RELATION BETWEEN GRADE AND ABUNDANCE OF MANGANESE NODULES

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ONE of the important but controversial problems in manganese nodules is the apparent relation between nodule grade (Ni + Cu) and nodule abundance (wet kg/m^2). Considerable work has been carried out to relate the grade and abundance of nodule deposits from the Pacific Ocean by calculating correlation coefficients for different data sets (table 1). However, the data are sparse on Indian Ocean nodules and the published work was based on a limited number of samples.

Data from more than 1000 locations in the Central Indian Ocean Basin (CIOB) where both bulk nodule chemistry and abundance were determined and utilized to study the relationship between grade and abundance of manganese nodule deposits. Grade is expressed as percentage nickel plus percentage copper (by weight), whereas the abundance of nodules on the seafloor is expressed as kg/m^2. At each station 5–7 freefall grabs were deployed and

Table 1 *Details of published work on grade (Ni + Cu) and abundance relationship of nodule deposits (Pacific/Indian Ocean)*

Reference	Area investigated	No. of samples	Correlation coefficients	Remarks
3	Pacific area between 4° to 10°N and 164° to 175°W		$r = -0.75$ at 80% C.L.	
2	Pacific Ocean as a whole	182	$r = -0.40$ at 99.9% C.L.	
2	Near 11°S 156°W, an area in Pacific	13	$r = -0.81$ at 99.9% C.L.	
2	Near 11°N 153°W, an area in Pacific	10	$r = -0.84$ at 99.9% C.L.	
4	Pacific as a whole	256	$r = -0.43$ at 99.9% C.L.	
4	Area between Clarion and Clipperton fracture zones		$r = -0.47$ at 99.9% C.L.	Weighted data set
5	Indian Ocean	25	$r = -0.40$	

Table 2 *Correlation coefficients matrix for chemical variables and nodule abundance*

	Abundance	Grade (Ni + Cu)	Mn/Fe	Cu	Ni
Ni	− 0.46	0.95	0.58	0.84	1.00
Cu	− 0.54	0.97	0.79	1.00	
Mn/Fe	− 0.54	0.72	1.00		
Grade (Ni + Cu)	− 0.52	1.00			

$n = 435$; All the values are significant at 99.9% L.O.S.

the nodule recoveries in the samples were averaged arithmetically to arrive at an abundance value for that station. Similarly, samples $> 0.5\ kg/m^2$ abundance were analysed for bulk chemistry and an average grade value (Ni + Cu) for the station is arrived at.

Individual locations of samples amount to > 1000, whereas the number of stations amount to 435. Correlation coefficients were calculated between chemical variables and abundance (table 2).

Studies carried out on CIOB nodule deposits reveal that the nodule abundances are reported more on hilltops and slopes compared to valleys and plains[1]. Supporting studies on Mn/Fe ratios show that the average Mn/Fe ratios on different topographic domains viz. hilltops (average = 2.1), slopes (average = 3.2), valleys (average = 2.9) and plains (average = 4.3), and between abundance and grade

