Metal content of manganese nodules in part of the

southeastern equatorial Pacific

By

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Under the terms being considered by the Third United Nations Law

of the Sea Conference, several groups of islands in the southeastern

equatorial Pacific would someday have jurisdiction over seabed

resources within an adjacent 200-mile Exclusive Economic Zone.

Scattered data have suggested (Piper and Williamson, 1977) that this

area contains nodules rich in nickel and copper. Therefore, we were

interested in examining the publicly available information on

the manganese nodules of this region. For this purpose, we used

sample data kindly supplied by Jane Z. Frazer from the Scripps Institu-

tion of Oceanography data bank. We examined data for the area bounded

by lat. 0° and 35°S. and long. 120° and 160°W. (fig. 1).

Nickel and copper analyses of manganese nodules in the Scripps

bank are available at only 146 stations within this region of some

16.5 million square kilometers. From such sparse data, no firm

conclusions may be drawn as to the magnitude or distribution of

potentially recoverable resources, but a few generalizations can be

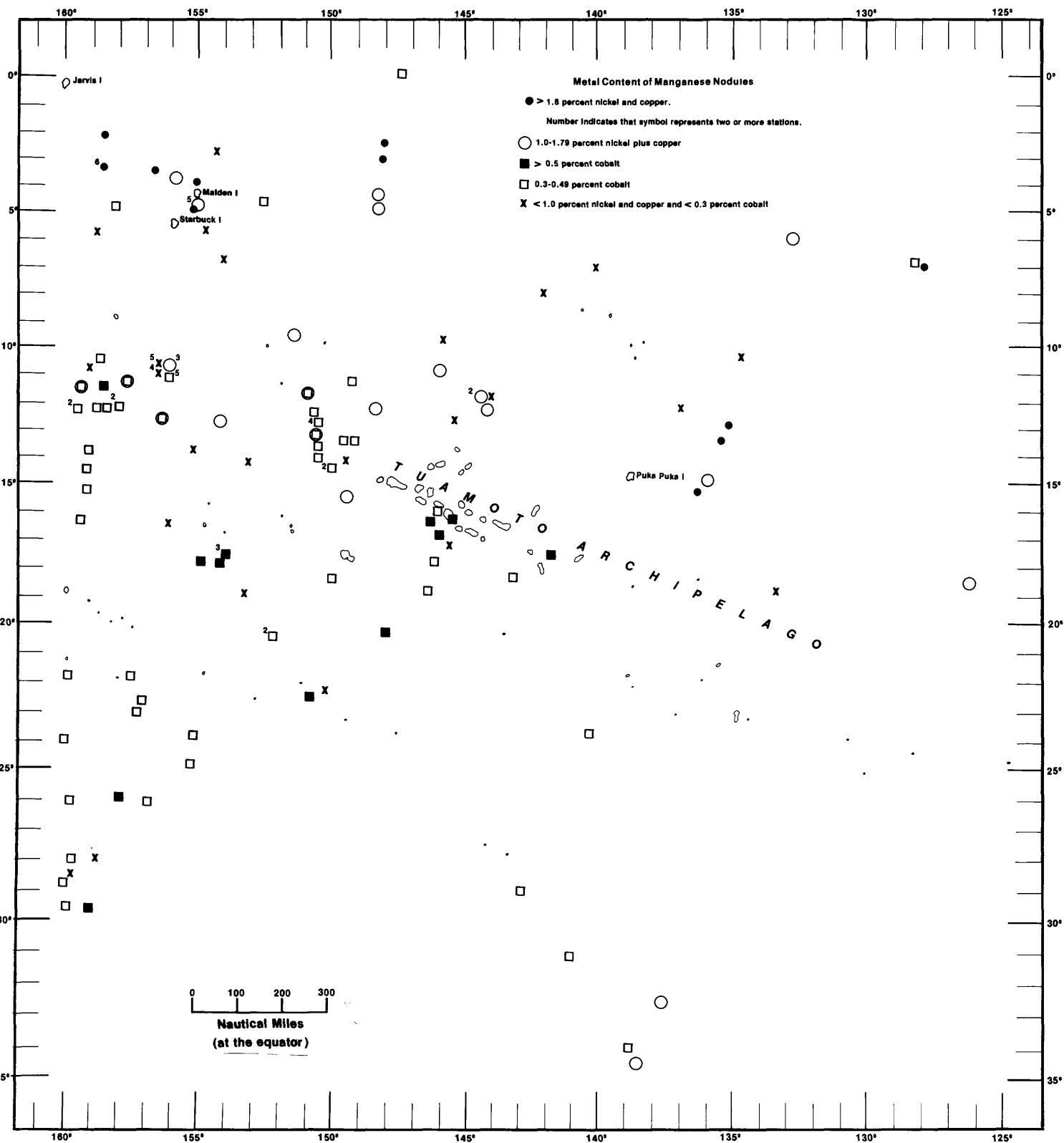made that may be helpful in appraising the possibilities.

