

Geotechnical properties of deep-sea sediments from Central Indian Ocean Basin

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Physical and geotechnical properties of 2 sediment cores from the nodule rich area of the Central Indian Ocean Basin are studied to know the sediment characteristics. Average water content of sediment from 2 deep-sea cores is 289% with 151% as liquid limit and 103% as plastic limit. Average values of wet density, porosity and specific gravity are $1.21 \times 10^6 \text{ g.m}^{-3}$, 87%, and 2.35 respectively. Organic carbon content is < 1% for both the cores. Sand, silt and clay contents are 16, 32 and 52% respectively. Sediments are siliceous ooze, medium to high plastic and fine grained in nature. The properties are quite comparable to those reported for Pacific Ocean sediments.

Much attention is being given for the development of mining technology required for nodule extraction. Since most of the nodule harvesters will have interaction with the seabed, their designing requires amongst other things, geotechnical properties of the sediments and nodules. The large capital investment, high risk and ecological disturbances associated with nodule mining require increased knowledge of the engineering properties of the deep-sea sediments. Geotechnical properties for the Pacific nodule rich area are reported earlier¹⁻⁶. So far the Central Indian Ocean Basin (CIOB) has been extensively explored for the abundance and chemical grade of nodules and general bathymetry⁷⁻⁹ in the nodule rich area. This paper presents physical and geotechnical properties carried out on 2 spade cores raised from the CIOB.

A spade corer (45 × 30 × 20 cm) was used for collecting sediment samples. The position of first core (NR2/55) was 10°S and 77°E and that of second (NR2/56) was 11°S and 78°E. The water depths were 5350 and 5500 m respectively. The cores (32 cm each) were subsampled onboard at an interval of 4 cm and the samples were kept in a deep freeze till various tests were conducted. Water content and specific gravity were determined by weight/volume method. Liquid and plastic limits were measured according to Richards¹⁰. Wet bulk density and porosity were estimated from the standard formula. The grain size analysis was carried out by pipette method. X-ray diffraction analysis was carried out on Phillips diffractometer with Cuk α radiations on air dried clay fractions only. The identification of clay minerals was done¹¹. Organic carbon content was determined by

wet oxidation method¹². The salt correction was not applied to any of the properties described here.

The general observation from both the cores (Fig. 1) is that the water content, liquid and plastic limits, bulk density, specific gravity and porosity did not show much deviation throughout the depth of 32 cm. The hand operated vane shear apparatus was tried on both the cores to measure undrained shear strength but did not show any reading. This is probably due to high water content (av 289%).

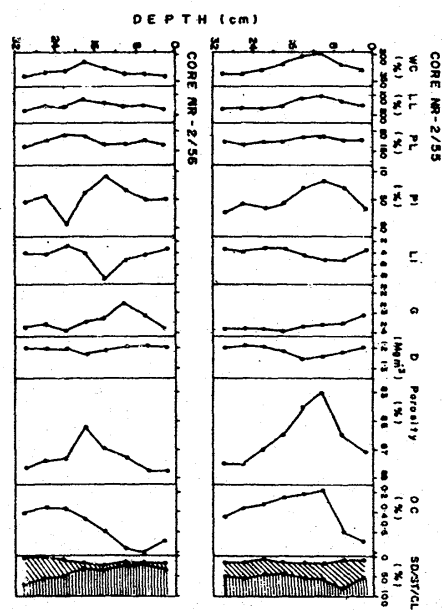


Fig. 1—Downcore variation of geotechnical properties for the two cores (WC = water content, LL = liquid limit, PL = plastic limit, PI = plasticity index, LI = liquidity index, G = specific gravity, D = wet density, OC = organic carbon, SD/ST/CL = sand/silt/clay)