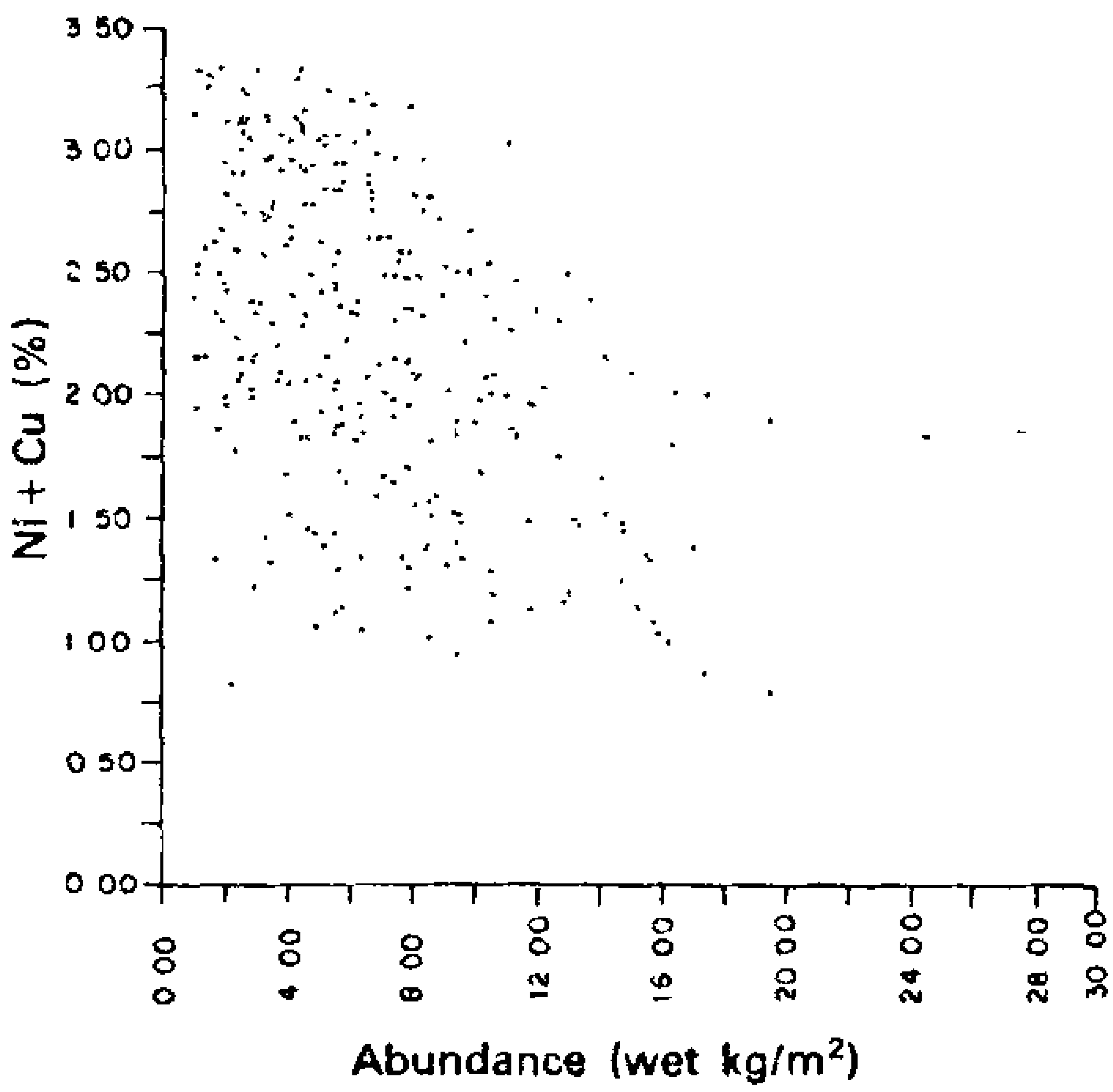

Figure 1. Scatter diagram showing the relation between abundance (wet kg/m^2) and grade (% Ni + % Cu) in nodules.

since the grade show strong positive relation with Mn/Fe ratio.

The assumption that grade and abundance are independent can cause a considerable overestimation of nodule resources[2]. The correlation coefficients (table 2) calculated on different data sets show that the inverse relation between grade and abundance holds good both regionally and locally (figure 1). Weak coefficients which are statistically significant at the 99.9% confidence level may be due to the mixed population considered in the data set. Considering the disposition and distribution of nodules on seafloor with different chemical compositions, the inverse relation may be proved universal for the world oceans.

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AZIMUTHAL RATIO TECHNIQUE OF INTERPRETING RADIAL SOUNDINGS

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VERTICAL electrical resistivity soundings (VES) are generally employed to obtain subsurface information regarding horizontal and vertical discontinuities is an area of interest. To detect the anisotropy of formations, radial soundings are carried out at a given station by obtaining VES data in two or more electrode spread directions (azimuths). The radial sounding data are normally interpreted by plotting the measured apparent resistivity values, using a suitable scale, obtained for the different azimuths on the respective axes and then joining the points obtained for the same current electrode separations, to get the polar diagram. The direction of elongation of the polar diagram indicates the direction of anisotropy, when present. In several polar diagrams it was observed that the direction of elongation changes from one azimuth to another with expanding current electrode separations, rendering the interpretation of such data difficult and ambiguous. In a few cases, the change of direction is so abrupt that the lines in the polar diagram cut across each other, thus making the interpretation almost impossible.

Extensive field investigations were carried out to study these aspects in areas having geological controls. It was observed that the abrupt change in the direction of elongation occurs due to the presence of lateral inhomogeneities or anisotropies other than textural or structural. A new method of presenting and interpreting the geoelectric radial sounding data is suggested in this paper.

