feldspar, etc.) and/or calcareous chemogenic material (ooids). The pelagic/hemipelagic clay consists of detrital minerals and biogenic materials (calcareous and siliceous) and constitutes the major facies assemblage. While the pelagic clays are generally present above core depths of 90 cm, the hemipelagic clays occur below core depths of 90 cm.

The cores were collected in the western part of the Bay (14° to 21°N lat. and 83° to 90°E long.), from water depths of 448 to 3066 m, the northern limit falling within the Swatch of no-ground submarine canyon (SNGSC) and the western limit in the continental slope off Vishakhapatnam. Cores were obtained from SNGSC, upper, middle and lower Bengal Fan[5] and also from the continental rise and slope off Vishakhapatnam Coast (see Figure 1 for sample location). All the cores were correlated by volume-specific magnetic susceptibility pattern matching (details will be published elsewhere), and the prominent peaks (P1, and P2) and troughs (T1 and T2) are shown in Figures 2–6.

The Bay of Bengal receives heavy terrigenous load, mainly siliceous material, from the major rivers draining the Himalayan ranges and the peninsular shield of India[6,7]. In the face of this heavy terrigenous input, the cores show three levels of rise in calcium carbonate concentration: (i) upper part (27–50 cm), an abrupt rise, seen only in one core (SM 43/15) off Vishakhapatnam coast; (ii) middle part (80–150 cm), mostly a gradual rise, superimposed by an abrupt rise in one case (core no. SM 43/17), and (iii) lower part (170 cm and more), where the rise seems to be gradual, superimposed by sharp rise in two cores (core nos. SM 43/94, 43/42) also close to the coast. It may be noted that the middle segment which shows a gradual rise in calcium carbonate percentage is not present in all the cores, indicating spatial variation in carbonate distribution. The peculiarities in the distribution of carbonate concentration in marine set up can be due to several factors namely, (i) biogenic productivity, (ii) displacement of carbonate

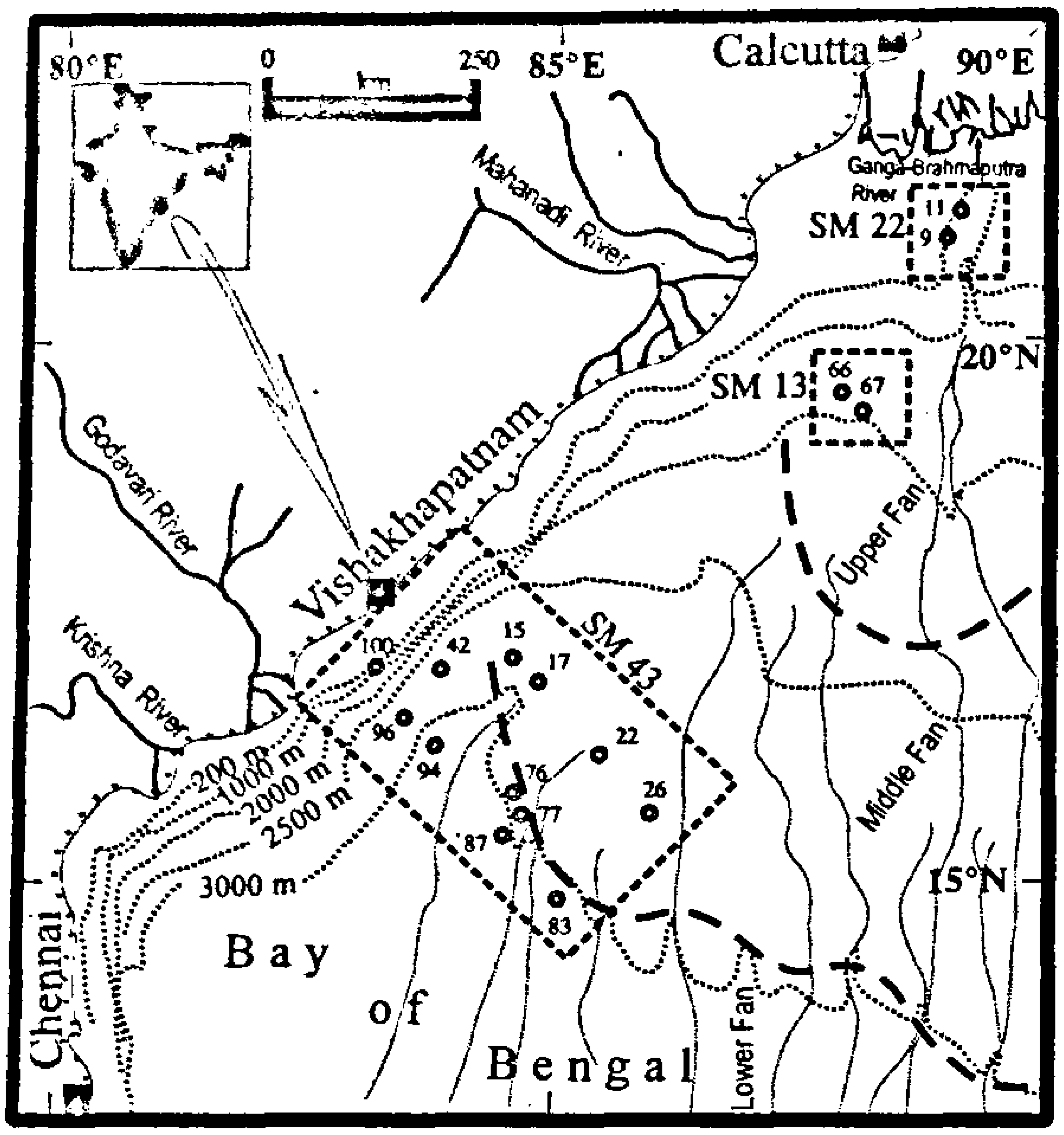


**Figure 1.** Location map showing core position and cruise no. (e.g. SM 43). The paleochannels are represented by dotted lines from north to south.

clastics by gravity flow, (iii) dissolution, and (iv) dilution by terrigenous material. This study on the Bay of Bengal cores with respect to their geomorphic environment throws light on the interaction between different factors that have controlled carbonate distribution.