Both the cores were mostly of siliceous ooze¹³ and showed bioturbation. The water content (WC) normally decreases¹⁰ with depth. But both the cores showed higher water content at the top and bottom than in the middle parts (Fig. 1). This may be due to higher percentages of clay and silt as well as due to higher porosity at the top and bottom than in the middle parts. The water content reported from the Pacific nodule rich area⁴ is in the range of 171 to 383% and sometimes >400%. The high water content is considered to be due to high contents of siliceous microfossils². Radiolarian microfossils were abundant (>60%, Gupta SM, personal communication). The liquid limit (LL) and plastic limit (PL) show water contents at which sediment consistency changes from these respective states¹⁴. Liquid and plastic limits did show similar trend like water content. In comparison to the NE central Pacific sediments¹, the values of liquid limit, water content and plasticity index of the CIOB sediments were lower. High value of liquid limit shows that the sediments are highly compressive⁵. These limits are mainly controlled by porosity and bulk density. The average plasticity index (PI) was 48%. The average liquidity index (LI) of 4.2 implies that the water contents are substantially greater than the liquid limits at all depths. Liquid limit and plasticity index for 2 cores when plotted on Casagrande plasticity chart (Fig. 2), showed fall of average values in the region of organic clays of medium-high plasticity.

Porosity (Fig. 1) was estimated from water content and specific gravity. The average porosity was 87% and did not show any change except in the middle part where it was up to 83%. Porosity controls the water content directly, hence shows positive correlation with water content. The microscopic examination of siliceous sediments from north Pacific Ocean revealed not only high porosity (av 89%) and water content (av 389%) but also porous and hollow grains¹⁵.

Wet bulk density (D) was calculated from specific gravity and water content assuming full saturation. It did not change much throughout the depth of both cores (Fig. 1). This is probably due to similar sediment type. The density generally is negatively correlated with water content and porosity¹⁶, and with liquid and plastic limits (Fig. 3). The range of the bulk density was $1.19-1.25 \times 10^6 \text{ g.m}^{-3}$. These lower values indicate higher water content due to relatively lesser percentage of sand/silt sized material.

Specific gravity (G) indicates mineralogical contrast¹⁷. But as there is no change in the clay mineralogy, the specific gravity remained same over full length (Fig. 1). Moreover, the siliceous sediments

consist primarily of opaline silica (sp. gr. 2.1), the average values¹⁵ of specific gravity are about 2.45.

The grain size analysis (Fig. 1) of all the samples showed that the coarse fraction (>62 μm) material is less as compared to silt and clay. Only in case of first core the top part showed higher sand content than silt content. The average sand content was 16% whereas average clay and silt contents were 52 and 32% respectively. Clay content showed positive but not significant correlation with the liquid and plastic limits. This is due to the presence of expandable clay mineral, smectite.

X-ray diffraction studies on air dried clay samples showed smectite, illite, kaolinite and/or chlorite as clay minerals throughout the length of the cores. The source of these minerals is believed to be the continental flux into the basin from the North¹⁸. The quartz and feldspar were common in all the samples. Clay minerals did not show any variation with depth.

