

Physical properties of a sediment core from the Central Indian Basin

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ABSTRACT

A box core of 7.5m was collected from the Central Indian Basin for the purpose of geotechnical studies and depthwise variation of physical properties and clay mineralogy. Water content, Atterberg limits, specific gravity are measured at regular interval and clay mineralogy of same samples is studied. In general, the core shows depthwise increase in shear strength, specific gravity and decrease in water content, and depicts lithological changes. At a depth of about 4.7 m a drastic change in the physical properties and clay mineralogy indicating sedimentary hiatus is observed which coincides with the Plio-Pleistocene boundary. The shear strength increases from 10 to 13 kPa at this depth, and inspite of higher clay size (<4 μ m) fraction and montmorillonite content, the water content and liquid limit reduce drastically showing same values. These indicate the highly compressed and consolidated nature of this layer which may be due to overburden pressure of thick water and sediment column. Wet density increases from 1.2 to 1.5 gm/cm³ and porosity decreases from 87 to 71% at this layer. The layer is about 30 cm thick and devoid of any radiolarian fossils which may be attributed to either sudden change in climate or volcanic activity which precluded preservation of radiolarian fossils. Illite-rich sediments in the core are attributed to Ganges turbidity currents from north whereas montmorillonite-rich layer is due to local volcanism in the Indian Ocean.

1 INTRODUCTION

Various sedimentary facies in the Indian Ocean and their mineralogical composition are studied by Goldberg & Griffin (1970), Kolla & Biscaye (1973), Kolla & Hayes (1974) for the clay mineralogy and grain size distribution. The vast occurrences of polymetallic nodule are reported from various basins in the Indian Ocean e.g. Central Indian Basin (CIB), Wharton Basin, Madagascar Basin, Crozet Basin (Frazer & Wilson 1980). But among these, the CIB contains abundant nodules of high metallic grade. The geotechnical studies of deep sea sediments of the Central Indian Basin (CIB) have become important (Khadge 1995) as this seafloor is covered by potentially mineable metal rich nodules (Valsangkar & Khadge 1989; and references therein) containing copper, nickel, cobalt, manganese and iron. To mine these nodules or to design suitable nodule collector, basic data required are physical and engineering properties of the sediments associated with the nodules. They could give some idea about sediment behaviour during the mining. In addition, these properties could be used for knowing the geological processes in the past, e.g. deposition, erosion, cementation. In the present paper physical properties along with clay mineralogy of a 5.2 m long core are described to know the impact of the depositional processes

during past. The drastic changes in the measured properties are attributed to the depositional change. This is the first attempt to correlate geotechnical and geological studies of the Indian Ocean sediments though they were recommended earlier (Kolla & Hayes 1974). The present work is part of the ongoing geotechnical program for the CIB sediments.

2 METHODS

A box core of 30x30 cm cross sectional area was collected at 9°S and 77°E (Fig.1) at a water depth 5400 m. The top (2.3 m) of the core was disturbed and hence could not be tested for properties. The lower 5.2m core was intact and showed no disturbance. Lithological description was made before subsampling at 40 cm interval. Shear strength was measured immediately by using hand operated vane shear tester. The water content, Atterberg limits, specific gravity were measured by weight/volume methods (ASTM 1978) and salt correction was applied following Noorany (1985). Wet bulk density, porosity are estimated from the formula (Bennett & Lambert 1971) assuming cent percent saturation of the sediments. Grain size analysis was carried out by pipette method (McManus 1988) and x-ray diffraction analysis was done on Phillips x-ray diffractometer with CuK α radiation on oriented samples. The glycol treated

