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Clay as indicator of sediment plume movement in deep-sea environment

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Future polymetallic nodules mining in the Central Indian Basin (CIB) will disturb not only the deep-sea sediments but also the benthic environment. Generation of voluminous sediment plume due to mining activity is unavoidable, even if the miner would screen the nodules just above the sea floor. The released sediments on the sea floor would migrate in the direction of the bottom water currents and affect the benthic community. It would be more hazardous when the sediment are discharged at the sea surface, as they would affect the entire water column, including light transmission, photosynthesis and productivity. The sediment plume generated by any mining system would cause long-term effects in the deep-sea environment. In order to predict the potential impact on benthic environment, it is necessary to estimate the quantity of plume to be generated, direction in which the plume would move, and how much distance the plume would travel. For this, the surface sediments in the CIB (5230 m depth) were artificially disturbed and resuspended 5 m above the seabed in 1997 during the Indian Deep-Sea Experiment. Initial studies have shown that the clay content during monitoring-1 phase significantly increased compared to post-disturbance, by 15 and 24% in the disturbed zone (DZ); 3 and 20% at the ends of the DZ; 9 and 18% north of the DZ, and 10 and 17% south of the DZ. Here, it is shown that the clay particles can be successfully used as an indicator of the plume direction as well as to estimate the distance travelled by the plume.

DISTURBANCE on the sea floor can change the physical characteristics of the deep-sea sediments. For example, artificial disturbance due to deep-sea mining of polymetallic nodules would induce resuspension and transportation of

sediments from one place to another. Such changes would also affect the benthic biota^{1,2} as the sediment plume is likely to migrate in the direction of bottom water currents³. In fact, it would affect the entire water column in many ways, including light transmission, photosynthesis and productivity⁴⁻⁶, if the sediments after separating from the nodules were discharged at the surface. According to one estimate, the nodule mining in the Central Indian Basin (CIB) would mobilize 57,602 tonnes of sea floor sediment per day or 14.4×10^6 tonnes annually. In other words, 3369.6 (wet) tonnes of nodules recovered per day would resuspend about 57,602 tonnes of sediment per day (Valsangkar, in preparation). It is expected that the sediment plume created due to disturbance on the sea floor by any nodule mining system will have long-term effects in the deep-sea environment. Therefore, the deep-sea sedimentological studies have an important role in deep-sea nodule mining activity.

Earlier studies on impact assessment of nodule mining were limited to the Pacific Ocean, whose results and findings can be summarized as follows. A German environmental group conducted Disturbance and Re-colonization (DISCOL) experiment in 1988-98 in the Peru Basin, Pacific Ocean, which was followed by post-disturbance studies after a gap of 6 months, and monitoring studies after 3 and 7 years. The results showed re-colonization of specific benthic organisms with decreased faunal density than the original undisturbed one⁷. The benthic impact experiment during 1991-94 by the National Oceanographic and Atmospheric Administration (NOAA), USA in the Clarion Clipperton Fracture Zone (CCFZ), Pacific Ocean, observed decrease in abundance of meiobenthos and increase in macrobenthos immediately after the disturbance⁸. Japan's deep-sea impact experiment (JET, 1994-97) showed similar results and it was interpreted that certain groups are more susceptible in adopting to the changed conditions due to disturbance on the sea floor, than the others². Similarly, a benthic impact experiment (IOM-BIE) by the InterOcean Metal (IOM) Joint Organization in CCFZ, Pacific Ocean (1995), showed alteration in meiobenthos assemblages and indicated variable effects on the composition of faunal density⁹.

In the Indian Ocean, Environmental Impact Assessment studies were initiated in 1996 in the CIB. This was a multi-disciplinary approach and apart from other aspects, the studies were also aimed to find out the (a) distribution of sediment sizes in the selected test and reference areas, (b) major composition of sediment plume generated due to artificial disturbance on the sea floor, and (c) distance and direction in which the plume movement took place.

