

# Influence of Regional and Local Topography on the Distribution of Polymetallic Nodules in Central Indian Ocean Basin

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## Abstract

Detailed bathymetric surveys from part of the Central Indian Ocean revealed several bathymetric features such as hills, slopes, valleys, and plains. Areas with a local relief of a few to hundreds of meters generally have a high abundance of polymetallic nodules with a patchy distribution. Areas with less relief have lesser abundance but a regular distribution. North–south topographic profiles have a smoother sea floor than the east–west ones. Near the minor faults, the abundance is high. Mn, Ni, Mn/Fe levels are higher in the plain areas, and rough terrains have high Fe, Co and low Mn/Fe levels.

## Introduction

Polymetallic nodules are distributed worldwide; although they have been studied for about a century, the factors responsible for their variety in abundance, chemistry, and growth are not fully understood. High abundances (10 to 15 kg/m<sup>2</sup>) of polymetallic nodules and up to 2.5 percent for Ni+Cu+Co combined are found in the Central Indian Ocean Basin and the Pacific Ocean. However, considerable variation is noticed in the distribution and chemical composition of the manganese nodules from the Central Indian Ocean Basin. It is necessary to study the reasons for these variations to make an assessment of the economic feasibility of nodule sites and for design of a mining system.

During the 'Surveys for the Polymetallic Nodules,' conducted by the National Institute of Oceanography in Goa, detailed echosounding surveys and nodule sampling with free fall grabs were undertaken in the Central Indian Ocean Basin. It is shown on the 12 kHz echosounding records that topographic relief of

a few to hundreds of meters is quite common. In this report, an effort is made to illustrate the bathymetric complexity of the region and establish relations between topography and the distribution of the polymetallic nodules. For comparison, both the large-scale regional and small-scale local topography of the area are considered.

The study is important in the assessment of economic feasibility of nodule deposits and the investigation of small-scale bathymetric obstacles that are likely to cause problems for the mining system to be developed. Bathymetry (water depth and topography) is a key factor in mine site sizing (Kaufman 1974). Besides from these long-term economic implications of the study, small-scale geological processes responsible for the varying abundance of ferromanganese nodules can be deciphered.

A number of bathymetric and basement features were encountered during the cruises, such as abyssal hills that reach heights up to a few hundred meters, slopes, and valleys. The average water depth is around 5,200 m. The ruggedness of the basement floor is considerable both regionally and locally. The local microrelief is suggestive of the synchronous tectonic activity with sediment deposition (Van Andel and others 1973).

## Previous Work

Studies have been performed in the Pacific Ocean to establish a relationship between topography and distribution of polymetallic nodules. Results indicate that nodules are more abundant in areas of high relief such

as the Clarion-Clipperton zone (Craig 1979). Maximum nodule coverage (Moore and Heath 1966) occurred on the steepest slopes, as well as on local topographic highs, hill tops, and slopes (Frazer and Fisk 1981). There is inverse relationship between grade and abundance of the polymetallic nodules (Menard and Frazer 1978). The abundance increases with depth and is high on the periphery and the flanks of abyssal hills and low in the troughs (Peutot and Melgouen 1979).

In the Atlantic Ocean it was reported that manganese nodules occur more on rugged topographic terrain and the distribution is patchy on such areas (Ewing and others 1973). Fewer or no nodules were reported from areas of low relief. In the Indian Ocean it was found that the abundance is higher on relief terrains and significantly lower on plains in the Central Indian Ocean Basin (Pattan and Kodagali 1988).