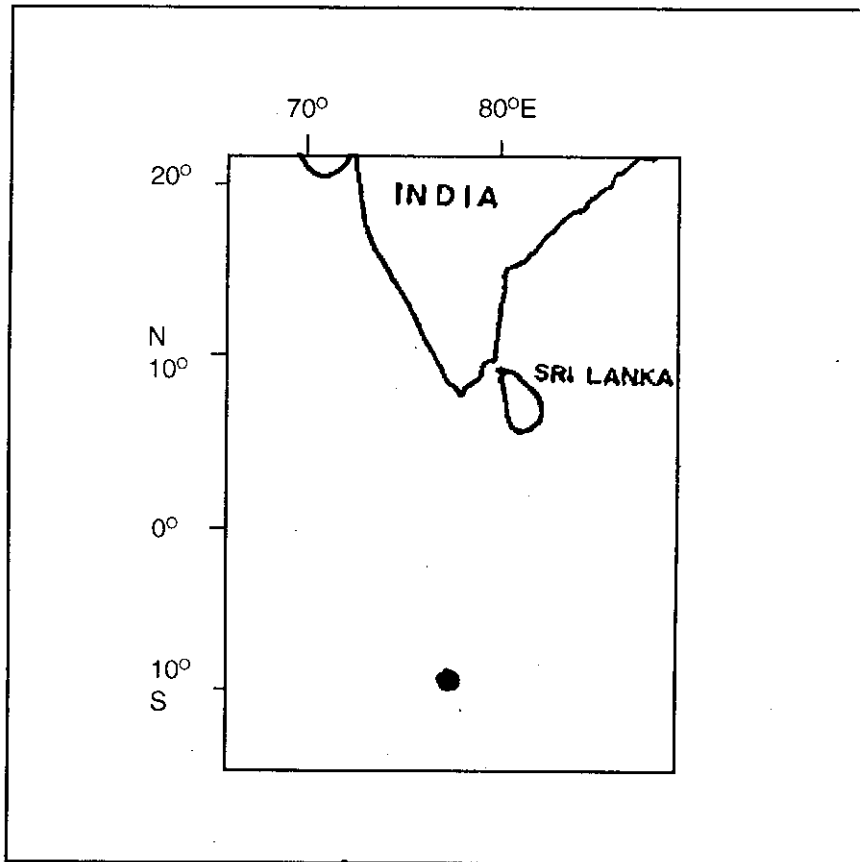


Figure 1. Map showing the core location in the Central Indian Basin

slides were used for semiquantitative analysis of the clay minerals (Biscaye 1965). Clay mineral identification was done using Caroll (1970).

3 RESULTS AND DISCUSSION

The core location falls in the area of siliceous ooze (Kolla & Hayes 1974; Nath et al. 1992) and well below the carbonate compensation depth (CCD). The sediments along the depth show gradual but less variation in the properties except at 4.3, 4.7 and 5.8 m depths. These layers are 30, 16 and 25 cm in thickness and very sticky in nature with no bioturbation but have thin ash layers and pumice pieces. Microscopic examination shows that entire core consists of abundant radiolarian tests except at these three depths (S.M.Gupta, Personal communication). Top of the core shows light to dark brown coloured clays with bioturbation and mottled appearance whereas the bottom 1.5 m is homogenous with immense bioturbation and light colour clays.

3.1 Grain size analysis and clay mineralogy

The grain size study of the sediments revealed clayey silt

composition of sediments with less than 10% of sand content. At the depth of 4.7 m silt content is high (57%) with 41% clay and 2% sand (Fig.2). The x-ray diffraction analysis of <2 μm fraction shows four common clay minerals viz. montmorillonite (M), illite (I), kaolinite (K) and chlorite (C); and quartz and feldspar as accessory minerals throughout the core length. However, their semiquantitative analysis showed variation in their percentage (Fig.2). Montmorillonite plays major role in water holding capacity of sediments as it is highly water absorbing. Only at a depth of 4.7 m its content has increased drastically. In spite of this the water content has not increased. This could be due to sedimentation during which the supply of this mineral from volcanic rocks was prominent (crystallinity of montmorillonite at these depths is highest and the peaks are also narrow and well developed). The general trend of this mineral content is first increase and then decrease below 4.7 m depth till bottom. The lowest values of water content, porosity and Atterberg limits show the case of high consolidation due to overburden pressure. However this has to be confirmed by consolidation tests of sediments.

The sedimentation rate in this region is 2-2.5 mm/ky (Banakar et al 1991) which means the age of the core bot-

tom is about 3.5 Ma. This is verified based on biostratigraphic age determination which gives an age of 3.5 Ma (S.M.Gupta, per.comm.). The age of sediments at 4.7m depth with depositional rate of 2.5 mm/ky would be 1.9 Ma which corresponds to the Plio-Pleistocene boundary. This is confirmed by radiolarian stratigraphy. There is a sedimentary hiatus at this depth which is revealed from disappearance of radiolarian fossils (S.M.Gupta, per.comm.). During rapid transport and deposition of finer particles by turbidity currents preservation of radiolarian fossils may have been precluded. The sharp contacts of these layers with underlying sediments of very different characteristics could also be attributed to the hiatus at Plio-Pleistocene transitional period. The pumice fragments present in these layers show the influence of volcanic material during deposition. This indicates the montmorillonite is of both — volcanic and terrestrial — origin. The presence of three sticky layers indicates cyclic process of deposition. Similar observation is reported by Kolla & Biscaye (1973) for cores in the vicinity. They attributed the dark grey, nonfossiliferous, smectite-rich sediments to local and Mid-Indian Ridge volcanism. The illite-rich sediments show their formation through turbidity currents which carry them right from the Bay of Bengal (Kolla & Biscaye 1973). The studied sediments at 4.7 m depth are also dark grey in colour and fine in texture. The average sand, silt and clay contents are 8.8%, 63.4% and 23.8% respectively.