## Core analytical data

The megascopic studies revealed that the surface sediments from deeper parts are dark yellowish brown (10 YR 4/2) clays whereas sub-surface sediments are light olive grey (5 Y 6/1; 5 Y 5/2) and olive grey clays (5 Y 4/1; 5 Y 3/2) and mud. Occasional influx of greyish-white-coloured sand, either calcareous or siliceous, was also observed. Sub-samples were collected from all the cores and the sampling interval was maintained at, more or less, equal distance of 20 cm and close sampling was done wherever it was felt necessary to represent all lithologies. Each sub-sample represented 4 cm thick sedimentary zone.

Textural study of the core samples indicates that the upper part of most of the cores comprises clay grade sediments while silty clay sediments occur in the lower part along with coarser fraction (Figures 2–6). The coarse fraction (> 63 μm) in the cores is composed mainly of *in situ* biogenic material. In some cases transported biogenic and chemogenic (ooid) material and

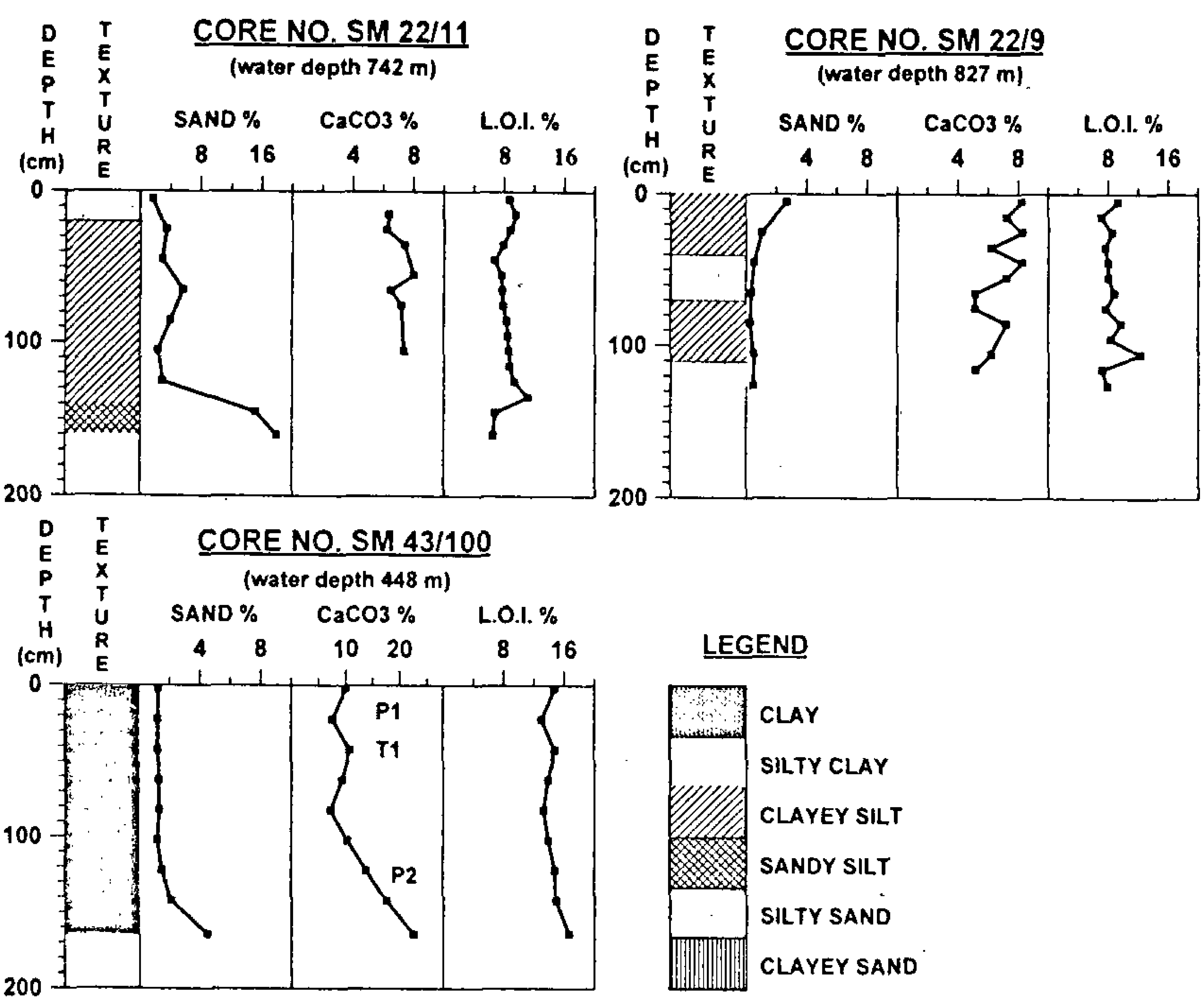


**Figure 2.** The temporal distribution of coarse fraction, calcium carbonate and loss on ignition in sediment cores from SNGSC (core nos. SM 22/11 and SM 22/9) and continental slope off Vishakhapatnam (SM 43/100). Correlation points (P – peak; T – trough) are marked by pattern matching of volume specific magnetic susceptibility.

terrigenous grains also constitute the coarse fraction. In majority of the cases there is a sympathetic relation between coarse fraction and carbonate concentration. Loss on ignition (LOI) was investigated on each sample by heating it at 1000°C for 1 h. Since LOI is predominantly due to loss of $CO_2$ from calcium carbonate, the LOI distribution is in general very similar to that of $CaCO_3$ concentration (Figures 2–6). The calcium carbonate concentration in the cores, determined by titration method[8], is indicated below in accordance with their geomorphic locations.