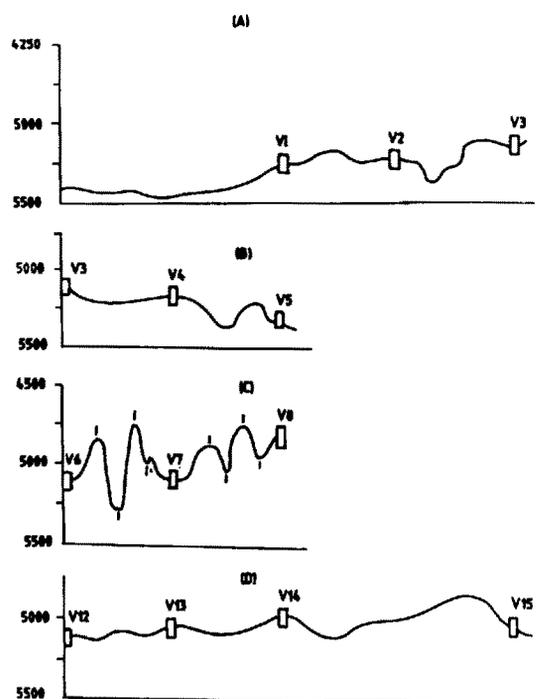
### Bathymetry and Sampling

Sixteen free fall grab stations at intervals of a quarter degree were occupied. This large data base was used to study the influence of the regional and local topography on the abundance of polymetallic nodules. Between four and seven free fall grabs (FFG) were launched at each station in a hexagonal or square pattern with one being in the center when an odd number was used. The distance between the grabs was approximately 200 m apart.

The free fall grab sampling approach has advantages over conventional dredging and other methods of sampling because a more accurate determination of sample location is given and thus exact abundance of nodules can be calculated. The time spent on the operations is also less as many grabs can be launched simultaneously. The rapid rate of sinking (75 to 80 m/min) of the device also minimizes the effect of currents.

Echosounding was carried out during the survey by Raytheon Echosounders (12 kHz) and recorded in the analog form on the Line Scan Recorder. During the survey, recorder was adjusted to four second sweep rate with four second delay to obtain an increased resolution of the topography.

Profiles drawn along the sampling stations show the topography of the area in which the sampling was done (Figs. 1 A-D). Three of these profiles are parallel to a latitude, whereas one is parallel to a longitude. These profiles are drawn with a vertical exaggeration of 1:20. The positions of the FFG launches are shown by a downward arrow on the detailed bathymetric profiles (Figs. 2 to 5) that are presented at true scale to give a correct picture of the local geology. These profiles and the sampling data are used to study the influence



**Figure 1 (A-D).** Bathymetric profiles (vertical Exaggeration [V.E.] = 1:20) illustrating regional bathymetry adjacent to FFG sampling stations. Blocks on each profile indicate position and depth ranges.

of regional and local topography on the abundance of the polymetallic nodules.

The average abundance at a station is calculated by dividing the total weight of the nodules collected at a station by the number of FFG that recovered the nodules. The average weight divided by the area of coverage of the grab (0.13 square meters) gives the average abundance of the nodules per station. The recovery efficiency for each station is also calculated (Table 1). It is the percentage ratio of the number of free grabs lowered at a station to the number that successfully brought in nodules. It is found that the total average efficiency is 65.8 percent and average abundance is 7.84 kg/m<sup>2</sup>.

### Results and Discussion

Though there are only 16 stations from which data is used for the present study, it is found that a sufficient variety of bathymetric domains are present in the region. The topographic profiles drawn (Figs. 1 A to D) illustrate the regional bathymetric character of the survey sites. The average sea floor abundance of the polymetallic nodules and the recovery efficiency of the free fall grabs is tabulated in Table 1.