For this purpose, an artificial disturbance was created on experimental basis (Indian Deep Sea Experiment, INDEX) in 1997 at 5300 m water depth in the selected 3000×200 m narrow strip in the CIB¹⁰. The disturbance forced resuspension of ~ 6000 m³ wet sediments (~ 580 tonnes of dry sediment) in the waters at 5 m above the sea floor. Prior to the

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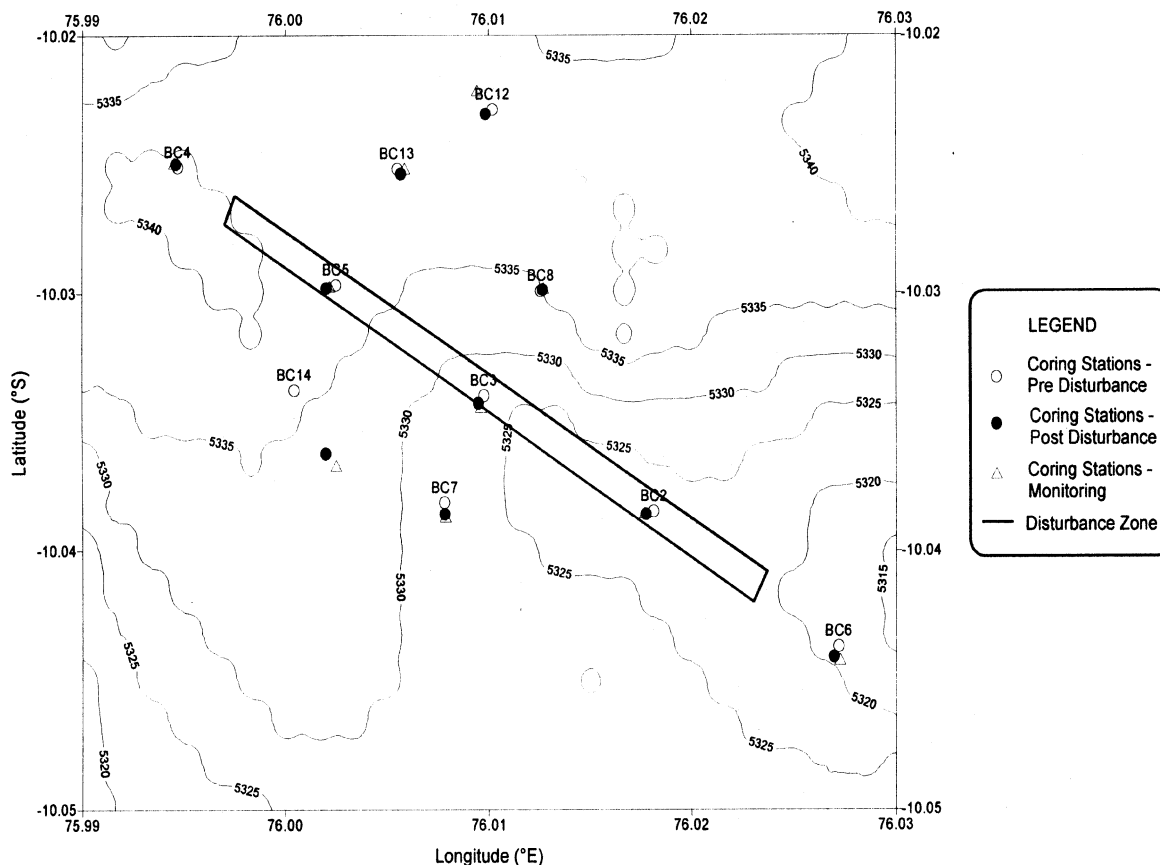


Figure 1. Sampling locations in and around the disturbed zone.

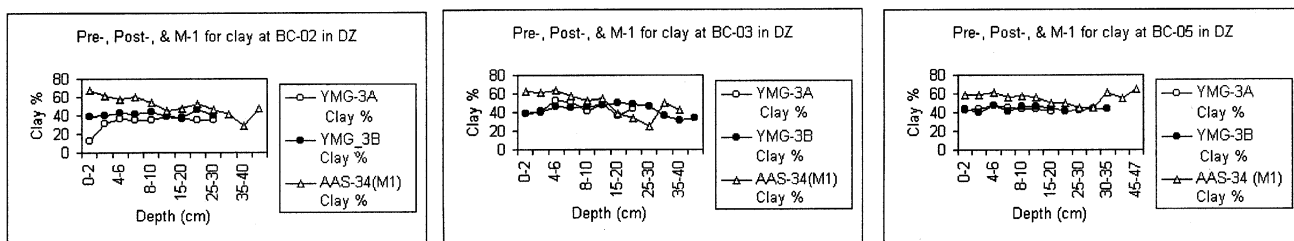


Figure 2. Comparison of clay % from pre- (open circle) and post- (closed circle) disturbance and monitoring-1 (triangle) phases at locations in DZ.