(a) *Swatch of no ground submarine canyon (SNGSC).* Core nos. SM 22/11, 22/9, there is no significant variation in $CaCO_3$ concentration from top to bottom of cores. Average value is low (~ 7%) (Figure 2).

(b) *Upper Bengal Fan.* Core nos. SM 13/66, 13/67, these cores show a horizon of high calcium carbonate (10–20%) at depths of 70–150 cm (Figure 3). The calcium carbonate quantity shows gradual variation and occurs within the silty clay horizon. In core no. SM 13/67 there are two levels (~ 80 cm and ~ 120 cm) where the

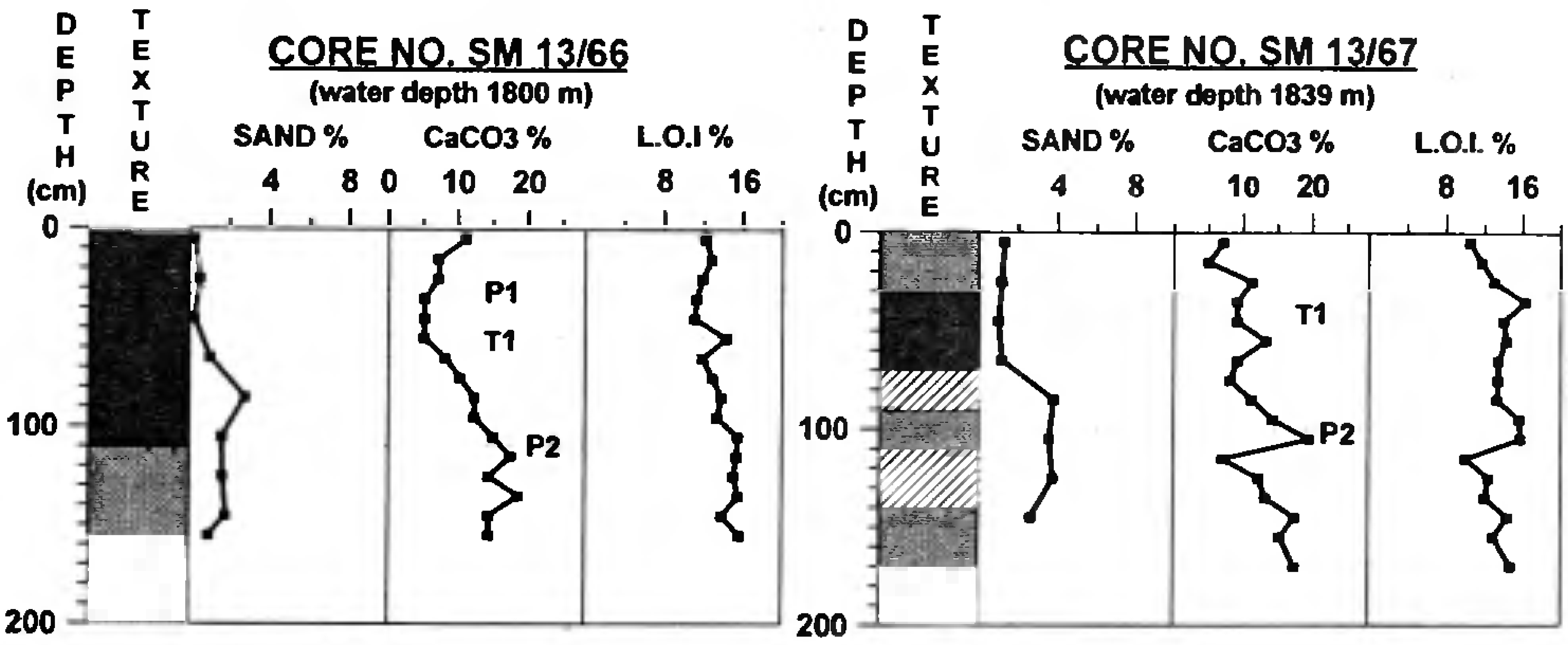


Figure 3. The temporal distribution of coarse fraction, calcium carbonate and loss on ignition in sediment cores from Upper Bengal Fan. The calcium carbonate shows a gradual increase below 70 cm core depth.