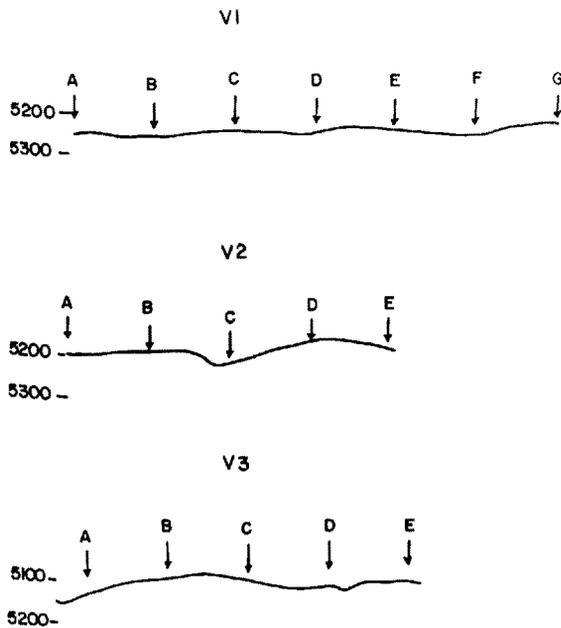


Figure 2. Detailed bathymetric profiles (V.E. = nil) and FFG launching sites at stations V1, V2, and V3.

Survey sites V1, V2, and V3 are set in an area of moderate bathymetric relief. Average water depth in these sites is 5,200 m. The profile (Fig. 1 A) shows the nature of the sea floor on a regional scale around these sites. This profile is parallel to a longitude. Site V1 is on the flanks of a broad valley, the deepest point of which is 5,500 m. At site V2 the relief is about 75 m, whereas site V3 is at shallowest depth (5,100 m). The local geology around these sites is indicated in the profiles drawn to true scale in Figure 2. It is observed in station V1 that the depth is uniform but as the site is on a valley slope in a regional sense, the abundance here is high, average  $9.85 \text{ kg/m}^2$ . In site V2, where the local relief also varied 50 m. Five grabs were lowered, three of which were at greater depths than the other two. The abundance from the group of three grabs is higher than that at shallowest depth. This shows that the distribution of nodules is patchy at sites having some local relief.

Site V4 is located near the top of a valley 250 m deep, and recovery is low ( $1.85 \text{ kg/m}^2$ ). Obviously, the nodules rolled down the valley. The sediment cover as evidenced from the echosounder records is very thin. Site V5 is along the same latitude and on the slope of an adjoining valley (Fig. 1B). This valley is rather steep and recovery in this site is absolutely nil, possibly because nodules rolled down the valley. At these two sites, the fact that regional topography seems to have influenced the abundance of nodules as local relief is inconsequential (Fig. 3).

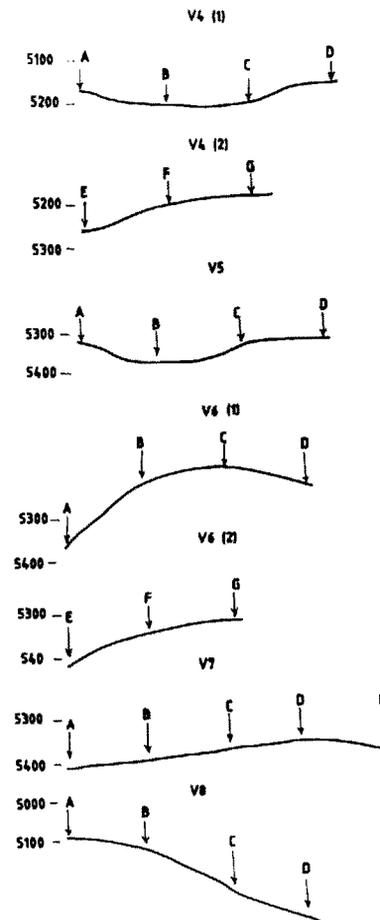


Figure 3. Detailed bathymetric profiles (V.E. = nil) and FFG launching sites at stations V4, V5, V6, V7, and V8.