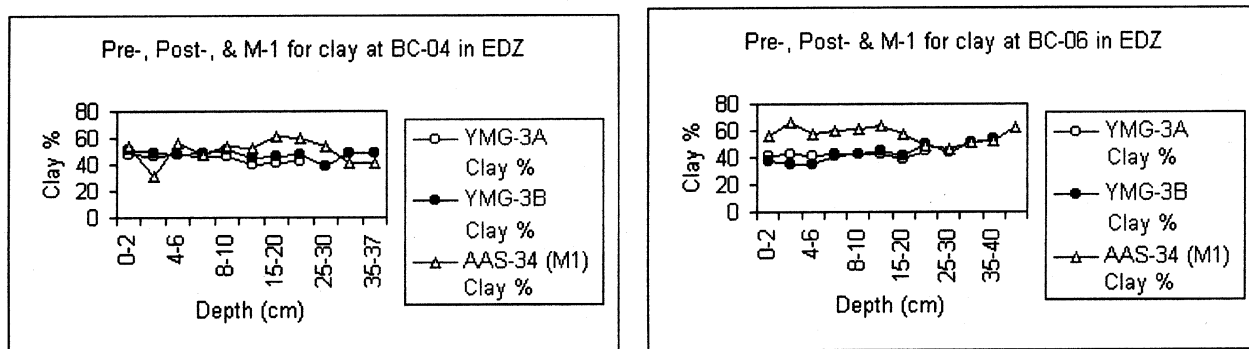


Figure 3. Comparison of clay % from pre- and post-disturbance and monitoring-1 phases at locations in EDZ. Symbols as in Figure 2.

benthic disturbance base-line studies were carried out in 1996¹¹ (EIA Project Report to DOD, New Delhi, NIO, Goa 1997, unpublished) and pre- and post-disturbance comparative studies were carried out in 1997 (Project Report, NIO, Goa, 1999, unpublished). Later, first monitoring (M-1) studies were carried out in 2001, nearly 44 months after the disturbance (Project Report, NIO, Goa, 2002, unpublished). Results obtained during three phases of studies helped not only to understand the process of restoration of benthic conditions in and around the disturbed area, but also in deducing the major composition of plume, and finding the directions of plume movement¹².

As mentioned above, the sediments from a small narrow strip (3000 × 200 m) were disturbed and scooped using an artificial disturber that fluidized and resuspended sediments 5 m above the seabed. Sediments were sampled using box core during pre- and post-disturbance¹² and monitoring-1 phases (Project Report, NIO, Goa, 2002, unpublished) (YMG-3A, YMG-3B and AAS-34 respectively; Figure 1). Out of 10 box cores studied, 3 cores (BC-02, -03 and -05) were in the disturbed zone (DZ), 2 (BC-04 and -06) at both ends of DZ (EDZ), 3 (BC-08, -12 and -13) north of the DZ (NDZ), and 2 (BC-07 and -14) south of the DZ (SDZ). Additionally, there were 2 cores (A1/A and A1/B) 12 and 17 km at DZ and 3 cores (T1/A, T1/B and T1/C) 70–90 km away, west of the DZ. The cores were sub-sampled at 2 cm interval down to 10 cm depth, and then at 5 cm interval for the remaining length of the core. Barnstead RO pure water was used for desalination of the sub-samples followed

by oven-drying at 60°C. The sand contents were determined after wet-sieving on 62 µm sieve, whereas silt (63 to 2 µm) and clay (<2 µm) were determined by the standard pipette analysis¹³.