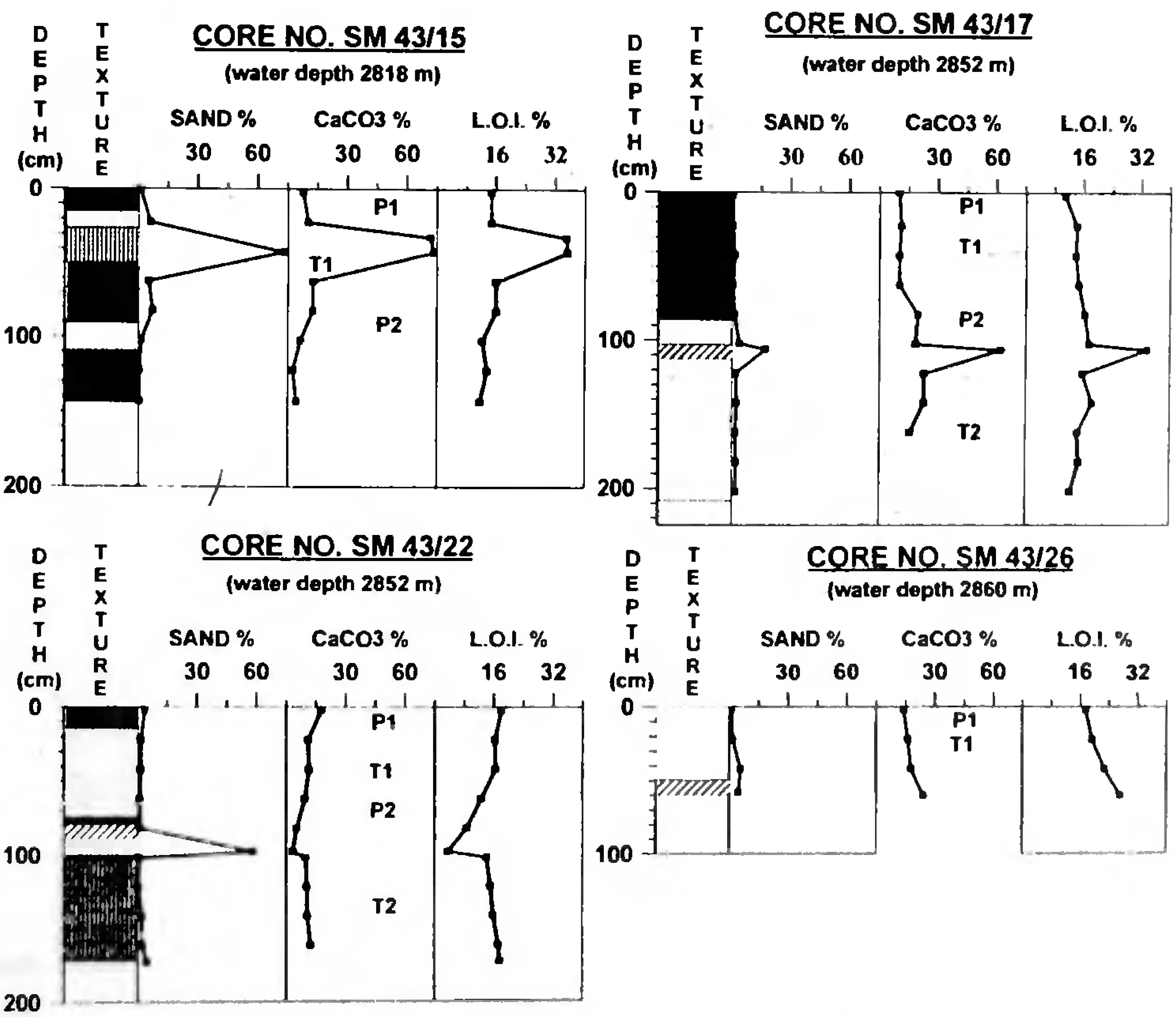


Figure 4. The temporal distribution of coarse fraction, calcium carbonate and loss on ignition in sediment cores from Middle Bengal Fan. The sharp increase in calcium carbonate between 27 and 49.5 cm (SM 43/15) and 104 and 112.5 cm (SM 43/17) is due to calcareous ooid turbidites, whereas the sharp decrease between 73 and 100 cm (SM 43/22) is related to siliceous turbidite.

calcium carbonate frequency goes down abruptly. These levels are characterized by siliceous materials, predominantly quartz and mica.

(c) *Middle Fan.* Core no. SM 43/26 shows high calcium carbonate (15–25%) at depths of 45–60 cm (Figure 4) and decreases gradually moving from bottom towards the top.

Core no. SM 43/22 shows sharp fall in calcium carbonate concentration at around 100 cm depth (Figure 4), which is marked by the presence of high siliceous sand fraction, composed mainly of quartz and mica and devoid of any fauna.

Core no. SM 43/17 shows a tendency of increase in the calcium carbonate concentration to 15–20% at depths of 80–160 cm (Figure 4). Within the depth range ~ 104–112.5 cm, there is an abrupt increase to ~ 60% which is also characterized by the presence of greyish-white-coloured calcareous sand containing ooids and shallow-water biogenic material. This high calcium carbonate zone was observed within the silty clay texture.

Core no. SM 43/15 at 80 cm core depth and below does not show any rise in $CaCO_3$ content (Figure 4). It is characterized by terrigenous clay deposit. At a higher level (27–49.5 cm), there is an abrupt rise in $CaCO_3$ concentration to ~ 75% which is characterized by the presence of greyish-white-coloured calcareous sand containing ooids and shallow-water biogenic material.

(d) *Lower Fan.* Among four cores (SM 43/76, 43/77, 43/87, 43/83), the first three cores show high calcium carbonate concentration at depths of 80–150 cm (Figure 5). In core SM 43/83 this depth is shallower (30–80 cm). In all these cores the calcium carbonate concentration shows a gradual increase at this level and the maximum concentration occurs near silty clay and clay boundary.

Core no. SM 43/94 shows no increase in $CaCO_3$ concentration at 80–150 cm level (Figure 6) and contains terrigenous clayey material. However, towards the bottom of the core at depths 233–253.6 cm there is an abrupt

