

NOTE

Influence of seamount topography on the local facies variation in ferromanganese deposits in the Indian Ocean

RANADHIR MUKHOPADHYAY* and BEJUGAM NAGENDERNATH*

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Abstract—The morphology and chemistry of ferromanganese nodules and encrustations from a seamount in the Central Indian Ocean Basin show local variations. Nodules from the summit of the seamount have sporadic distribution, are less spherical, have smooth surfaces, have lowest oxide/nucleus (O/N) ratios, and contain low values of Mn/Fe, Ni and Cu. In contrast, nodules from plains at the base of the seamount show greater abundance, are more spherical, have rougher surfaces, register high O/N ratios, and highest Mn/Fe, Ni and Cu. An increase in element concentration (Mn/Fe, Ni%, Cu%) and roughness of nodule surface is directly proportional to the increased thickness of the "acoustically transparent layer". Morphochemical characters of these nodules suggest hydrogenetic and diagenetic formation in the summit and plain areas, respectively.

INTRODUCTION

FERROMANGANESE oxide deposits in the form of nodules and encrustations have long been the topic of research for their strategic metal contents. The regional and local variations of deep sea nodule characters have been reported by MERO (1962), CRONAN (1972, 1980), CRAIG (1979), HALBACH *et al.* (1981), GLASBY *et al.* (1982), FRIEDRICH *et al.* (1983), EXON (1983), USUI *et al.* (1987) and MUKHOPADHYAY (1987). Comparative studies of acoustic stratigraphy with nodule distribution (MOORE and HEATH, 1966; CALVERT *et al.*, 1978; MIZUNO *et al.*, 1980; USUI and TANAHASHI, 1986) and morphology (PIPER *et al.*, 1979) have shown evidences of their relationship to substrata. Variation in nodule characters as a function of diagenetic metal supply has been suggested by MURRAY and IRVINE (1894), MANHEIM (1965), CRONAN and TOOMS (1969), PRICE and CALVERT (1970) and KLINKHAMMER (1981). PIPER and BLUEFORD (1982) suggested nature of bottom sediments and sedimentation rate also can account for local variation in nodule character.

As a part of the programme, "Exploration for Polymetallic Nodules", initiated by the Department of Ocean Development, Government of India, extensive sampling of ferromanganese nodules and encrustations was done in the Central Indian Ocean Basin. The present investigation is based on samples collected during a cruise onboard M.V. *Skandi Surveyor*. Dredging was carried out in the northern part of the basin on and

* National Institute of Oceanography, Dona Paula, Goa, India.

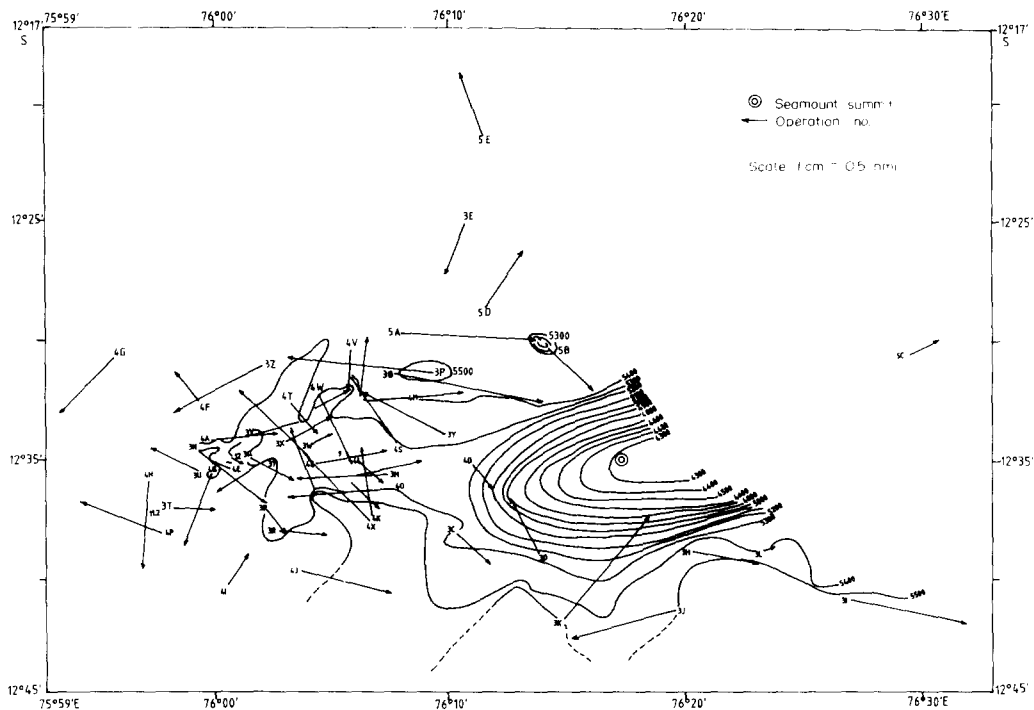


Fig. 1. Bathymetric map of the study area showing dredging tracks.

around a seamount (summit depth less than 4300 m, Fig. 1). The substratum of the dredged area is composed of siliceous clay sediments.