Comparison of clay content between pre- and post-disturbance and M-1 samples shows similar downcore trends and noticeable increase in clay content during post-disturbance and M-1 in all the samples from DZ, EDZ, NDZ and SDZ (Figures 2–5). Particularly during M-1, it is observed that with reference to post-disturbance, the clay content in the surface sediments increased by 15 and 24% in DZ; 3 and 20% in EDZ; 9 and 18% in NDZ, and 10 and 17% in SDZ. Also, most of the sub-samples changed from clayey silt to silty clay during M-1 phase. These changes were noticeable up to 30 cm depth in the DZ, 20 cm in EDZ, 35 cm in NDZ and 40 cm in SDZ.

Similarly, samples from two reference locations (~12 and 17 km in NDZ) also showed an increase in clay content during M-1 by 15% at A1/A and 17% at A1/B (Figure 6). Enrichment of clay contents in the reference locations closer to the DZ seems to be affected due to high influx generated by the sediment plume.

Average particle flux showed nearly fourfold increase during the disturbance experiment at INDEX site, that was reduced to twofold during post-disturbance measurements due to settlement of particles¹⁴. The increase and decrease in the sediment flux therefore suggest that the resuspended sediment particles remain in suspension for longer periods in the near-bottom water column, which allows sufficient

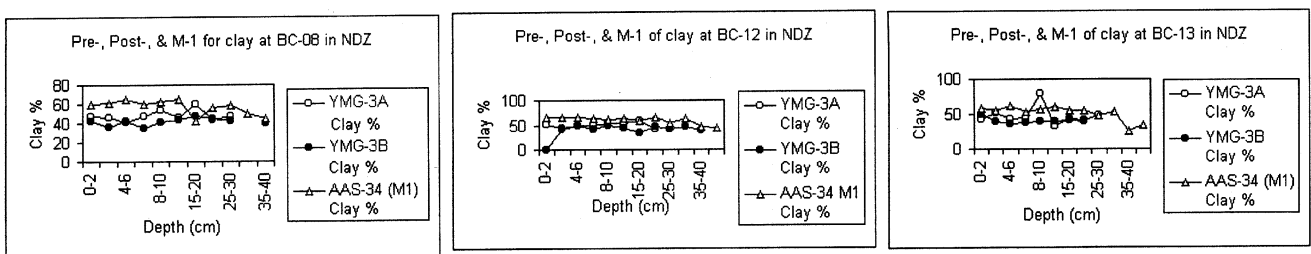


Figure 4. Comparison of clay % from pre- and post-disturbance and monitoring-1 phases at locations in NDZ. Symbols as in Figure 2.

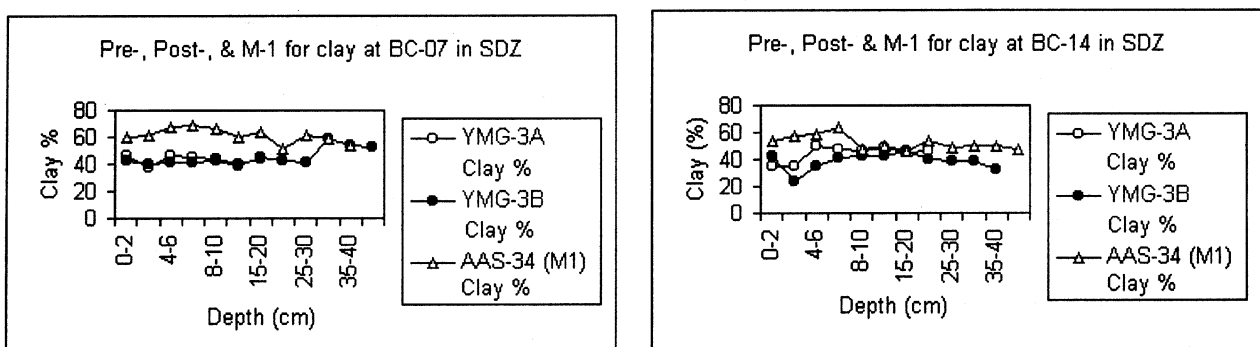


Figure 5. Comparison of clay % from pre- and post-disturbance and monitoring-1 phases at locations in SDZ. Symbols as in Figure 2.

