UNDERWATER GEOMORPHOLOGY AS A FUNCTION OF THE VARIATIONS IN FERROMANGANESE NODULE CHARACTERS IN THE INDIAN OCEAN

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ABSTRACT

Ferromanganese nodules from three areas in the northern part of the Central Indian Ocean Basin have been studied. Statistical analysis shows significant variations in morphological and physical characters of nodules between the area S_5, which is situated on the northwestern slope of a seamount, and the other two areas, S_4 and S_6, which are away from the seamount. Surface roughness, porosity and water content are directly proportional to nodule size. Nodules from area S_5 which occur at shallow depth, are mostly large in size, contain rock-fragments as the nucleus, and are rich in Co and Fe and poor in Mn, Ni and Cu. In contrast, nodules from areas S_4 and S_6 occur at deeper depths, are mostly medium to small in size, contain consolidated mud as the nucleus, and are rich in Mn, Ni and Cu but poor in Fe and Co. Variation in nodule characters indicates a strong influence of seamount topography on the substantial contributions of transitional elements from seawater and sediment interstitial water to the nodules occurring in shallow and deep areas respectively.

INTRODUCTION

ECONOMICALLY exploitable ferromanganese nodule deposits occur in the Central Indian Ocean Basin[1]. Ocean-wide regional studies on morphology and chemical composition of nodules from the Indian Ocean have been made[2-5]. Nodules from small areas of the Indian Ocean have also been studied[6-8].

MATERIALS AND METHODS

Nodule samples were hauled by dredge during different cruises of MV *Skandi Surveyor* under a project of the Department of Ocean Development, Government of India. These samples are from the ocean floor with depth ranging from 4874 m (area S_5) to 5100 m (area S_6) and 5300 m (area S_4, figure 1). About 30 km south-east of area S_5, a seamount is encountered whose summit rises to 4300 m from the adjacent seabed depth of 5400 m. Area S_5 is situated on the northwestern slope of the seamount and the other two areas (S_4 and S_6) are situated in the plains, away from the seamount.

Nodules are classified into four sizes: 2-4 cm (small), 4-6 cm (medium), 6 8 cm (large) and >8 cm (very large) (table 1). Sixty nodules belonging to different size classes from three areas were taken for detailed study.

Mammillae are localized tumorous growths of oxide precipitation, ornamented on the surface of nodules[9]. Nodules usually contain mammillae of different sizes and reliefs. Mammilla size is the length 'ratio' between base of mammilla and diagonal diameter of whole nodule. Mammilla relief, on the other hand, is the 'ratio' of height to base length of the mammilla itself (figure 2). The most common categories of mammilla size (very coarse, 1–1/4; medium, 1/10–1/15) and mammilla relief (very high, 1; moderate, 1/3) were considered to deduce their optimum level of combination in bringing about changes in physical characters and chemical composition of nodules.

Physical properties of nodules, viz. density, porosity and water content, have been determined[10]. Some of the morphological and physical parameters were statistically evaluated to understand their interdependence. The parameters are (A) morphological—(i) mammilla size (very coarse, 1-1/4), (ii) mammilla size (medium, 1/10-1/15), (iii) mammilla relief (very high, 1), (iv) mammilla relief (moderate, 1/3); (B) physical—(v) wet density, (vi) dry density, (vii) water content, (viii) porosity (table 1).

One-way multivariate analysis of variance (MANOVA) technique was employed to test the area-wise variation in these morphophysical and physical characters. This analysis is based on natural break-down of the variability into 'between' and 'within' components of variation[11,12].