Figure 1. Nickel plus copper and cobalt contents of manganese nodules in the southeastern equatorial Pacific.

The data on metal content for all samples available within the region are summarized in table 1. Although the analyses show that the samples have a wide range in composition, they may be grouped into three categories:

1) those rich in nickel and copper, 2) those rich in cobalt, and
3) those not rich in nickel, copper, or cobalt. As shown in both figures 1 and 2, the relation between high nickel plus copper and high cobalt contents is antithetic.
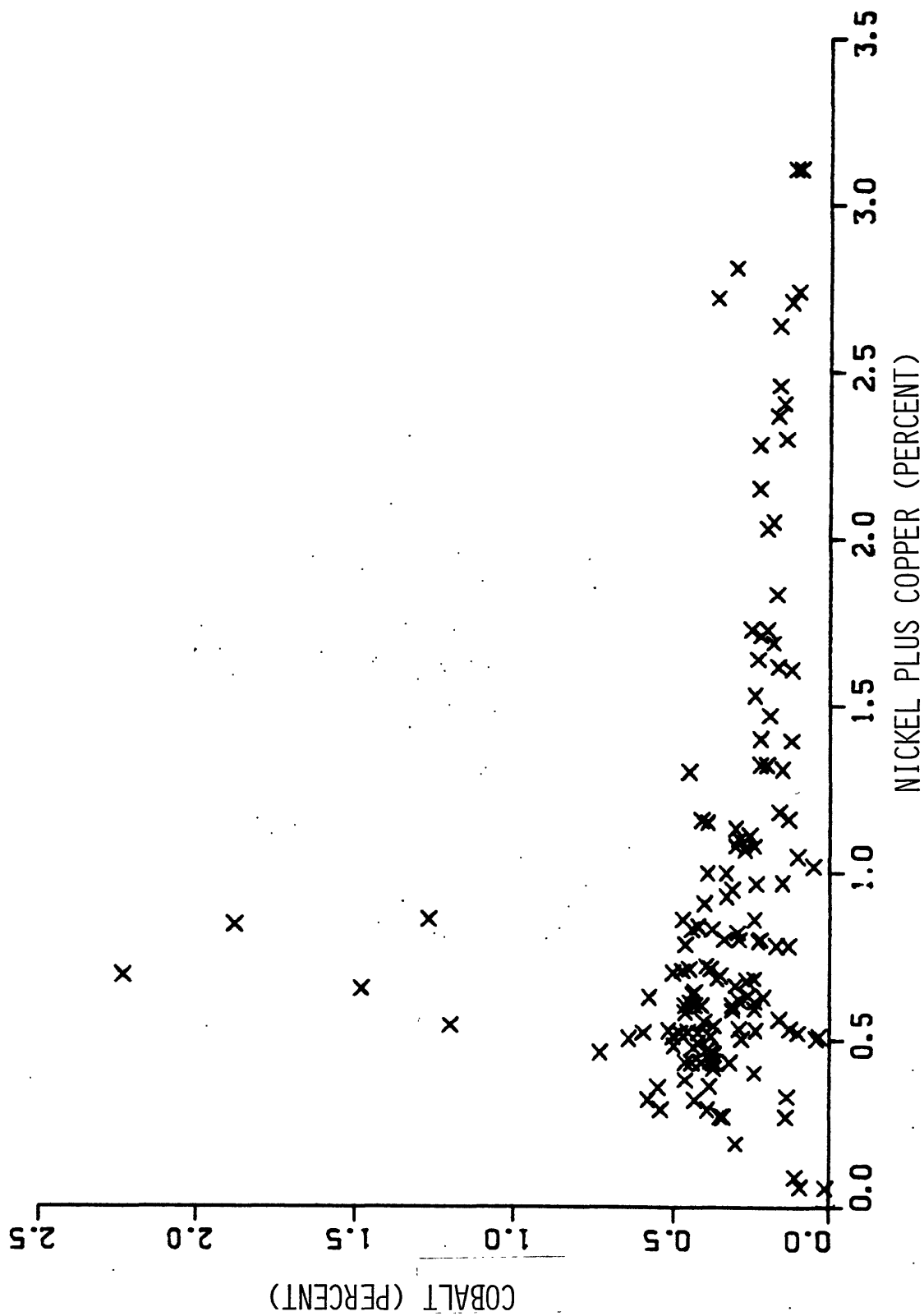
Figure 2.--Graph showing the antithetic relation between high cobalt (>0.5 percent) and high nickel plus copper (>1.0 percent) contents in manganese nodules of the southeastern equatorial Pacific.