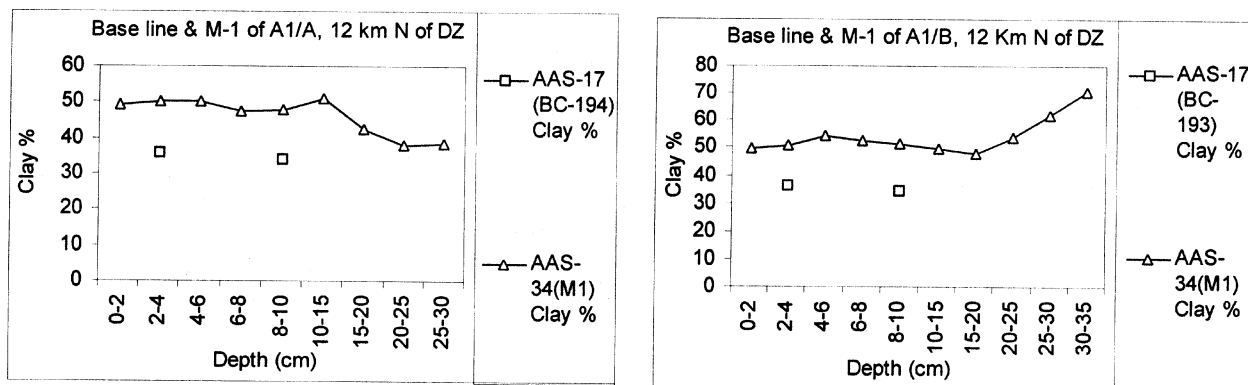


Figure 6. Comparison of clay % from base line (square) and monitoring-1 (triangle) phases at reference locations in NDZ.

