

## Internal constitution of manganese nodules from the Central Indian Ocean Basin

A K Ghosh

Department of Geology, University of Calcutta, Calcutta 700 019, India

and

Ranadhir Mukhopadhyay

National Institute of Oceanography, Dona Paula, Goa 403 004, India

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Morphological, chemical, physical and acoustic properties of Mn-nodules in the Indian Ocean are inter-linked and depend much on local and regional oceanic environments. These nodules are anisotropic and sound propagation is faster parallel to their elongation. Denser nodules show low attenuation. Density and P-wave velocity in nodules increase significantly on saturation with water. Nodule density is related directly to nodule size, P-wave velocity and Mn/Fe ratio; and inversely to water content, attenuation and Co concentration. Nodules with rough surface from siliceous clay region record highest density, P-wave velocity and Mn/Fe ratio.

In the wake of recently shown interest in metal resource potential of manganese nodules, studies of their internal constitution, such as physical and acoustic characteristics have received immense importance, as these characters appear to be related to nodule composition as well as their mineralogy. The velocity of sound wave through the nodule reflects constitution and composition of the matter by which it is formed. Studies<sup>1-3</sup> on physical properties of nodules from the Pacific and the Indian Ocean have been carried out. Acoustic properties of nodules have been examined from the Pacific, the Atlantic<sup>4-7</sup> and the Indian Ocean<sup>3,8</sup>. But the possible relationship between the physico-acoustic and chemical properties of the Indian Ocean nodules is not yet clear. In this paper an attempt has been made to highlight such relationship in nodules from the Central Indian Ocean Basin, and their relation to the nature of bottom sediments.

### Materials and Methods

Manganese nodules for the present study were collected from 16 stations using freefall grabs during a number of oceanographic cruises in the Central Indian Ocean Basin (Fig.1). A total of 22 nodules showing variable morphology were studied. The samples were collected from all the 3 major sedimentary environments of the basin namely—calcareous ooze (2 stations, depth 4224 m),

siliceous clay (11 stations, depth 5131 m) and pelagic clay (3 stations, depth 5011 m).

Standard procedures<sup>1-3,9,10</sup> were adopted to study morphological and physical parameters of nodules. Physical and acoustic properties of nodules were determined in both dry and wet conditions by immersing the sample in de-ionised water. But study of all the samples in wet condition could not be carried out as some nodules disintegrated when immersed in water. For measurement of acoustic properties two distal ends of nodule were polished to make parallel faces. The speeds of compressional ( $V_p$ ) and transverse ( $V_s$ ) sound waves through nodule were

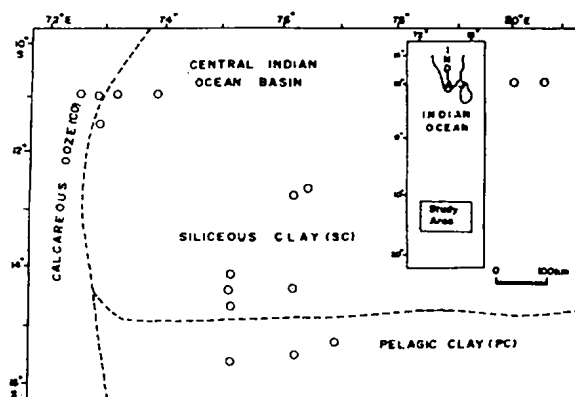


Fig. 1—Area of study showing distribution of bottom sediments and location of sample stations

measured by a pair of transducers mounted on parallel faces. Electrical pulse generated by a pulse generator activated these transducers. The transducers, in turn, transform the electrical pulse into acoustic pulse which travelled through the nodule. The wave speed was calculated from the path length traversed by the pulse in unit time. Each sample was tested for a number of occasions and the mean values (standard deviation  $\pm 53$  m. sec<sup>-1</sup>) are considered here. The ratio between the maximum and minimum velocities of sound waves along different direction of nodule gave coefficient of anisotropism, and loss of acoustic pulse per unit length of propagation was the degree of attenuation. Chemical analysis of 10 representative nodule samples from all sediment domains were carried out to correlate physical constitution and chemical composition of nodules.

**Results and Discussion**

Data on physical and acoustic properties of the present set of nodules were critically evaluated in terms of nature of bottom sediments, surface texture of nodules and nodule size (Table 1). All nodules were anisotropic (range of coefficients of anisotropism 1.04-1.29), with the wave speed propagation found faster along the elongation of samples. Anisotropism being directly proportional to the density of nodules, less dense and highly porous nodules recorded higher values indicating less coherent internal constitution of those nodules.

From Table 1, it is seen that occurring on a relatively shallower seafloor, the nodules from calcareous sediment area of the west, record least density and highest attenuation. These nodules hold larger amount of water and consequently allow P-wave to propagate at a faster velocity in wet condition. Chemically these nodules contain less concentration of Mn, Ni, and Cu and high concentration of Fe and Co. Nodules from siliceous clay, the deepest area covering the major part of the area of study, however show opposite trend. Nodules of this area are least attenuated and allow P-wave to propagate at a higher velocity in dry condition and have low concentration of Fe and Co but high contents of Mn, Ni and Cu. Nodules from the southern pelagic clay area show concentration of elements and values of acoustic properties irregularly intermediate between those obtained for nodules from the other 2 sediment areas. However, in the event of saturation with water for 24 h, increase in density has been maximum in nodules from pelagic clay area (47%), moderate in those from siliceous clay (43%) and minimum in those from calcareous ooze (40%). Velocity increase is maximum in nodules from calcareous sediment domain (54%), followed by nodules in siliceous (35%) and pelagic clay sediment domains (29%).