Wetzel & Balson (1992) reported that sedimentation after the Pliocene was dominated by turbidites and the sedimentation rate during that period was typical of mud-turbidites and rapid deposition during late Pleistocene (20 cm/ky). This fact supports the present observation corresponding to top 4m sediments which are silt rich. The distinct layers below 4 m depth show high montmorillonite. Also the x-ray diffraction patterns show that this montmorillonite has well developed peaks indicating non-terrestrial but additional source of supply. This could be due to weathering of volcanic ridge basalts which contribute for montmorillonite and pumice pieces.

3.2 Physical properties

Natural water content (WC) decreases with depth, accordingly the specific gravity, wet density, porosity show consistent change along the depth (Fig.2). Water content varies with the textural change and clay mineralogy. Upto 3.5 m it is almost constant (WC = 370%). However, at 4.7m it shows drastic decrease despite higher clay fraction and montmorillonite content. As the montmorillonite is highly water absorbent clay mineral, water content should have been more at this layer than in other parts of the core but it appears that due to the overburden pressure the sediments have been highly compressed and hence, drained of maximum

water. Again below 5m depth due to high bioturbation the porosity increases and hence water content shows an increase. However, below 6m depth due to homogeneous nature of sediments and similar degree of bioturbation, water content remains same. Other reason for high water content of surface sediments (300-400%) is presence of about 60% microfossil/radiolarian tests which are hollow and could be filled with water.

The Atterberg limits also show consistency in depthwise variation with natural water content. The liquid limit (LL) and plastic limit (PL) indicate medium to high plastic nature (average LL=207%, average PL=109%, average plasticity index = 99%) of sediments except for sticky layers. At sticky layer the water content equals liquid limit (Fig.2, WC=LL=94%) which shows that sediments have already attained their liquid state by draining the water due to overburden pressure. Thus sediments at this layer are less plastic and more compressed (plasticity index = 47%) than other depths of the core.

Specific gravity (Sp Gr) changes with the mineralogical change (Keller & Lambert 1980) and textural variation. As the four major clay minerals of deep-sea have different specific gravities, the sediment specific gravity varies according to the mineral composition. Specific gravity variation with montmorillonite content has been observed in the core under study. The top 4m shows decrease in specific gravity and then shows an increase from 2 to 2.5 as the montmorillonite content increases from 40 to 67% at 4.7m. Below this depth it decreases gradually.

Porosity and wet density are calculated using water content and specific gravity. They show reverse trend in variation with depth. Up to 4 m depth porosity is 88 - 90% and density is 1.2 g/cm³. However at 4.7m density increases to 1.54 g/cm³ whereas porosity decreases to 71%. Bioturbation plays important role in changing sediment properties (Wetzel 1990). It can be seen that the core is bioturbated over full length except at three zones and intense bioturbation at the bottom part. Due to this porosity is high (88%) but reduces to 71% at sticky layer. Below 6 m, however, both remain constant.

3.3 Shear strength

The variation in undrained shear strength shows sediment characteristics and could be used as additional tool for geological interpretation. Though this type of study is rare, its usefulness for geological interpretation should be tested. The general trend of homogenous sediments would be gradual increase in strength with depth. It is controlled by factors such as water content, porosity, cementation etc. The present core shows depthwise increase in shear strength from 2.2