Sites V6, V7, and V8 are along the same latitude (Fig. 1 C). They are set in the roughest topographic terrains encountered during this study. Two uncharted abyssal hills with peaks reaching to over 350 m are observed. The structures as seen in the figure may illustrate the trend of intermediate lineation zones. Lines on the profile indicate the possible faults. These faults which might have originated at the bottom and extended to the top (Andrews 1971) are perpendicular to the south east Indian Ocean Ridge. Site V7, set in a broad valley, shows local variations in depth up to 50 m. Average sea floor coverage of the nodules in the site is  $8.65 \text{ Kg/m}^2$ . Site V8 is on the shallow part of the valley but the local depth variation (Fig. 4) is considerable (up to 250 m). The recovery in each grab lowered in this station is shown in Table 2. Recovery in this highly rugged area is high, the average being  $14.55 \text{ kg/m}^2$ . But the distribution is patchy with two grabs showing negligible recovery. This phenomenon of higher abundance in places of high relief is in ac-

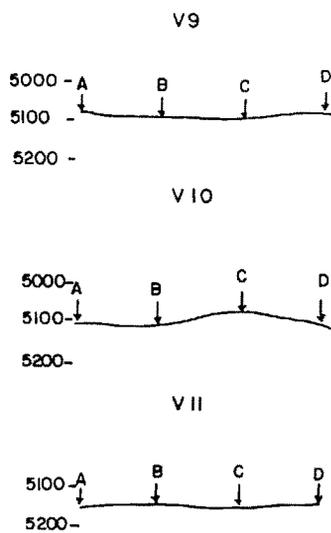


Figure 4. Detailed bathymetric profiles (V.E. = nil) and FFG launching sites at stations V9, V10, and V11.

cordance with what is reported in North Equatorial Pacific Ocean (Craig 1979).

Sites V12, V13, V14, and V15 are set in areas of comparatively low bathymetric relief (Fig. 2D). At Site V12, depth is 5,150 with very less local relief. Recovery ( $3.85 \text{ kg/m}^2$ ) also is low. Same is the case with sites V13 and V14 which are on a higher altitude on the peaks of the sides of a valley and understandably report less coverage ( $1.0$  and  $2.3 \text{ kg/m}^2$ , respectively). Nodules might have rolled down the valley here as there are no obstacles posed by the presence of the micro relief (Fig. 5). Site V15, on the other hand, situated on the same latitude is at the bottom of the depression which is 175 m deep. The local topography as seen from the detailed profiles (Fig. 5) is also quite rugged. As in the case of site V8 which also had high relief, this site also has a higher abundance of  $15.846 \text{ kg/m}^2$ . The distribution of the nodules is patchy in this station also. Two out of the seven FFG lowered did not bring any nodules.

The recovery in each grab lowered at stations V3, V8, and V15 is shown in Table 2. It shows how sporadic the distribution of nodules is in these regions of rugged topography. In contrast to this, the data of grabs from sites V4, V9, and V13 show uniform distribution of nodules. The local and regional topography at these stations is much less rugged in comparison to sites V3, V8, and V15. This shows that the distribution in areas of rugged topography with higher average abundance, have patchy distribution of ferromanganese nodules whereas areas with little or no relief have lesser abundance but more uniform distribution.

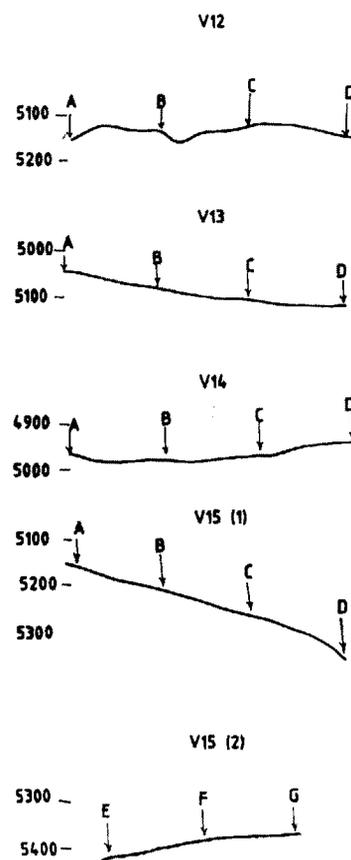


Figure 5. Detailed bathymetric profiles (V.E. = nil) and FFG launching sites at stations V12, V13, V14, and V15.