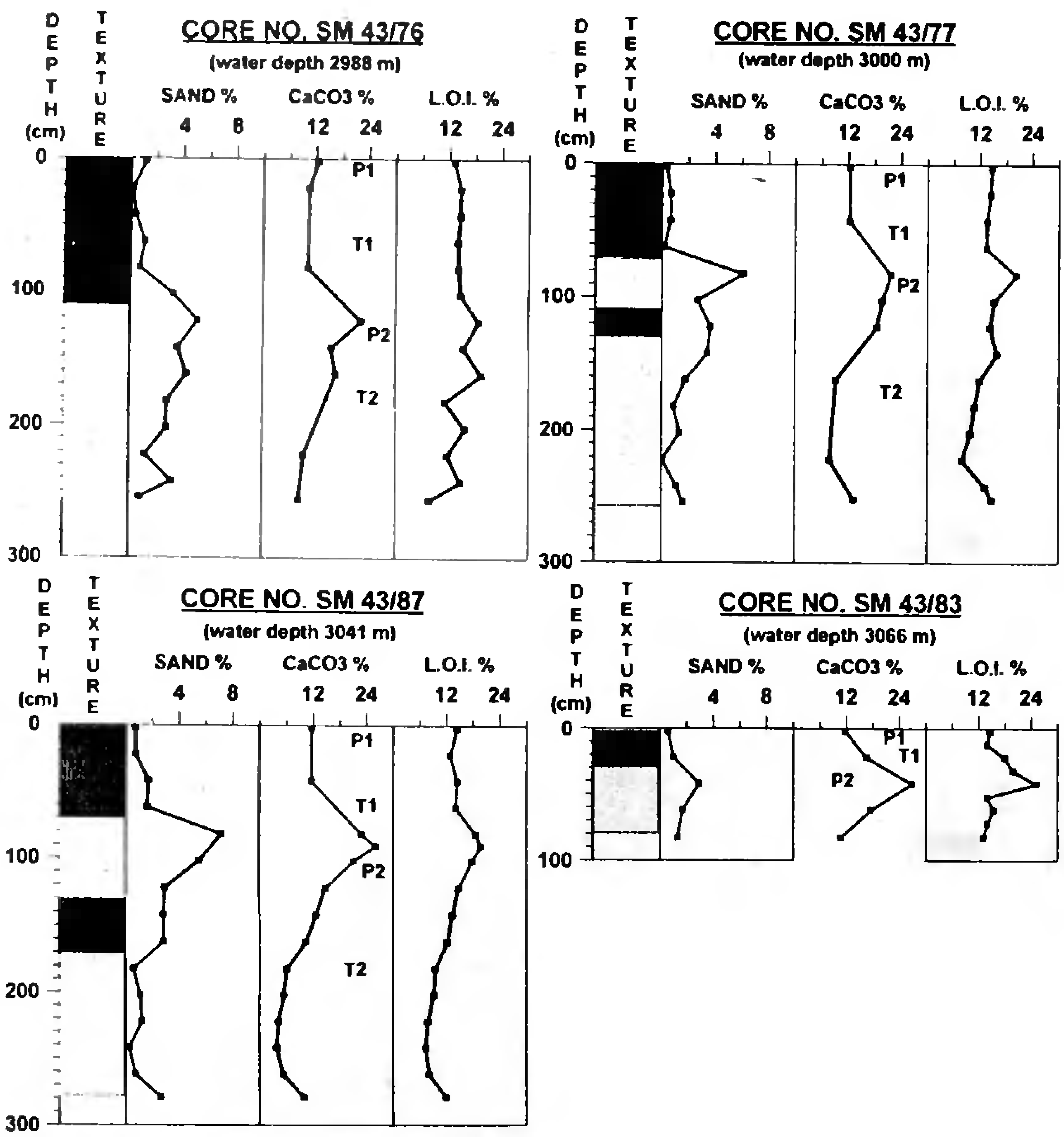


**Figure 5.** The temporal distribution of coarse fraction, calcium carbonate and loss on ignition in sediment cores from Lower Bengal Fan. The calcium carbonate shows a gradual increase in the middle segment of the core.

increase of $CaCO_3$ concentration which coincides with the emplacement of a greyish-white-coloured sand, predominantly consisting of calcareous bioclastic material and terrigenous quartz.

(e) *Continental rise.* Core nos. SM 43/96 and 43/42 show no increase in $CaCO_3$ concentration at the 80–150 cm depth level (Figure 6) and contain terrigenous clay. However, at ~200 cm depth there is a gradual rise in $CaCO_3$ concentration in both the cores. Additionally, core SM 43/42 shows a thin (4 cm thick) calcareous sand bed, predominantly consisting of bioclastic material, which resulted in an abrupt increase in $CaCO_3$ concentration at that level (172–176 cm).

(f) *Continental slope off Vishakhapatnam.* Core no. SM 43/100 does not show any increase up to 150 cm level. But below this level at around 160 cm it shows a gradual rise in calcium carbonate concentration like other cores located in the continental rise and the western margin of Lower Fan.

## $CaCO_3$ distribution in seabed surface sediments

Calcium carbonate content in core top sediments from all the 16 cores has been plotted in Figure 7 *a* for understanding the basic principle of the calcium carbonate distribution in the present day sediments. From north to south, towards deep sea, the calcium carbonate content shows an increasing trend from an average of 7.4% at SNGSC to 9.2% in the Upper Fan and 15.9% in the Middle Fan (Core nos. SM 43/22, 43/26). However, in the Lower Fan it reduces to 11.78%. Further NW, in both Middle Fan (SM 43/17, 43/15) and continental rise (SM 43/96, 43/42) it declines to 10%. This low calcium carbonate concentration also continues to the continental slope sediments off Vishakhapatnam (core no. SM 43/100) (Figure 7 *a*).

The surface distribution pattern brings out two major facts: (i) The N to S gradient of increase in calcium carbonate concentration shows the effect of terrigenous dilution by Ganga river system. Away from the river mouth (i.e. SNGSC) the concentration increases up to the Middle Fan; the decrease in Lower Fan can be