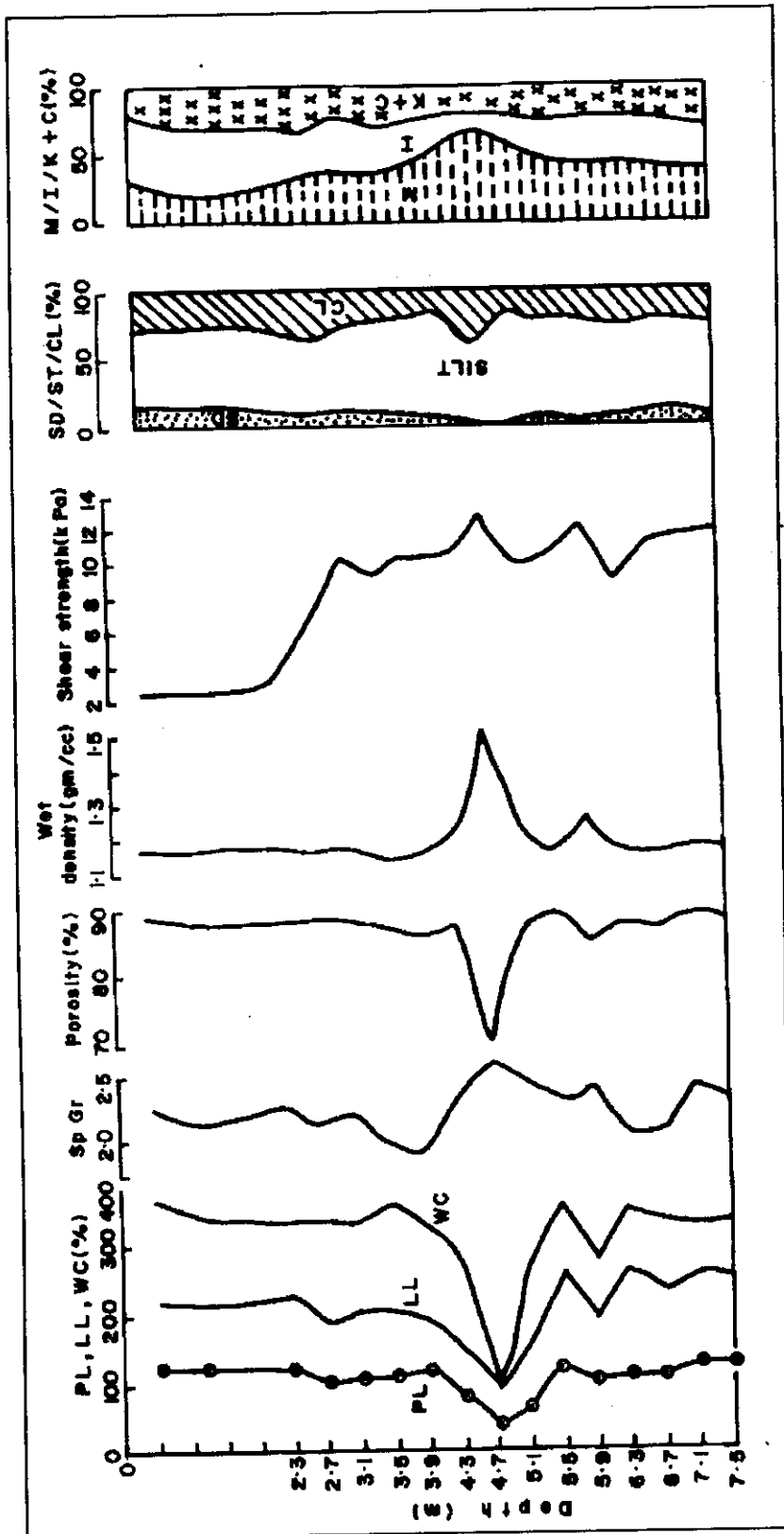


Figure 2. Depthwise variation in physical properties, shear strength, grain size and clay mineralogy of the sediment core from the CIB. Drastic change in properties at 4.7 m depth is attributed to the Plio-Pleistocene boundary at about 1.9Ma.

kPa at surface to 13 kPa at the bottom. The spike at 4.7 m depth implies different mode of sediment deposition. This drastic increase in shear strength from 10 kPa to 12.8 kPa shows change in mineral composition and rate of deposition during Pliocene-Pleistocene. Shear strength is an important parameter that determines bearing capacity and settlement characteristics of sediments. Therefore its in situ determination is preferable though it is not immediately possible. However, it is expected that the present strength values would be lower than the in situ ones mainly due to probable disturbance, reduction in hydrostatic pressure and temperature after the core is onboard.

4 CONCLUSIONS

The sediments under study, in general, show less variation in physical properties but good correlation among themselves which could be used for geological interpretation. The sediments are clayey silt in composition. The surface and bottom sediments are bioturbated, medium to high plastic, and fine grained in texture. At surface and bottom parts of the core, values of natural water content, Atterberg limits, porosity, sand content ($>63\mu\text{m}$) are high whereas specific gravity, wet density and shear strength values are low. Illite-rich sediments in the core could be attributed to Ganges turbidity currents from the North (Kolla & Biscaye 1973). The values of shear strength are lower than those reported from the nodule rich areas of the Pacific Ocean. The siliceous sediments up to 200cm depth from the Pacific Ocean showed undrained shear strength from 10-19 kPa (Hirst & Richards 1975).

The core shows a clear cut Plio-Pleistocene boundary at the depth of 4.7 m based on paleontological studies. The clay mineralogy and physical properties show drastic change at this depth indicating sedimentation in a different regime. The total absence of radiolarian fossils at this depth shows either climatic change and/or volcanic activity that precluded their preservation. The drastic increase in well developed montmorillonite content implies its source from the ridge weathered rocks and not through terrigenous supply. The earlier reported influence of Mid-Indian Ridge and local volcanism in the smectite-rich sediments south of 8°S latitude (Kolla & Biscaye 1973) is well observed in this core which is represented by the sticky layer. The increase in shear strength and decrease in natural water content despite high clay fraction ($<4\mu\text{m}$) and montmorillonite content indicate compressed and consolidated nature of sediments of 30 cm thick layer due to overlying water column and fast deposited sediment column during the late Pleistocene.

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