Overall, it is observed that the nodule abundance is in direct relation to the local relief. The regional topography in which the station is set also plays a key role in the distribution and coverage of the polymetallic nodules. It is also observed that the distribution is patchy in areas where the abundance is high and relief is more. In plains, although the abundance is less the distribution is uniform.

The profiles parallel to the latitudes were found to indicate more ruggedness of the sea floor in comparison (Figs. 1 B–D) with profiles parallel to the longitude (Fig. 1 A). Such areas may be associated with some structural trend, and they also show irregular microtopographic character. The nodule coverage in such areas is variable. Areas with some bathymetric relief but lacking in ruggedness of local topography contain lower but more uniform nodule abundance.

The formation of manganese nodules is dependant primarily on existence of a solid substrate (seed) in an oxidised environment (Horn and others 1973). The nodules accrete around nuclei composed of rock fragments, palagonite, fragmented nodules, sediment clasts,

**Table 1.** Nodule Recovery, Abundance, and Chemical Analyses at Different Stations

Station no.	Recovery efficiency (%)	Nodule abundance (Kg/m <sup>2</sup> )	Average (No. of assays)	Mn (%)	Fe (%)	Co (%)	Ni (%)	Cu (%)	H <sub>2</sub> O (%)	Ni + Cu + Co (%)	Mn/Fe
V1	71	9.85	7	27.98	7.37	.13	.97	1.11	18.11	2.21	3.96
V2	80	6.35	8	28.32	7.42	.14	1.02	1.17	17.13	2.33	4.05
V3	100	6.31	7	21.97	10.37	.17	.78	.66	19.12	1.61	2.18
V4	71	1.85	3	32.81	5.69	.11	1.09	1.38	18.07	2.08	6.01
V5	00	—					no sample				
V6	57.14	9.42	6	21.91	13.22	.21	.68	.49	21.38	1.39	1.67
V7	80	8.65	8	25.51	9.61	.17	.95	.89	19.06	2.01	2.8
V8	75	14.55	6	20.32	10.89	.17	.72	.51	18.08	1.4	1.87
V9	100	7.5	8	25.74	8.52	.15	.9	.95	17.9	2.0	3.36
V10	85.7	8.14	10	21.79	10.15	.15	.76	.7	18.62	1.69	2.49
V11	00.0	—					no sample				
V12	50	3.85	3	25.4	8.93	.15	.94	1.16	18.42	2.25	2.91
V13	75	1.0	2	29.77	6.85	.14	1.0	1.14	14.25	2.28	4.45
V14	75	2.3	5	29.27	7.29	.13	.96	1.18	17.38	2.28	4.10
V15	71	15.84	8	20.68	16.14	.25	.45	.32	22.75	1.02	1.27
V16	42.85	03.85	6	23.6	8.5	.14	.85	.8	16.75	1.79	3.05

shark tooth, etc. Abyssal sedimentation also has influence on nodule development. Rapid sedimentation reduces nodule growth by burying nodules and potential nuclei. The sediment thickness which varies considerably over short distances is also influenced by bathymetric relief (Johnson 1972).

Sediment transport from abyssal hills to adjacent valleys increases sedimentation rates, thus decreasing the rate of nodule development in low lying areas. Slow deposition rates bring forth rapid nodule development in and around hill flanks and crests, which explains the higher abundance in these regions.

#### *Metal Content in Nodules*

Table 1 gives the bulk chemical composition of the manganese nodules. These analyses were carried out using standard Atomic absorption spectrophotometer methods. Nodules were chosen for analyses as a representative in shape, size, and morphology for the particular grab sample. The bulk chemical compositions represent the compositional trends, but variations in chemistry for internal chemical layers and size and morphology cannot be studied (Halbach and others 1975). Some known correlations exist between transition elements composing nodules in world Ocean. According to Cronan (1972) there is a direct relationship between Manganese and Cu+Ni content. Fe shows positive correlation with cobalt content and inverse correlation to Mn, Cu, and Ni. Mn/Fe ratio is also an indicator in the chemical variability of nodules.