TABLE 1

Metal content (percent), nodule concentration (kg/m^2), water depth (m), and metal ratios of manganese nodules from stations in the southeastern equatorial Pacific

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	146	17.6	0.21-33.6	6.0	
Fe	148	13.7	2.2-31.2	4.6	
Ni	146	0.57	0.02-1.8	0.36	
Cu	146	0.37	0.01-1.54	0.33	
Ni+Cu	146	0.94	0.05-3.11	0.67	
Co	144	0.35	0.01-2.23	0.29	
Pb	86	0.09	0.01-0.46	0.08	
Zn	72	0.10	0.015-1.51	0.18	
Concentration	33	16.4	0.18-39.5	11.0	
Depth	147	4458	807-5438	1101	
Mn/Fe	146	1.53*	0.02-6.00	1.13	-0.24**
Ni/Mn	144	0.033*	0.006-0.095	0.017	0.69**
Cu/Mn	144	0.021*	0.002-0.167	0.019	0.67**
Cu/Ni	146	0.61*	0.083-1.75	0.26	0.87**
(Ni+Cu)/Mn	144	0.055*	0.007-0.262	0.033	0.70**
(Ni+Cu)/Fe	146	0.094*	.005-.576	0.111	-.61**
Co/Mn	142	0.021*	0.003-0.071	0.014	0.24**
Co/Fe	144	.026*	.001-.174	.021	0.27**
Co/(Ni+Cu)	144	.587*	.029-3.232	.538	-0.26**
Depth vs. (Ni+Cu)	144	——	————	——	0.025
Depth vs. Co	142	——	————	——	-0.58

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

Nodules rich in nickel and copper

It is generally agreed that manganese nodule deposits must contain at least 1.8 percent nickel plus copper to be of commercial interest in first generation mining. Nodules of this or better quality have been found at 16 localities within the region, ten of them clustered in an area between Jarvis Island and Starbuck and Malden Islands. All 16 localities are between lat. 2° and 16°S. and are within 200 miles of one of the islands shown in figure 1. Three of the localities are in an area east of Puka Puka Island, and part of that area is within its 200-mile zone. Unfortunately no data are available on the concentration of nodules containing more than 1.8 percent nickel plus copper, but the 16 localities are within the areas broadly characterized by Cronan (1977) as containing intermediate to extensive nodule concentrations.

The metal contents and other data for these samples are summarized in table 2. As may be seen from table 3, which shows average metal contents of manganese nodules from other subsea environments and areas, the South Pacific nodules rich in nickel and copper are almost identical to those of the Clarion-Clipperton prime area in the northeast equatorial Pacific, not only in their nickel and copper contents, but also in their manganese, iron, and cobalt contents.

TABLE 2

Metal content (percent) and metal ratios of nodules containing 1.8 percent or more nickel plus copper. The nodules are from the southeastern equatorial Pacific. No data on concentration of nodules were available.

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	16	27.77	14.02-32.40	4.95	
Fe	16	7.54	5.30-11.74	2.05	
Ni	16	1.31	1.00-1.80	0.26	
Cu	16	1.17	0.74-1.54	0.22	
Ni+Cu	16	2.48	1.83-3.11	0.38	
Co	16	.18	0.09-0.36	0.07	
Depth	16	4885	4138-5175	310	
Mn/Fe	16	4.02*	1.60-6.00	1.43	-0.66**
Ni/Mn	16	0.05*	0.04-0.08	-.01	0.28**
Cu/Mn	16	0.04*	0.03-0.07	0.01	0.70**
Cu/Ni	16	0.91*	0.51-1.21	0.20	0.22**
(Ni+Cu)/Mn	16	0.09*	0.07-0.15	0.02	0.60**
(Ni+Cu/Fe	16	0.36*	0.16-0.58	0.12	-0.49**
Co/Fe	16	0.02*	0.01-0.06	0.01	0.05**
Co/Mn	16	0.007*	0.003-.012	0.003	0.08**
Co/(Ni+Cu)	16	0.07*	0.03-0.13	0.03	-0.17**
Depth vs. (Ni+Cu)	16	——	———	——	0.08
Depth vs. Co	16	——	———	——	0.04