The azimuthal ratios are obtained by determining the ratios of apparent resistivity values for corresponding current electrode separations ($\bar{A}\bar{B}/2$) of any two azimuths, (α, β) preferably perpendicular to

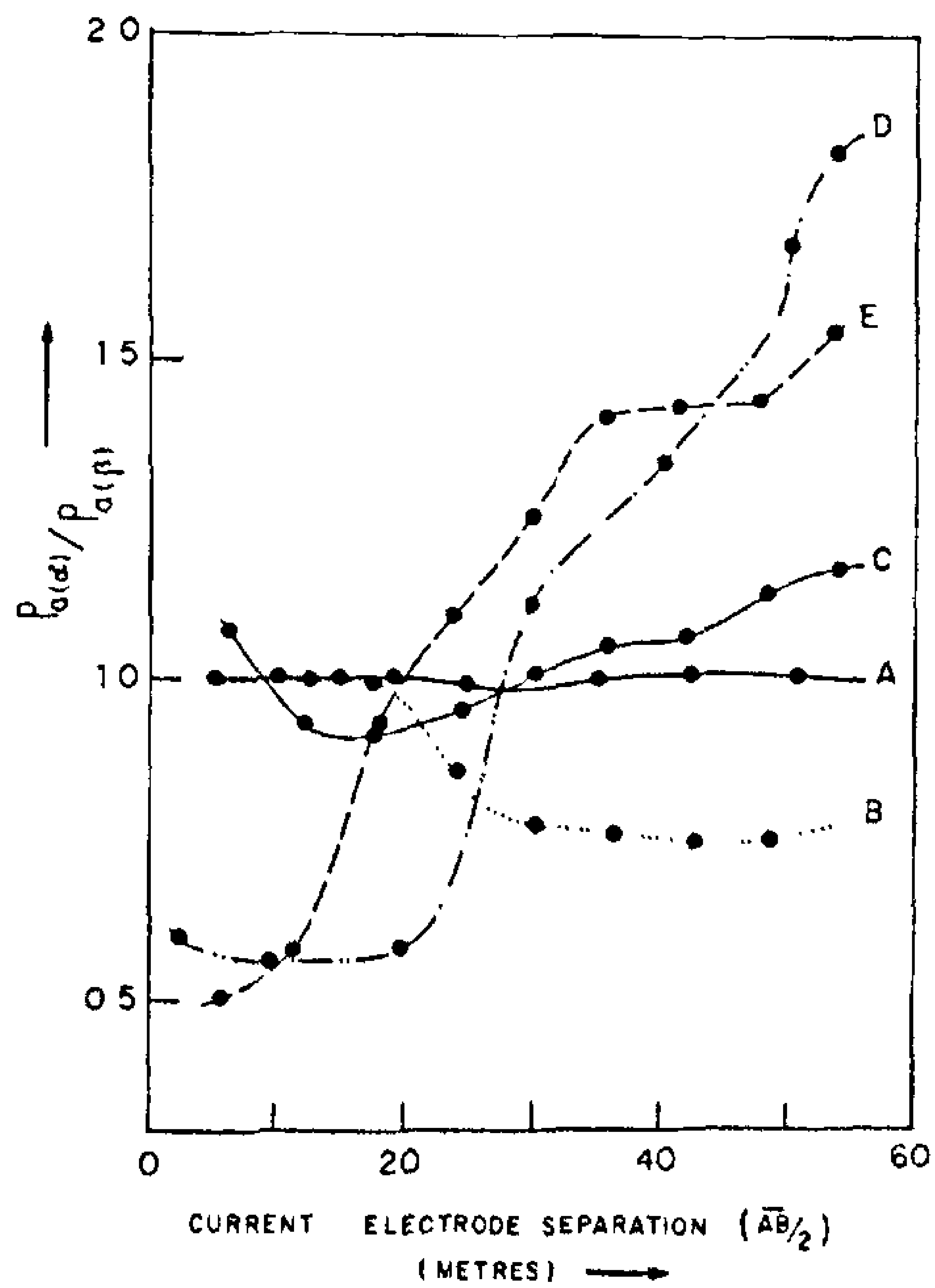

Figure 1. Azimuthal ratio graphs for some of the geological conditions.