Chemical analyses of nodules (Table 1) shows great variability in composition in spite of stations being quite close to each other. Generally it is observed that Mn-Ni and Fe-Co have direct relationship. Mn/Fe

ranges from 1.2 to 4.45, only one station average is 6.01. According to the genetic classification of polymetallic nodules based on the Mn/Fe ratio and Cu+Ni+Co content, deep-sea nodules are of "hydrogenous" origin if the Mn/Fe ratio is in the range of 0.5-5.1 and there is high Cu+Ni+Co content (Bonatti and others 1972). At places such as the spreading centers and near the submarine volcanoes, resulting deposits are "hydrothermal." Such deposits have Mn/Fe ratio less than 0.5 and low Cu+Co+Ni levels. Obviously, all the samples collected and analyzed during the present study fall in the "hydrogenous deposit" class.

**Table 2.** Nodule Abundance From Different Grabs Lowered at Stations From Rugged Terrains and Plains

Station no.	Regions of rugged topography:		Station no.	Regions of plain topography:	
	Free fall grab	Abundance (Kg/m <sup>2</sup> )		Free fall grab	Abundance (Kg/m <sup>2</sup> )
V3	A	10.0	V4	A	03.87
	B	15.38		B	0.00
	C	15.38		C	00.92
	D	0.77		D	04.62
	E	0.62		E	00.77
V8	A	16.00	V9	F	00.92
	B	16.00		G	04.62
	C	0.0		A	03.85
V15	D	11.54	B	03.85	
	A	16.77	C	04.00	
	B	00.00	D	09.70	
	C	27.69	V13	A	01.55
	D	00.00		B	02.46
	E	24.23		C	02.46
	F	08.46		D	00.00
G	01.08				

The varying chemical composition is related to nodule size and/or to morphology (Halbach and others 1975). From this study it is observed that the diversity in chemistry can also be due to the combination of geochemical processes acting in different bathymetric settings. The Mn/Fe ratio is comparatively higher in stations set in a plain topographic terrain (stations V4, V9, and V13). Among these, the station V4 has maximum Mn/Fe ratio of 6.01. These stations also report high Mn and Ni (1.09, 0.9, and 1.0, respectively). Stations V3, V8, and V15 lie on regions of rugged topography and report low Mn/Fe ratio of 2.18, 1.87, 1.27, respectively, which is much less in comparison to area from plain terrain. Also, these stations report high cobalt (.17, .17, and .25) and high Fe content. The direct relationship between Mn and Cu+Ni and Fe-Co content as established by Burns and Fuestenau (1966) and Cronan (1972) is vindicated in the Central Indian Ocean also.

### Conclusions

1. Polymetallic nodule abundance has direct relationship with bathymetric relief. The more relief, the higher the abundance will be. Both regional and local topography have direct bearing on nodule abundance.
2. Distribution of nodules is patchy in areas of high relief and uniform in plains.
3. Sea floor topography as seen in profiles parallel to latitude is more rugged compared to that in profiles parallel to longitude. Regions where few minor faults are identified (Fig. 2 C) yield higher abundance of nodules.
4. Nodules from plains have high Mn/Fe, Mn, Ni whereas those from rugged regions have high Fe, Co but low Mn, Ni and Mn/Fe.

### Acknowledgments

The author is grateful to late H. N. Siddiqui, former Director, National Institute of Oceanography, Goa, for his encouragement and guidance. Thanks are also due to B. N. Desai, Director and P. S. N. Murthy, Head of Geological Oceanography Division, for encouragement and facilities extended. Critical comments by R. R. Nair, Project leader are also acknowledged. The chemical data is taken from the NIO(PMN) data bank. Financial assistance was provided by the Department of Ocean Development under the program of 'Surveys for Polymetallic Nodules.'

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Manuscript received 12 November 1987; revision received 10 May 1988.