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

TABLE 3

Average metal content of manganese nodules from various environments and areas

	World [1]	Seamounts [1]	Abyssal [1]	Clarion-Clipperton area [2]	Southeastern equatorial Pacific [3]	
					Ni+Cu 1.8%	Co 0.3
Mn	16.17	14.62	16.78	25.43	27.77	17.5
Fe	15.61	15.81	17.27	6.66	7.54	15.6
Ni	0.49	0.35	0.54	1.27	1.31	0.45
Cu	0.26	0.06	0.37	1.02	1.17	0.24
Co	0.3	1.15	0.26	0.22	0.18	0.49

[1] Cronan (1977)

[2] McKelvey, Wright, and Rowland (1979)

[3] this study

Twenty-nine samples from the southeastern equatorial Pacific region contain 1.0-1.79 percent nickel plus copper (table 4). For the most part, these localities are adjacent to others containing less than 1 percent nickel plus copper, but all except three of them are north of lat. 16°S.

TABLE 4

Metal content (percent), nodule concentration (kg/m^2), water depth (m), and metal ratios of manganese nodules containing 1.0 - 1.79 percent nickel plus copper. The nodules are from the southeastern equatorial Pacific.

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	28	18.2	8.2-22.8	3.3	
Fe	29	10.9	6.4-14.5	2.1	
Ni	29	0.81	0.46-1.18	0.18	
Cu	29	0.54	0.39-0.77	0.11	
Ni+Cu	29	1.36	1.02-1.73	0.25	
Co	28	0.23	0.05-0.45	0.10	
Concentration	7	4.80	0.18-12.40	4.20	
Depth	28	5006	4346-5340	255	
Mn/Fe	28	1.74*	0.67-2.99	0.52	0.06**
Ni/Mn	28	0.046*	0.027-0.083	0.013	0.19**
Cu/Mn	28	0.031*	0.020-0.068	0.011	-.041**
Cu/Ni	29	0.69*	0.39-1.22	0.18	0.42**
(Ni+Cu)/Mn	28	0.078*	0.054-.0124	0.021	0.12**
(Ni+Cu)/Fe	29	0.133*	0.085-.0270	0.051	-0.49**
Co/Mn	27	0.013*	0.005-0.024	0.005	0.50**
Co/Fe	28	0.021*	0.004-0.034	0.008	0.48**
Co/(Ni+Cu)	28	0.177*	0.049-.0355	0.086	-0.11**
Depth vs (Ni+Cu)	28	——	————	——	-0.24
Depth vs Co	27	——	————	——	0.05

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

Nodules enriched in cobalt

Only one of the samples containing more than 1.8 percent nickel plus copper and only four of those containing 1.0-1.8 percent nickel plus copper contain more than 0.3 percent cobalt. Nodules from most of the localities for which analyses are available in the region south of the areas containing nodules rich in nickel plus copper, however, contain more than 0.3 percent cobalt, and some contain more than 1 percent. The metal content and other data on samples containing 0.3-0.49 percent and 0.5 percent or more cobalt are summarized in tables 5 and 6.

The region within which the nodules are enriched in cobalt contains many seamounts and ridges associated with the archipelagic islands, and many of the cobalt-enriched samples are from such features. As may be seen from table 3, these nodules are generally similar in composition to those found elsewhere on seamounts, plateaus, and ridges.

TABLE 5

Metal content (percent), water depth (m), and metal ratios of manganese nodules containing 0.5 percent or more cobalt. The nodules are from the southeastern equatorial Pacific. No data on concentration of nodules were available.

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	15	18.8	8.1-31.8	6.3	
Fe	15	15.8	12.8-18.2	2.1	
Ni	15	0.4	0.2-0.7	0.1	
Cu	15	0.15	0.07-0.3	0.08	
Ni+Cu	15	0.56	0.29-0.86	0.17	
Co	15	0.92	0.50-2.23	0.56	
Depth	15	2871	807-5338	1785	
Mn/Fe	15	1.23*	0.60-2.48	0.53	-0.36**
Ni/Mn	15	0.02*	0.01-0.03	0.00	0.89**
Cu/Mn	15	0.009*	0.002-0.019	0.005	0.05**
Cu/Ni	15	0.41*	0.11-0.84	0.22	0.06**
(Ni+Cu)/Mn	15	0.031*	0.022-0.042	0.006	0.80**
(Ni+Cu)/Fe	15	0.04*	0.02-0.06	0.01	-0.26**
Co/Mn	15	0.047*	0.024-0.071	0.016	0.85**
Co/Fe	15	0.06*	0.03-0.17	0.04	-0.43**
Co/(Ni+Cu)	15	1.62*	0.71-3.23	0.67	0.64**
Depth vs (Ni+Cu)	15	----	-----------	----	-0.49
Depth vs Co	15	----	-----------	----	-0.61

*   The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

TABLE 6

Metal content (percent), nodule concentration (kg/m^2), water depth (m), and metal ratios of manganese nodules containing 0.3-0.49 percent cobalt. The nodules are from the southeastern equatorial Pacific.