Physical and acoustic properties of nodules when compared to their surface texture (Table 1) reveal that rough surface nodules are more porous and allow P-wave to propagate at a faster velocity at dry

Table 1—Physical, chemical, morphological and acoustic properties of manganese nodules from Central Indian Ocean Basin

	Water depth m	Den- sity g.cm <sup>-3</sup>	Poro- sity %	Water cont. %	P-vel (dry) m.sec <sup>-1</sup>	P-vel (wet) m.sec <sup>-1</sup>	S-vel (dry) m.sec <sup>-1</sup>	Attenuation db.cm <sup>-1</sup>	Concentrations (%)					Mn/Fe ratio
									Mn	Fe	Ni	Cu	Co	
Bottom sediment types*														
CO (2)**	4224	1.68	54.67	48.25	1926	2957	0952	28.4	21.07	12.01	0.87	0.47	0.21	1.75
SC (17)	5131	1.96	62.98	45.73	2144	2564	1101	22.1	24.49	08.60	0.97	0.95	0.13	3.17
PC (3)	5011	2.00	58.92	41.92	1896	—	1075	22.7	22.35	11.34	0.75	0.67	0.21	2.04
Nodule surface texture														
Smooth (7)	—	1.99	61.26	46.56	1696	2597	1049	—	22.95	11.04	0.83	0.73	0.18	2.08
Rough (15)	—	1.98	63.48	47.36	2179	2586	1114	—	25.15	07.42	0.97	1.04	0.13	3.39
Nodule size class														
VS (2)	—	1.99	58.79	45.73	—	—	—	—	—	—	—	—	—	—
S (8)	—	2.02	61.03	45.44	1741	2499	1076	—	—	—	—	—	—	—
M (6)	—	2.00	59.95	48.95	2166	3277	1312	—	—	—	—	—	—	—
L (5)	—	2.45	60.10	44.57	2160	2568	1182	—	—	—	—	—	—	—
VL (1)	—	1.84	57.90	45.90	2192	2630	1107	—	—	—	—	—	—	—

\* CO — Calcareous ooze, SC — Siliceous clay, PC — Pelagic clay

\*\* Figures in the parentheses indicate number of samples examined

VS — Very small (< 2 cm), S — Small (2-4 cm), M — Medium (4-6 cm), L — Large (6-8 cm), VL — Very large (> 8 cm)

condition than in nodules with smooth surfaces. Again rough surface nodules contain higher amounts of Mn, Ni and Cu and lesser of Fe and Co in comparison to those in smooth nodules. Saturated nodules of smooth and rough surface texture show increase in density by 31.68 and 31.42%, respectively. P velocity, however increases by 23 and 15% respectively, in case of smooth and rough surface nodules.

Physical and acoustic properties of nodules at dry conditions in different size classes show (Table 1) that compressional ( $V_p$ ) wave propagates at highest speed through nodules of very large size (> 8 cm), at high speed in medium (4-6 cm), at moderate speed in large (6-8 cm) and at least speed in small (2-4 cm) size nodules. In case of wet nodules, P-wave travels at highest speed through medium size nodules followed by that through very large, large and small nodules. The highest speed of P-waves in the medium size nodules is probably because of their higher water content. A somewhat distinct trend of increasing density with increase in nodule size up to the large size class is also notable (Table 1). On saturation with water, increase in density is found maximum in nodules of larger size (94%) followed by nodules of very large (46%), very small (45%), small (44%) and medium (35%) size classes. Increase in P-wave velocity however shows a reverse trend. It is highest in medium size nodules (50%) and least in those of large size (19%). This is, perhaps due to the least water content in large size class and highest water content in medium size nodules.

Nodules of the Indian Ocean have the average density of  $2 \text{ g.cm}^{-3}$ , porosity 56% and water content 46%. Both compressional ( $V_p$ ) and transverse ( $V_s$ ) waves propagate at the highest velocity through dry nodules from siliceous clay region. This is because of higher density of nodules of these regions as supported by least attenuation. Wet nodules from this region show a direct relation between their water

content and P-wave velocity. These nodules have rough surface texture and contain higher concentration of Mn, Ni and Cu. All these characters may be related to siliceous clay bottom sediment which is less dense and more porous than pelagic clay sediments, thereby facilitating a higher degree of diagenetic contribution of metals to the nodules through sediment interstices. Nodules with smooth surface textures are rich in Fe and Co and record higher attenuation. This type of nodules occur mostly in calcareous ooze and pelagic clay sediment domains. Relatively denser and less porous bottom sediments of these types would possibly hinder diagenetic contribution of metals to these nodules.

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