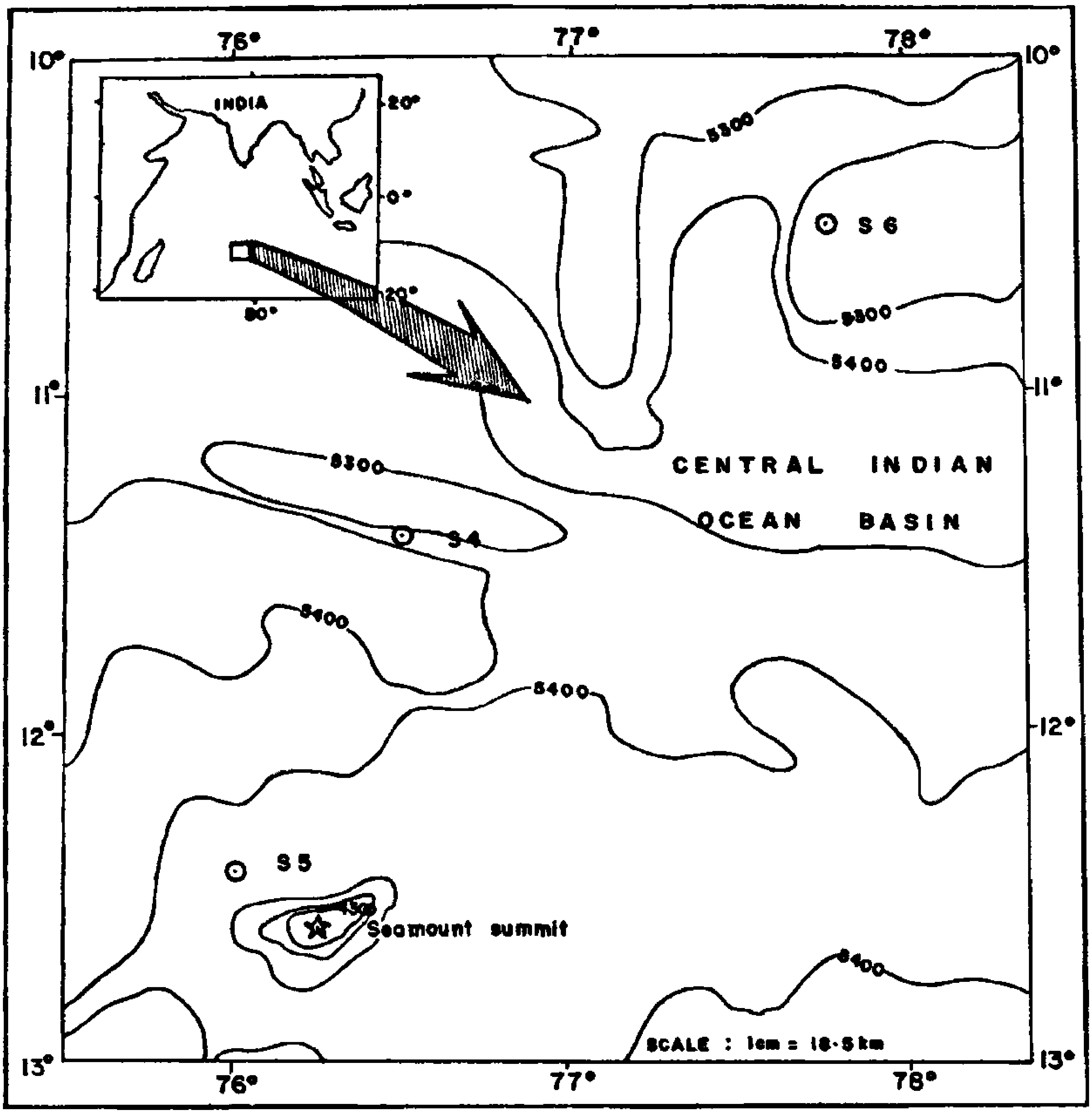

Figure 1. Location of the sampling areas.

The breakdown is as follows:

$W = S_W$ for $(N-K)$ degrees of freedom,
$B = S_B$ for $(K-1)$ degrees of freedom,
$T = S_T$ for $(N-1)$ degrees of freedom,

here

S_B = between-area variance–covariance matrix,
S_W = within-area variance–covariance matrix,
S_T = total variance–covariance matrix,
K = number of areas,
N = number of physical and morphological parameters.

$S_T = S_B + S_W$.