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	58	17.0	7.9-31.6	3.3	
Fe	58	15.9	5.6-26.6	3.6	
Ni	58	0.44	0.12-1.42	0.22	
Cu	58	0.24	0.08-1.30	0.170	
Ni+Cu	58	0.68	0.27-2.70	0.38	
Co	58	0.40	0.31-0.50	0.05	
Concentration	15	20.0	2.1-35.6	10.0	
Depth	56	4501	1175-5438	943	
Mn/Fe	58	1.14*	0.55-3.95	0.46	0.04**
Ni/Mn	58	0.026*	0.007-0.058	0.011	0.59**
Cu/Mn	58	0.013*	0.006-0.041	0.006	0.71**
Cu/Ni	58	0.550*	0.136-1.420	0.190	0.83**
(Ni+Cu)/Mn	58	0.039*	0.017-0.086	0.016	0.67**
(Ni+Cu)/Fe	58	0.049*	0.014-0.340	0.047	-0.45**
Co/Mn	58	0.025*	0.011-0.054	0.007	-0.03**
Co/Fe	58	0.027*	0.016-0.077	0.010	0.06**
Co/(Ni+Cu)	58	0.717*	0.132-1.345	0.293	-0.09**
Depth vs (Ni+Cu)	56	----	-----------	----	0.11
Depth vs Co	56	----	-----------	----	-0.38

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

Nodules not rich in nickel, copper, or cobalt

Localities at which manganese nodules contain less than

1 percent nickel plus copper and less than 0.3 percent cobalt are

only 22 percent of the localities in the region for which analyses

were available. They appear to be randomly distributed.

Their characteristics are summarized in table 7.

TABLE 7

Metal content (percent), nodule concentration (kg/m^2), water depth (m), and metal ratios of manganese nodules containing <1.0 percent nickel plus copper and <0.3 percent cobalt. The nodules are from the southeastern equatorial Pacific

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	31	12.87	0.21-20.27	4.85	
Fe	32	14.2	2.2-31.2	5.4	
Ni	32	0.38	0.02-0.87	0.19	
Cu	32	0.19	0.01-0.37	0.10	
Ni+Cu	32	0.57	0.055-0.970	0.240	
Co	32	0.20	0.01-0.30	0.08	
Concentration	11	18.7	2.4-39.5	10.8	
Depth	32	4541	1200.5300	895	
Mn/Fe	31	0.96*	0.024-2.910	0.490	0.38**
Ni/Mn	31	0.034*	0.006-0.095	0.020	0.60**
Cu/Mn	31	0.021*	0.002-0.167	0.029	0.49**
Cu/Ni	32	0.586*	0.083-1.750	0.315	0.40**
(Ni+Cu)/Mn	31	0.055*	0.007-0.262	0.045	0.66**
(Ni+Cu)/Fe	32	0.044*	0.005-0.139	0.026	0.07**
Co/Mn	31	0.017*	0.004-0.048	0.010	0.68**
Co/Fe	32	0.015*	0.001-0.041	0.008	0.41**
Co/(Ni+Cu)	32	0.437*	0.059-1.579	0.356	0.48**
Depth vs (Ni+Cu)	32	----	--------	----	0.48
Depth vs Co	31	----	--------	----	0.28

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

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Factors influencing variations of nodule composition

The southeastern equatorial Pacific nodules examined here show interesting relationships in their composition and distribution. As shown in table 1, the nickel and copper contents of the nodules show a strong positive correlation with each other, a moderately strong positive correlation with manganese, a moderately strong negative correlation with iron, and a weak negative correlation with cobalt. In contrast, cobalt shows a weak positive correlation with iron. As may be seen from figure 1, areas containing nodules rich in nickel plus copper are distinct from those containing nodules rich in cobalt, except for a transitional area in the western part of the region between lat. 11° and 13°S. in which nodules contain more than 0.3 percent cobalt and more than 1 percent nickel plus copper.