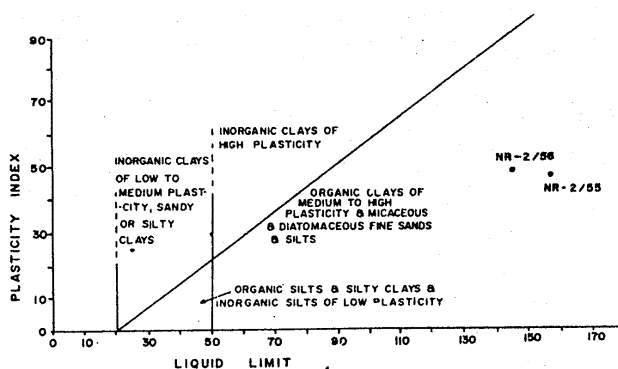


Fig. 2—Casagrande plasticity chart

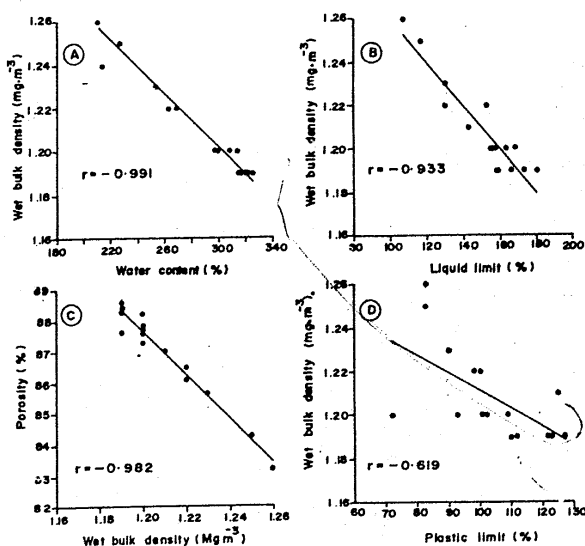


Fig. 3—Variation of wet bulk density with (A) water content (B) liquid limit (C) porosity (D) plastic limit

This may be due to similar sediment type and the environment of deposition.

The organic carbon (OC) plays an important role in water content and liquid and plasticity characters of the sediments¹⁹. To confirm this all samples were analysed for OC content (Fig. 1). But the samples did not show much shift from the average value. Generally in deep-sea sediments, OC content is very less as compare to coastal areas²⁰. OC content in deep sea clays and oozes varies from 1 to 2% whereas in coastal areas it may be as high²¹ as 10%. In the present study average OC content was 0.47% (0.19 to 0.8%). OC content is generally positively related to water content and porosity²², but present data did not show significant correlation of OC with any of the properties. This may be due to very low variation in OC content.

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References

- 1 Richards A F, Hirst T J & Parks J M, *Oceans '76*, (1976) 2B.
- 2 Richards A F & Parks J M, *Proc Off Tech Conf*, 1 (1977) 377.
- 3 Hirst T J & Richards A F, *Proc Off Tech Conf*, 1 (1975) 923.
- 4 Tsurusaki K & Handa K, in *Deep sea mineral resources investigation in the western part of Central Pacific Basin (GH78-1 cruise)*, *GSI cruise report 17*, edited by T Moritani & S Nakao, (Sumitomo, Tokyo) 1981, 103.
- 5 Tiscot J P & Gerard B, *Proc Off Tech Conf*, 4 (1981) 139.
- 6 Noorany I, in *Strength testing of marine sediments, laboratory and insitu measurements*, edited by R C Chaney & K R Dewars, (ASTM STP 883, Philadelphia) 1984, 251.
- 7 Valsangkar A B & Khadge N H, *Mar Min*, 8 (1989) 325.
- 8 Pattan J N & Kodagali V N, *Mahasagar-Bull Natn Inst Oceanogr*, 21 (1988) 7.
- 9 Jauhari P, *Mar Min*, 6 (1987) 419.
- 10 Richards A F, in *Deep-sea sediments, physical and mechanical properties*, edited by A L Inderbitzen, (Plenum Press, New York) 1974, 271.
- 11 Carroll D, *Clay minerals: A guide to their X-ray identification*, special paper 126, (Geological Society of America, Colorado) 1970, 1.
- 12 El Wakeel C K & Riley J P, *J Cons Perm Int Explor Mer*, 22 (1957) 180.
- 13 Rao V P C, *Mar Geol*, 74 (1987) 151.
- 14 ASTM, 1972 *Book of ASTM standards*, part II, (ASTM, Philadelphia), 1972, pp. 225.
- 15 Poulos H G, *Marine geotechnics*, (Unwin Hyman, London) 1988, pp. 86.
- 16 Keller G H, in *Deep-sea sediments, physical and mechanical properties*, edited by A L Inderbitzen, (Plenum Press, New York) 1974, 77.
- 17 Keller G H & Lambert D N, *Mar Geotech*, 4 (1980) 125.
- 18 Rao V P C & Nath B N, *Indian J Mar Sci*, 17 (1988) 202.
- 19 Chassefiere B & Monaco A, *Mar Geol*, 87 (1989) 167.
- 20 Bennett R H, Lehman L, Hulbert M H, Harvey G R, Bush S A, Forde E B, Crews P & Sawyer W B, *Mar Geotech*, 6 (1986) 61.
- 21 Gross M G, *Geol Soc Am Bull*, 83 (1972) 3163.
- 22 Booth J S & Dahl A G, *Mar Geotech*, 6 (1986) 281.