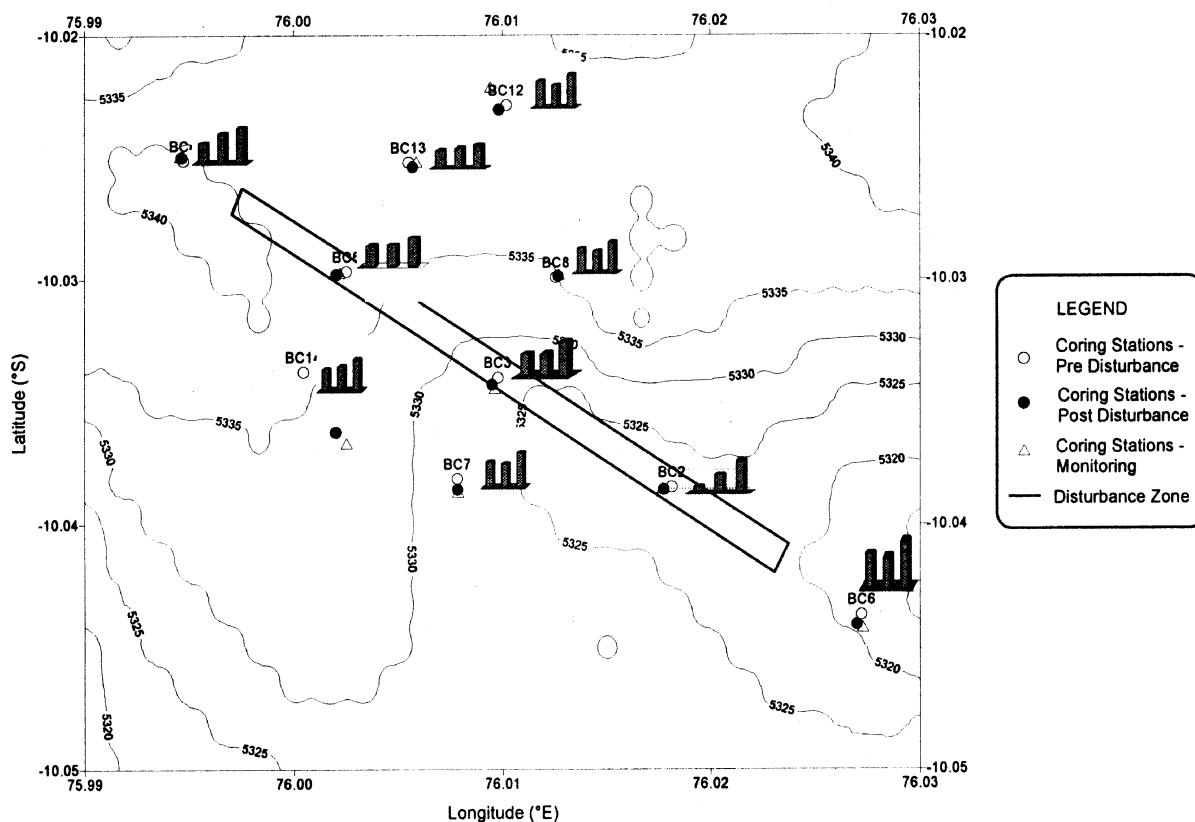


Figure 7. Overall distribution of clay % in DZ during pre- and post-disturbance and monitoring-1 phases.

time period for the gradual settlement of fine particles. Previous studies have shown that compared to sand, clay particles remain in suspension for a long to very long time promoting resedimentation within and around the DZ, during which they can also be displaced to other locations along with the plume depending upon the strength and direction of the bottom water currents¹².

Increase in clay content observed at all the locations during M-1 phase is attributed to the delayed settling of fine clay-sized particles, which remained in suspension and moved along with the plume after the sediments were resuspended and discharged during INDEX in 1997. It

further implies that the clay particles of the resuspended sediments remain in suspension within the plume for a longer time, and can move away from the disturbed site to other locations due to currents. Settling of suspended clays in due course of time therefore leads to increase in the clay content at the new location. Another possibility for the increase in clay content is because of disaggregation and powderization of coarser particles¹⁵.

Applying the above for the INDEX, it can be said that the plume must have moved in all directions in and around the DZ (Figure 7). Current measurements in the DZ have shown that the bottom water currents within a cycle

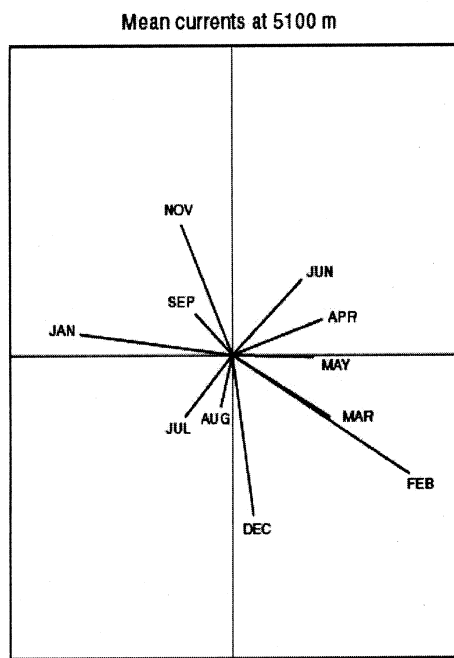


Figure 8. Mean current directions in the DZ³.

changed directions frequently (Figure 8)³ and could be responsible for dispersal and increase of clay content in all directions away from the disturbed site. Thus, during the post-disturbance studies, the increase in clay content noticed in the samples from SW locations of the DZ was in accordance with the measured current direction for the respective month but the observed increase during M-1 studies in all directions of the DZ is due to the delayed settlement of very fine particles (clays) over a period of at least one cycle (about 1 year) of currents, during which the mean currents moved in all directions.

Accordingly, the distance travelled by the plume from the centre of the DZ can also be approximated from the pronounced increase in clay contents at two reference locations (A1/A and A1/B about 12 and 17 km NW of DZ), whereas no change in clay contents at three locations (72 to 92 km in WDZ) clearly indicates that the plume did not migrate to 70 km in WDZ. This suggests that the INDEX plume might have migrated in all directions up to a radius of about 17 km from the DZ. Model studies have shown that the concentration of sediment particles would decrease to ambient at about 15 km from the source, for a continuous discharge for 6 days¹⁶.

Pre- and post-disturbance studies followed by monitoring phases for benthic disturbance by the INDEX in the CIB thus illustrated that the clay particles of the sediment plume can be successfully used as indicators to trace the direction and distance of plume movement in and around the disturbance area.

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