The latitudinal control on the metal contents of the nodules is also seen in tables 8 and 9, which show that all the samples in the region north of lat. 16°S. average 1.12 percent nickel plus copper and 0.27 percent cobalt, whereas all the samples south of lat. 16°S. average only 0.57 percent nickel plus copper and 0.52 percent cobalt.

TABLE 8

Metal content (percent), nodule concentration (kg/m²), water depth (m), and metal ratios of manganese nodules from the southeastern equatorial Pacific between lat. 0° and 16°S.

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	98	18.29	0.21-33.60	6.28	
Fe	100	12.3	5.3-31.2	4.2	
Ni	99	0.66	0.02-1.80	0.37	
Cu	99	0.46	0.02-1.54	0.37	
Ni+Cu	99	1.12	0.06-3.11	0.72	
Co	97	0.27	0.01-0.55	0.12	
Concentration	24	14.6	0.2-32.1	9.5	
Depth	98	4758	1175-5393	734	
Mn/Fe	98	1.80*	0.02-6.00	1.30	-0.35**
Ni/Mn	97	0.037*	0.006-0.095	0.016	0.74**
Cu/Mn	97	0.026*	0.002-0.167	0.021	0.77**
Cu/Ni	99	0.66*	0.083-1.750	0.250	0.89**
(Ni+Cu)/Mn	97	0.063*	0.007-0.262	0.035	0.78**
(Ni+Cu)/Fe	99	0.121*	0.005-0.576	0.125	-0.65**
Co/Mn	95	0.017*	0.003-0.054	0.010	-0.57**
Co/(Ni+Cu)	97	0.377*	0.029-1.530	0.309	-0.41**
Co/Fe	97	0.023*	0.001-0.077	0.010	0.49**
Depth vs (Ni+Cu)	97	———	———————	———	0.22
Depts vs Co	95	———	———————	———	-0.23

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

TABLE 9

Metal content (percent), nodule concentration (kg/m²), water depth (m), and metal ratios of manganese nodules from the southeastern equatorial Pacific between lat. 16° and 35°S.

Variable	No. stations	Mean	Range	Standard deviation	Correlation coefficient
Mn	48	16.1	2.3-31.8	5.0	
Fe	48	16.6	2.2-26.6	4.0	
Ni	47	0.40	0.05-1.18	0.23	
Cu	47	0.17	0.01-0.55	0.10	
Ni+Cu	47	0.57	0.06-1.73	0.30	
Co	47	0.52	0.04-2.23	0.43	
Concentration	9	21.0	2.1-39.5	14.0	
Depth	49	3858	807-5438	1431	
Mn/Fe	48	1.01*	0.44-2.48	0.39	0.25**
Ni/Mn	47	0.025*	0.007-0.083	0.014	0.46**
Cu/Mn	47	0.011*	0.002-0.038	0.006	0.20**
Cu/Ni	47	0.500*	0.113-1.417	0.258	0.67**
(Ni+Cu)/Mn	47	0.036*	0.017-0.121	0.019	0.41**
(Ni+Cu)/Fe	47	0.037*	0.009-0.072	0.023	-0.043**
Co/Mn	47	0.030*	0.007-0.071	0.016	0.76**
Co/(Ni+Cu)	47	1.020*	0.080-3.230	0.650	0.127**
Co/Fe	47	0.034*	0.004-0.174	0.032	-0.095**
Depth vs (Ni+Cu)	47	——	————	——	0.029
Depth vs Co	47	——	————	——	-0.61

* The mean of the ratios between the respective metals. The ratios between the means may be easily calculated from the data above