ANOVA is done in terms of the matrices **W** and **T** by means of Wilks' (lambda) criterion

$$\Lambda = |\mathbf{W}|/|\mathbf{T}|.$$

The test of significance was done by the F-statistic which is given by

$$F = \frac{1-\Lambda}{\Lambda} \times \frac{(N-K)}{(K-1)} = \frac{1-\frac{|\mathbf{W}|}{|\mathbf{T}|}}{\frac{|\mathbf{W}|}{|\mathbf{T}|}} \times \frac{(N-K)}{(K-1)}$$

$$= \frac{|\mathbf{B}|}{|\mathbf{W}|} \times \frac{(N-K)}{(K-1)}$$

Table 1 *Morphological and physical characters of nodules in different size classes*

Area	No. of samples analysed	Nodule population* (%)	Mammilla size: Very coarse 1-1/4 (%)	Mammilla size: Medium, 1/10–1/15 (%)	Mammilla relief: Very high, 1 %	Mammilla relief: Moderate, 1/3 (%)	Wet density (kg/m^3)	Dry density (kg/m^3)	Water content (%)	Porosity (%)
Small size class (2–4 cm)										
S_4	7	46.66	22.41	34.75	59.66	11.92	1.93	1.33	45.53	60.38
S_5	8	51.41	25.03	35.06	36.00	34.72	2.18	1.66	37.58	59.76
S_6	7	72.14	29.65	20.27	48.62	6.63	1.74	1.26	37.89	47.82
Medium size class (4–6 cm)										
S_4	9	46.85	19.32	27.37	55.47	12.71	2.04	1.44	42.35	60.71
S_5	8	30.38	79.08	3.12	8.33	0	1.98	1.45	37.24	53.50
S_6	7	12.96	23.87	31.72	55.07	10.94	1.86	1.35	48.13	65.04
Large size class (6–8 cm)										
S_4	3	03.85	1.66	36.11	58.88	11.51	2.27	1.64	49.30	81.51
S_5	3	10.77	28.79	13.03	2.15	9.70	1.91	1.44	31.04	47.00
S_6	3	02.13	23.86	14.81	44.74	15.74	1.91	1.38	37.58	52.22
Very large size class (>8 cm)										
S_5	3	02.86	17.10	25.87	28.45	26.58	2.61	1.97	33.35	65.73
S_6	2	00.08	46.66	3.33	33.33	14.99	2.17	1.60	35.61	56.93

*Area S_4 is also populated (0.08%) by very large size nodules.

or, $$F=\frac{|S_B|}{|S_W|}\times\frac{(N-K)}{(K-1)}$$

for $(K-1, N-K)$ degrees of freedom.

The results of the analysis and tests are given in table 2. To calculate the variance–covariance matrices S_B and S_T the raw data were standardized into deviates from the column and grand means respectively. Since MANOVA requires the raw data to be expressed in uniform units of measurement the morphological and physical features, except the densities, were expressed as percentages. The wet and dry densities (kg/m^3) were therefore tested by one-way univariate analysis of variance (ANOVA).

The concentrations of five major elements, viz. Mn, Fe, Ni, Cu and Co, in these nodules were determined by atomic absorption spectrophotometry (table 3, PMN Data Processing Group).