The thickness of the "acoustically transparent layer" (A.T.L.) of sediments was delineated using a 3.5 kHz echosounder (Table 1). Assorted ferromanganese nodules, having different sizes, shapes and surface texture, recovered from different dredge hauls (Table 2) were categorized into different size classes (2–4, 4–6, 6–8 and >8 cm). Owing to large mesh size of the dredge, nodules less than 2 cm in size could not be collected.

Elemental concentrations in nodules were determined by Atomic Absorption Spectrophotometry (CRONAN and MOORBY, 1981). Five major transitional elements, Mn, Fe, Ni, Cu and Co, were analysed (Table 2; Indian National Oceanographic Data Centre).

RESULTS AND DISCUSSION

Most of the dredging operations are done on the western and southwestern slopes of the seamount (Fig. 1). Halfway down the northwestern slope of the seamount, a deep narrow valley, almost perpendicular to the slope trend, was encountered. Dredged material from this valley was comprised largely of transported (slumped) nodules and encrustations from the upper slope (Fig. 1). Topographically the study area is divided into 4 zones—upper slope, valley, lower slope and plains.

The distribution of ferromanganese nodules and encrustations is very sporadic. The western and southwestern slope of the seamount and plains appear to contain the most nodules. Out of a total of 54 dredging operations, 41 operations yielded varying amounts

Table 1. Distribution of samples in different topographic locations. Figures in parentheses indicate number of operations carried out

Sample types	Upper slope (9)	Valley (4)	Lower slope (29)	Plains (12)
Nodules (kg)	1040.9	720	3141	1348
Encrustations (kg)	190.5	145	429	160
Total (kg)	1231.4	865	3183.9	1508
Average recovery per operation	136.8	216.2	109.8	125.6
Recovery range (kg)	0–615	0–560	0–580	0–450
Abundance (kg m ⁻²)	05.53	08.28	07.23	06.71
Water depth (m)	4691	5233	5197	5269
A.T.L. thickness (m) (average)	08.18	12.36	11.17	09.75
A.T.L. thickness (m) (range)	0.43–19.56	9.78–14.67	1.96–28.25	4.56–17.11

of nodules, while the remaining operations were futile (Table 1). The recovery of bulk sample ranged from 5 to 610 kg (Table 1). Maximum size of the nodules was 16.5 cm, with a clayey nucleus of 14.05 cm in thickness. Polyspheroidal nodules formed by coalescence were found mostly on the down slope of the seamount and plain areas (Table 2). In general, altered rock fragments and consolidated muds form the nucleus of the nodules. Clay around the nucleus in a few of the samples is wet and soft, although no visible cracks are present on the nodule surface.

Encrustations were recovered in 15 dredges, which can be broadly differentiated into three types: (i) with 6–7 cm thick oxide coating around a palagonitic core and of smooth surface texture; (ii) having a hammocky surface and 4 cm thick oxide layers around the

Table 2. Morphological description and chemical composition of nodules from different topographic locations

Parameters	Upper slope	Valley	Lower slope	Plains
Predominant size	Medium	Large	Medium	Medium
Size length (cm)	4–6	6–8	4–6	4–6
Nodule population (%) in predominant size	66.68	37.50	44.94	41.90
Shape	SS,D,E	D,P,S	E,D,PS	D,SS,E
Sphericity (%)	30	20	28	29
Surface texture	G,CG,SM	CG,B	CG,G,SM	SM,G,CG
Nucleus nature	MN,MA	MN	MN	MN,PN
Nucleus type	HM	ARF	ARF	ARF,ON
Oxide/nucleus Thickness ratio	1.75	0.16	0.13	0.66
Mn% (Avg.)	23.71	19.96	22.34	28.76
(Range)	30.13–19.38	21.05–18.87	23.34–21.25	34.93–25.98
Fe% (Avg.)	09.40	10.52	11.08	06.57
(Range)	05.10–13.94	09.38–11.56	09.99–12.17	04.79–12.03
Ni% (Avg.)	00.98	00.77	01.08	01.34
(Range)	00.57–01.76	00.62–00.92	00.95–01.23	01.07–01.60
Cu% (Avg.)	00.93	00.62	00.80	01.35
(Range)	00.45–01.78	00.46–00.76	00.65–00.95	00.59–01.66
Co% (Avg.)	00.13	00.14	00.20	00.12
(Range)	00.01–00.22	00.12–00.16	00.17–00.23	00.07–00.20

SS, subspheroidal; D, discoidal; E, elongated; PS, polyspheroidal; P, prolate; G, granular; CG, coarse granular; SM, smooth; B, botroids; MN, mononucleate; PN, polynucleate; MA, mixed assemblage; HM, hardened mud; ARF, altered rock fragments; ON, old nodules.

core of weathered rocks; and (iii) with an oxide coating of 0.5–1 cm around consolidated mud and with a hammocky and knobby surface texture.