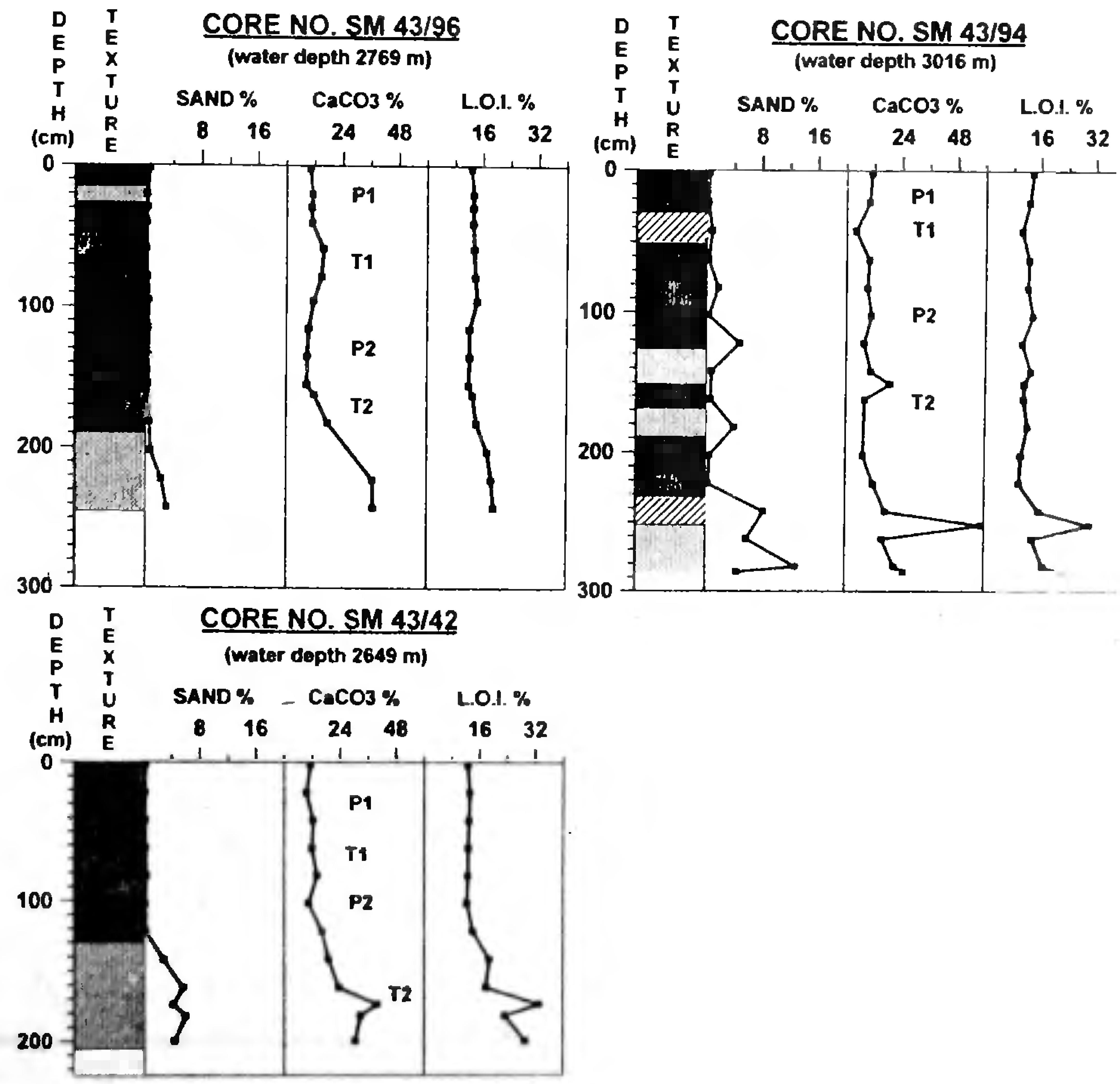


Figure 6. The temporal distribution of coarse fraction, calcium carbonate and loss on ignition in sediment cores from Lower Bengal Fan (SM 43/94) and continental rise west of Bengal Fan (SM 43/96 and SM 43/42). The calcium carbonate shows no variation in concentration in the middle segment of the cores.

explained by the influence of Godavari discharge. (ii) Off Godavari mouth also the same phenomenon was observed, i.e. calcium carbonate concentration increases in W to E direction away from the river mouth. Currently, the Godavari discharge is influencing not only the Lower Fan, as already mentioned, but also a part of the Middle Fan (Core nos. SM 43/15 and 43/17). The clay mineral distribution pattern in the sea bed surface sediments also supports this conclusion[9]. Godavari sediments show higher concentration of smectite, indicating influence of the Deccan Trap provenance while Ganga river system carries more of illite and chlorite suite from the Himalayan provenance.

Thus it appears that terrigenous dilution is the main factor controlling calcium carbonate distribution in the present day sea bed sediments. Dissolution is not important as the biogenic materials contain well-preserved tests and do not show any effect of dissolution. Secondly, productivity should normally be higher near the coast due to the availability of nutrient-rich water resulting from upwelling. The majority of the studied core samples represent the Bengal Fan sediments, one of the largest submarine fans in the world. In view of the fact that the Bay of Bengal receives enormous terrigenous supply (about $2.2 \times 10^{15}$ gm/a) by the major rivers[7], it seems to be the largest controller of calcium carbonate concentration. This explains the increasing trend in calcium carbonate concentration towards the deep sea. This is in agreement with the published data from the slope region to the equatorial Indian ocean, which demonstrate a sea-ward increase in calcium carbonate concentration due to dilution effect[10]. The particle flux study[11] also demonstrates a similar trend. The studies from the eastern continental shelf of India, also demonstrate a sea-ward increase in calcium carbonate concentration due to the dilution effect[12–15]. In addition, the northern slope sediments (i.e. SNGSC), which receive the highest terrigenous input by Ganga–Brahmaputra river system have comparatively low calcium carbonate concentration than the Vishakhapatnam slope sediments (Figure 7 *a*).

## Temporal distribution of calcium carbonate

The temporal distribution of calcium carbonate demonstrates two patterns – abrupt or gradual variation in calcium carbonate concentration. The abrupt variation, observed in few cores (Figures 4 and 6), at three stratigraphic levels (around 50, 100 and 250 cm core depth), corresponds with greyish-white-coloured calcareous or siliceous sand and suggest a sudden influx probably due to turbidity current/gravity flow. Middle Fan cores (SM 43/17 and SM 43/15) predominantly comprise of calcareous ooids and biogenic material (hence calcareous ooid turbidite) and were transported from the continental shelf off Vishakhapatnam during the lowered sea level[16]. The presence of ooid turbidite at different levels (104–112.5 cm and 27–49.5 cm core depth) suggests two periods of turbidity current activity. The first activity probably took place during the Last Glacial Maximum in Late Pleistocene and the second activity prior to the stabilization of sea level in the Early Holocene[16]. Rao *et al.*[17] also reported ooids and benthic