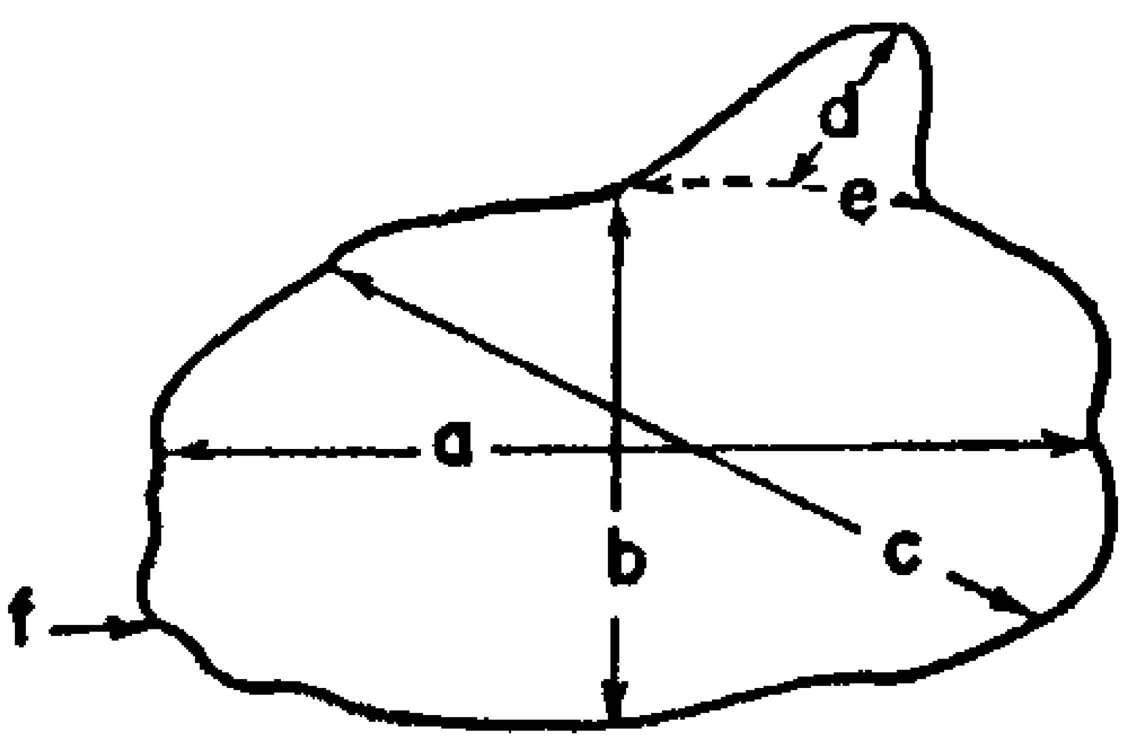

Figure 2. Schematic diagram of a nodule (*f*) showing external features. [a, Long axis; b, Short axis; c, Intermedia axis; d, Height of mammilla; e, Base of mammilla.]

RESULTS AND DISCUSSION

Significant variation in morphological and physical parameters was observed in the nodules of small, medium and large sizes from the different areas (table 1). The ANOVA test (table 2) indicates that nodule densities (wet and dry) do not differ markedly between areas in the case of larger nodules (>6 cm). However, the difference is significant for nodules of small size (<4 cm). Some of the inter-parameter correlations in nodules can be listed as follows: (i) wet density and porosity are, in most cases, directly proportional, (ii) mammilla size is inversely proportional to mammilla relief, (iii) water content of nodules is generally directly proportional to their porosity, (iv) wet density varies directly to water content only in larger size classes (>6 cm), and (v) the number of mammilla is higher on the surface of larger nodules.

In general, nodules are mostly spheroidal to sub-spheroidal in the smaller size classes. The form gradually changes to discoidal, ellipsoidal and tabular with increase in size. Nodules from area S_6 differ markedly in characters from those of the other

Table 2 *Results of MANOVA and ANOVA tests*

Size class	MANOVA			ANOVA	
			F-statistic	F-statistic	
	Between areas* $\lvert S_B \rvert$	Within area $\lvert S_W \rvert$	$\frac{\lvert S_B \rvert}{\lvert S_W \rvert} \times \frac{(N-K)}{(K-1)}$	Wet density	Dry density
Small	0 19919	0.00091	1987.30	3 98	46 47
Medium	0.00218	−0 00034	44 798**	10 64	8 73
Large	0 39442	0 01130	104 70	0.21†	395 04
Very large	—	—	—	0 80†	0 08†

*Highly significant difference was observed between areas at $\alpha=0.05$, **F-statistic treated as positive as it lies in the non-negative range; †Nodule densities do not differ significantly between areas at $\alpha=0\,05$.