Nodules from plains at the base of the seamount record the highest Mn/Fe (4.356) ratio and Ni + Cu (2.735%) and lowest Fe (6.57%) and Co (0.125%). Nodules from upper slope areas, on the other hand, contain lower Mn/Fe (2.94) and Ni + Cu (1.88%) with low Fe and Co concentrations (9.36 and 0.116%, respectively). Those from lower slopes contain Mn/Fe (2.12) and Ni + Cu (1.87%). Co is comparatively high in these nodules (0.20%). Nodules from a valley environment (deep furrow at NNW slopes) contain the lowest Mn/Fe (1.91) and Ni + Cu (1.38%) and higher Fe (10.47%) and Co (0.14%) (Table 2).

Except in the valley, the compositions of nodules are in accordance with previous reports (CRONAN, 1977; CALVERT *et al.*, 1978; HALBACH and OZKARA, 1979; CRONAN and MOORBY, 1981; HALBACH *et al.*, 1982). Variation in the composition and morphology of the valley nodules from those of typical deep sea nodules suggests the possibility of downward gravity transport on the seamount.

Local variation in nodule surface texture, sphericity and thickness ratio between oxide layers and nucleus (O/N) along the western slope profile of the seamount is very conspicuous (Fig. 1; Table 2). On the slopes, close to the seamount summit, the nodules are extremely smooth textured, having an average sphericity of 34% and O/N ratio of 0.995, whereas lower slopes contain an admixture of smooth and rough textured nodules. These nodules show a mean sphericity value of 31.9% and O/N ratio of 1.146. The westernmost region in the plain area contains mostly rough nodules with only a few smooth textured ones. Sphericity of these nodules is as high as 39%, with an O/N of 1.05.

Nodules generally increase in size with depth. An increase in the degree of roughness of nodule surface is directly proportional to the increase in the thickness of A.T.L. (Table 2). Oxide/nucleus thickness ratio is low in nodules from the upper slope, moderate in lower slopes and high in plain areas. Low thickness of oxide precipitation in nodules at elevated areas and high oxide thickness in nodules at greater depth suggest hydrogenetic and diagenetic mode of formation, respectively (HALBACH *et al.*, 1979; CRONAN, 1980). With the increase in nodule size, the O/N ratio also increases.

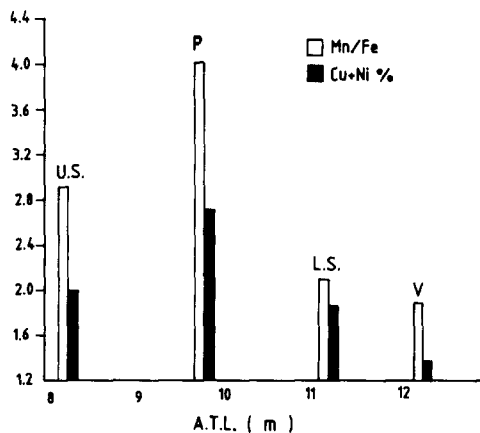


Fig. 2. Relation between transparent layer of sediments and chemical composition of nodules. U.S., upper slope; P, plain; L.S., lower slope; V, valley.

This phenomenon is displayed by nodules from most of the topographic domains, indicating an extra source of ferromanganese oxide supply from sediment. Larger nodules are mostly found in the areas of thick A.T.L. (lower slope and plains).

Encrustations occur mostly on the upper slope having a thin A.T.L. of about 15 m thickness (Table 1). A close relation between the thickness of oxide layers and surface texture of the encrustations is observed. The thicker the oxide coating, the smoother the texture; conversely the thinner the coating, the rougher the texture. Thin oxide-coated encrustations on the plains suggest possible displacement, thereby avoiding hydrogenetic precipitation at shallower depths. Greater oxide thickness on encrustations with smooth texture from upper slope regions, on the other hand, suggests faster hydrogenetic precipitation.

Nodules occurring in the plain areas, with thicker A.T.L., have the highest Mn/Fe ratio and Ni + Cu content, suggesting that the sediment is a potential source of metal supply. In contrast, nodules from the valley region, owing to displacement, contain low Mn/Fe and Ni + Cu% despite occurring in a thick substratum (A.T.L.).

Lack of uniformity in morphology and chemistry of nodules, in a small area, reduces the possibility of any nearby seamount contributing transitional elements to the abyssal environment (CRAIG, 1979). It appears that variation in the morphochemistry of nodules from the present area is a function of topographic variations associated with the seamount.

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