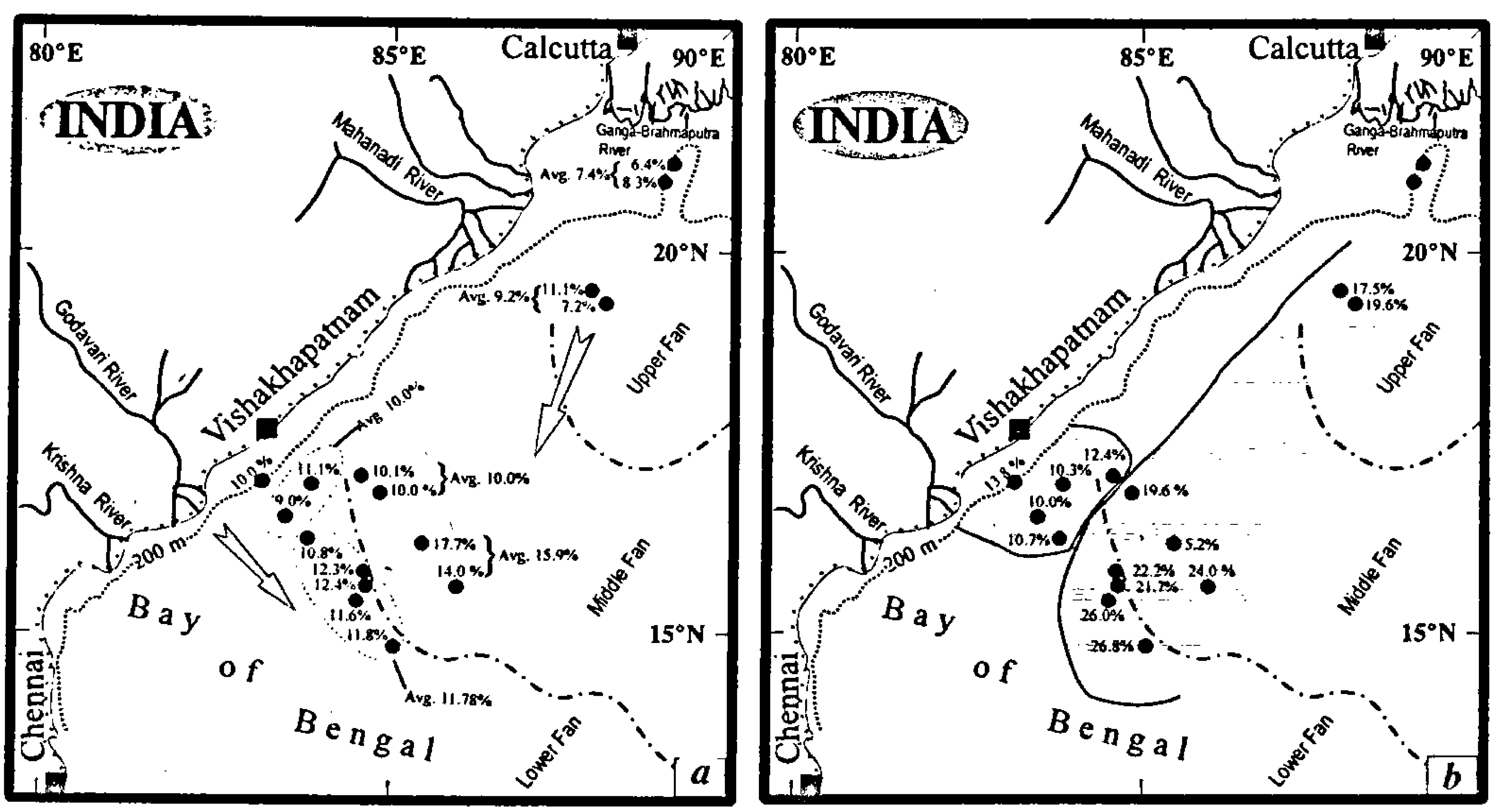


**Figure 7.** Spatial distribution of calcium carbonate: *a*, in Holocene (core top sediments) and *b*, during the Last Glacial Maximum (~ 18 ka). The calcium carbonate concentration increases towards deep-sea, both off Ganga and Godavari river mouth and is indicative of terrigenous dilution effect. Note that there is no variation in calcium carbonate concentration during Holocene and LGM off Godavari river mouth (marked by dotted area), however, in other cores there is a sharp increase (marked by hatched lines). However, the low value observed in one core (SM 43/22) within the high calcium carbonate zone of LGM time is due to siliceous turbidite.

foraminifera from the continental rise sediments off Vishakhapatnam coast. Sharp peaks of calcium carbonate (40% to 60%) in core nos. SM 43/42 and SM 43/94 (Figure 6), from the continental rise and western margin of Lower Fan, are due to the influx of biogenic material (calcareous biogenic turbidite). They are also derived from the Vishakhapatnam shelf probably during the regressive sea level in Late Pleistocene[1,18]. Whereas, sharp decrease in calcium carbonate concentration, observed in few cores (SM 43/22; SM 43/67), is due to emplacement of siliceous sand or silt sized material[1,18] (predominantly quartz and mica) from the shelf regime under gravity flow activity (siliceous turbidites). This indicates that the abrupt variation in calcium carbonate is due to sudden influx of material from the shelf regime under turbidity current/gravity flow activity during different periods.

As already mentioned under core analytical data, a number of cores show higher calcium carbonate concentration, having gradual increase, in the middle segments at depths of 80–150 cm. Figures 3–5 show the high calcium carbonate zones of the middle segment: from base upwards, the calcium carbonate concentration gradually increases, reaches a peak and then it reduces again to the background level (i.e. ~ 10%). The spatial distribution of $CaCO_3$ (Figure 7 *b*) shows that there is an increase in the calcium carbonate concentration from 20% in the Upper Fan (core no. SM 13/67) to ~27% in the Lower Fan (core no. SM 43/83) which may be ascribed to less terrigenous dilution in the down fan direction. However, the increased concentration to a value more than double the background level, i.e. from 10% to 27% is quite interesting. The coarse fraction (63 μm), containing well-preserved pelagic foraminifera shells, also shows an increase in concentration, which clearly suggests that calcium carbonate is derived from skeletal components of *in situ* nature and, therefore, is biogenic. The enrichment of biogenic calcium carbonate indicates either a higher productivity or a depleted terrigenous supply or both during this period.