Table 3 *Abundance and chemical composition of nodules (mean values) from different areas*

	S_4	S_5	S_6
Mean of samples	28	20	4
Abundance (kg m²)	06.30	05.52	—
Distance from seamount (km)	33	134	287
Water depth (m)	5300	4874	5100
Manganese (%)	23.62	21.36	25.00
Iron (%)	06.09	06 13	06.69
Nickel (%)	01.43	01.24	01.50
Copper (%)	01.41	01.34	01.50
Cobalt (%)	00.11	00.12	00 09
Mn Fe	03.88	03 48	03.74
Ni+Cu (%)	02.84	02.58	03 00

two areas. Unlike in areas S_4 and S_5 the major nodule population in area S_6 falls under the small size class (72 14%, table 1). These nodules are less mammillated, more rounded and sub-spheroidal to spheroidal in shape. This might be due to the movement of the nucleating material (mostly rock fragments) for long distances from its possible source in the seamount situated approximately 300 km south of area S_6 (figure 1). Average *in situ* (wet) density is highest for nodules from area S_5 (2.17 kg m³), lowest for those from S_6 (1.92 kg/m³) and intermediate for those from S_4 (2.08 kg/m³). Thus morphological and physical characters of nodules are found to vary with geographical location of the areas. However, water content of the nodules appears to be close in both the areas in very large size class.

The important geological factors responsible for the initiation and accretion of deep-sea ferromanganese nodules are availability of nodule nuclei, supply of transitional elements to the abyssal environment and stationing of nodules at the sediment–water interface[13,14]. Nodule nuclei from area S_5 are comprised almost wholly of volcanic rock fragments. This fact may be attributed to the close vicinity of this area to the seamount (figure 1). Nodules from the other two areas, S_4 and S_6, on the other hand, have nuclei made up of either consolidated mud or older nodules or rock fragments. Nodules from the shallowest part of the present study (area S_4, 4874 m) show the lowest values for Ni+Cu and Mn/Fe ratio but the highest value for Co (table 3). In contrast, nodules from the deepest part (area S_4, 5300 m) contain a high percentage of Ni+Cu but low Co and have a high Mn/Fe ratio. Nodules of area S_6 occur at intermediate depth (5100 m) and give values for the transitional elements that are intermediate between those of the other two areas. Thus distributional and chemical (table 3) variability in surficial nodule deposits could be related to local topographic variation caused by presence of the seamount.

Variation in morphology and chemistry of nodules in such a small area reduces the possibility that the seamount contributes transitional elements to the abyssal environment[15]. This suggests different modes of formation for nodules from different areas. Nodules of area S_5 occur at shallow depth on the slope of the seamount. These nodules are of larger size and have high Co and low Mn/Fe and Ni+Cu, indicating a substantial contribution of hydrogenous precipitation to their formation. On the other hand, nodules from areas S_4 and S_6 occur in a deeper abyssal environment. These nodules are predominantly of smaller size and have high Mn/Fe and Ni+Cu and low Co. All these suggest a major contribution from sediment interstitial water[13,16]. It thus appears that geomorphology of the seabed as a contributor to topographic variations in the area influences morphology and chemistry of these nodules.

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NEWS

DAMAGE TO HYDROPOWER PLANTS OF MODERN CONSTRUCTION

The statistical analysis of 1300 insured hydroelectric power stations reveals the main centres of damage, particularly in installations of more recent construction. Product faults are the primary cause of such a damage. Therefore, two experts have been discussing this matter in "Der Maschinenschaden"—a German specialist journal for risk technology. Because of an interest far above average, the editor has just now published the English translation of an offprint of 16 pages A4 with 36 instructive illustrations. This remarkable publication is available for all parties interested in this field

An exemplary description, based on practical experience, is given of damage, possibility of repair and damage prevention measures, both in respect of hydraulic plants (hydroturbines, pump turbines and fittings) as well as of hydropower generators. With the latter ones, it is generally found that in the case of salient-pole machines, slight defects at the magnet wheel usually lead to quite significant damage to the stator; not to mention several other causes of damage in the context of this matter. (Obtainable from: Allianz Technische Information. D-8000 Munchen 44, Postfach 440124, Federal Republic of Germany; Ordering No. TI-E6-205; Price for the Offprint edition: 18 DM)