** Correlation between the respective metals

The previously observed (Cronan and Toombs, 1969) positive correlation of nickel and copper with depth and the negative correlation of cobalt with depth are confirmed for the samples from this region (see figs. 3 and 4), but with a modification. Rather than a linear correlation of grade with depth, figs. 3 and 4 show two overlapping populations related to a grade-depth cutoff for both nickel plus copper and cobalt; within each population, grade and depth are only weakly correlated. Thus, nodules containing more than 1 percent nickel plus copper occur only at depths greater than about 4300 m. However, the nodules at depths greater than 4300 m have nickel-plus-copper-versus-depth correlation coefficients of only 0.007 (113 stations); the nodules having nickel plus copper contents of less than 1 percent have nickel-plus-copper-versus-depth correlation coefficients of only 0.111 (100 stations). For cobalt, nodules containing 0.75 percent or more occur only at depths less than 1800 m. However, nodules at depths less than 1800 m have cobalt-versus-depth correlation coefficients of only -0.19 (10 stations); nodules containing less than 0.75 percent cobalt have cobalt-versus-depth correlation coefficients of only -0.26 (137 stations).
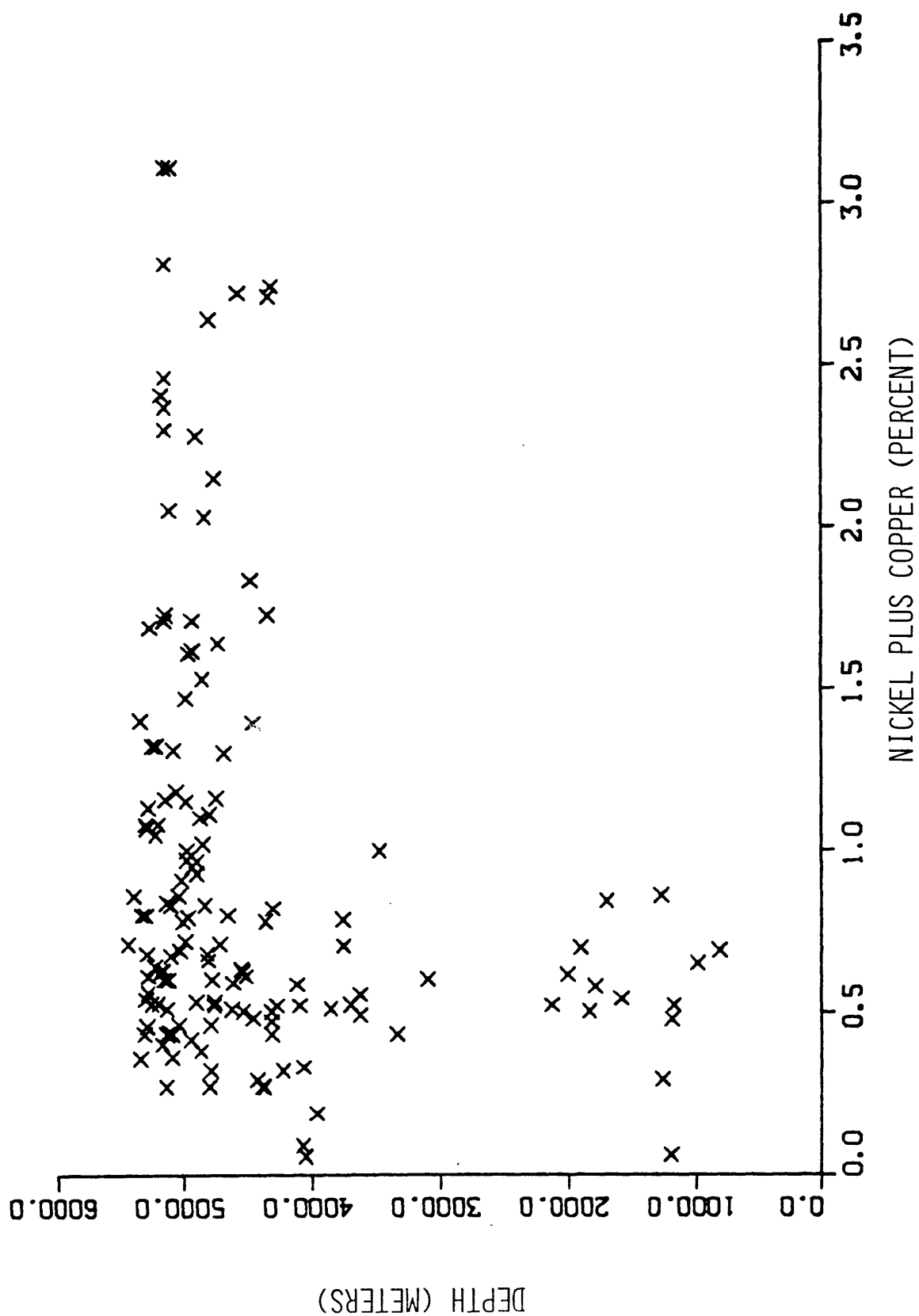
Figure 3.—Relation between water depth and nickel plus copper content of manganese from the southeastern equatorial Pacific.
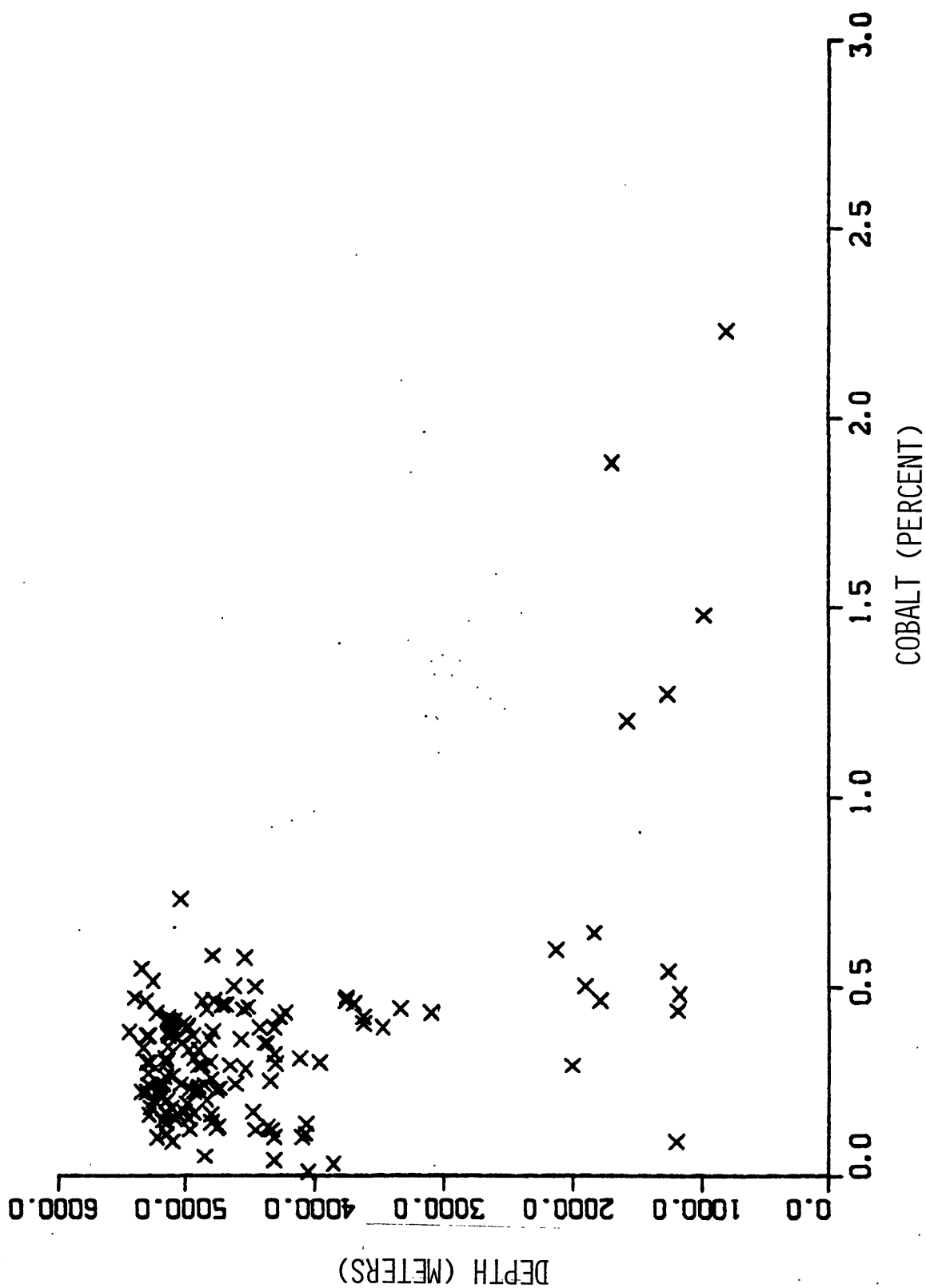
Figure 4.—Relation between water depth and cobalt content of manganese nodules from the southeastern equatorial Pacific.

Conclusions

Even though the publicly available data on the manganese nodules of the southeastern equatorial Pacific are sparse, they suggest that deposits containing more than 1.8 percent nickel plus copper may be present in places north of lat. 16°S. including some within 200 miles of islands in the Line, Marquesas, and Tuamoto groups. The area between Jarvis Island and Starbuck and Malden Islands and that east of Puka Puka Island seem to have some potential for such deposits, but additional samples are required to determine whether deposits there or elsewhere within the region are minable. Even if minable deposits do exist, they seem unlikely to be as extensive as those of the Clarion-Clipperton prime area in the northeastern equatorial Pacific.

Nodules in the southern part of the region shown in fig. 1 are somewhat enriched in cobalt but contain less than 1 percent nickel plus copper. A few localities are known where the cobalt content exceeds 1 percent, but additional samples are needed to show whether or not there are any extensive deposits of this quality. Even if such deposits exist, uncertainties concerning the stability of cobalt prices at their current high level may discourage for some time attempts to mine nodules whose value would depend largely on the marketability of that metal alone.

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