This high calcium carbonate zone probably marks the Last Glacial Maximum (LGM). Prell *et al.*[19], on the basis of oxygen isotope stratigraphy, reported the LGM level (18000 B.P.) at 80 cm core depth in Bengal Fan sediments. According to Cullen[20], the LGM level varied between 60 and 100 cm in the cores of central part of Bay of Bengal (along 90°E long. and 12° to 18°N lat.). The sedimentation rate reported by various authors[11,19,21] indicates 2–4 cm/ky for the Bay of Bengal sediments. Since the middle segment of the cores in the area of study coincides with the LGM depth range as reported by these authors, the higher calcium carbonate concentrations at depths 80–150 cm can be correlated with the LGM event. As already mentioned, core no. SM 43/17 shows abrupt rise in calcium carbonate concentration to 60% within the high calcium carbonate zone of ~ 20%. This abrupt rise is due to ooid turbidite which has been correlated with LGM ooid developed in the eastern continental shelf[16].

If one assumes that forams are taken as the best index of overall productivity, it is quite reasonable to say that productivity was high during the glacial period. However, the relatively high calcium carbonate in the Lower Fan compared to Upper Fan indicates a depleted terrigenous supply by the major rivers. Moreover, the organic matter and quartz which is terrigenous in nature shows low percentage during this period[1]. The palynological data[22] (SM 43/87) also suggest a depleted terrigenous supply during this period. This further confirms that the higher concentration of biogenic calcium carbonate during glacial period is related to productivity as well as less terrigenous supply. Northeastern Arabian Sea core also shows a higher concentration of calcium carbonate during glacial period, probably due to less dilution by terrigenous influx derived from the Indus river[23]. However, the Pacific Ocean experienced calcium carbonate maxima during glacial period related to higher productivity[24–26].

The terrigenous dilution in the Bay of Bengal sediments seems to be the largest controller of calcium carbonate and may reflect the terrigenous supply of the Himalayan and Peninsular rivers during the glacial and interglacial periods. Extensive palaeo-oceanographic studies suggest that the LGM was marked by a weak Indian SW monsoon and a strong NE monsoon[20,27,28]. The SW monsoon contribute around 80 per cent of total sediment discharge by Ganga–Brahmaputra rivers[20]. The less precipitation in the continent and high salinity in the Bay of Bengal suggest that the discharge from Ganga–Brahmaputra rivers was very low during this period[20,27]. This explains the highest concentration of calcium carbonate during glacial period. However, the tectonic factor cannot be ignored. This was a time when deposits of thick sandy sediments had been taking place in alluvial flats in the subsiding Indo-Gangetic foredeep. This would have reduced siliceous clastic supply in the fan area.

It is interesting to note that during this period the cores toward the eastern continental margin of India (core SM 43/94 and SM 43/96) (Figures 6 and 7 *b*) show no increase in calcium carbonate concentration, even though the rest of the area shows a major increase. This indicates that the terrigenous supply in this part of Bay of Bengal was not affected during the glacial period. These cores are more or less nearer to the Godavari river mouth in the Vishakhapatnam coast. The smectite-rich clay minerals associated with these sediments suggest that they were derived from Deccan trap by Godavari river[1]. This is explained by high terrigenous supply from the Godavari river, possibly influenced by a strong NE monsoon[28] during the Last Glacial Maximum. The NE monsoon picks up moisture from the Bay of

Bengal and precipitates over the eastern part of the peninsular India, occasionally giving rise to floods. This indicates that the Godavari river discharge was probably high during the last glacial period and diluted the calcium carbonate content in the continental rise sediments off Godavari river mouth.

In the lower segment of the cores below an average depth of ~250 cm, three cores (SM 43/96, 43/42, 43/94) off Vishakhapatnam coast show high calcium carbonate concentration, the highest values being 35%. The base of the calcium carbonate high is not visible because of insufficient length of the gravity cores but towards top, in the visible part, the calcium carbonate concentration shows a gradual decrease to the background value of ~ 10%. Thus it is comparable to the middle segment (80–150 cm) calcium carbonate increase. Two of the longer cores of Bengal Fan (SM 43/77, SM 43/87, Figure 5) also show increasing trend of calcium carbonate concentration towards the bottom of the cores (below ~ 250 cm depth). The increase in calcium carbonate concentration in both eastern offshore cores and the Bengal Fan shows that during this period, siliceous clastic input was low from the Godavari river. It is interesting to note that the magnetic susceptibility dispersal pattern[29] on the same cores clearly showed the predominance of Godavari source over Ganga–Brahmaputra river system source that has probably occurred during the LGM in this area.

The upper part (above 50 cm) of all the cores in the Fan and off east coast does not show any increase in the calcium carbonate concentration above the background value (~ 10%). Low concentration of calcium carbonate in the upper part of the cores suggests high influx of terrigenous fine clastic material, predominantly clay, after the sea level rise in post-glacial period.

In a recent publication[30] on cores from the central part of Bengal Fan it has been suggested that Holocene period is enriched in calcium carbonate sedimentation, which is contrary to our observation. In our study of 16 cores from different geomorphic environments of Bay of Bengal starting from the continental slope to abyssal depth, the Holocene sediments do not show any enrichment in calcium carbonate. It may be noted that the high calcium carbonate zone during LGM shows a rise from ~ 110 cm in core no. SM 43/87 to ~ 40 cm in core no. SM 43/83 (Figures 1 and 5), i.e. the LGM horizon is shallowing in SE direction. The samples of Pavana Putra *et al.*[30] lie still further SE, hence the LGM level is expected to be still shallower; the high calcium carbonate in the central part of Bengal Fan is, in our opinion, not Holocene but late Pleistocene in age.


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