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THE SEDIMENTARY DEPOSITS OF THE TIKI BASIN (SOUTH-EAST PACIFIC) PASSAGE FROM CARBONATE OOZES TO " METALLIFEROUS SEDIMENTS "

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ABSTRACT. – A sedimentological, mineralogical and geochemical study was made on surface sediment samples associated with nodules in the Tiki Basin (Central South Pacific). The aim of this study was to find variations in the sediment composition with respect to bathymetry and to thus show a relationship between nodule formation and sedimentation. It is now well known that nodules rich, from an economical point of view, are located in this area at a depth more than 4100 meters.

The progressive transformation of a carbonate ooze rich in Foraminifera and poor in siliceous biogenic material into a metalliferous sediment has been shown. The $CaCO_3$ dissolution involves Fe and Mn enrichment of the sediment. The content of these elements becomes stable and independant of the $CaCO_3$ dissolution when the sediment in which nodules are present contains less than 70 % $CaCO_3$.

The carbonate dissolution induces successive neoformations: Fe-Mn hydroxides precipitation, then, Fe-rich smectite formation related to the dissolution of siliceous organisms, and finally micronodule and zeolite formation.

The metalliferous sediments of the present study are similar to those described in the Bauer depression. Their great geographical extend leads us to reconsider the hypothesis of hydrothermal enrichment in Fe and Mn.

Conditions of metalliferous sediments formation are proposed:
- no terrigenous removal,
- reduced planktonic activity,
- strong dissolution of siliceous biogenic material until complete disappearance,
- strong dissolution of carbonate biogenic material,
- little volcanic material.

These observations have allowed us to explain why metalliferous surface sediments have been described in the South Pacific where all of the above conditions have been met. This must also explain the particularities of the nodules in this area.

RÉSUMÉ. – Une étude régionale des caractères sédimentologiques, minéralogiques et géochimiques des sédiments superficiels associés aux nodules polymétalliques a été effectuée dans le bassin de Tiki (Pacifique sud-est); les nodules économiquement intéressants y sont localisés entre 4200 et 4250 mètres. Cette étude précise que la zone bathymétrique propice aux nodules correspond à des particularités du sédiment et permet d'envisager ainsi des relations entre la genèse des nodules et les phénomènes sédimentaires se faisant dans les dépôts superficiels.

Le passage progressif depuis les vases carbonatées à des sédiments de type « métallifère » est mis en évidence. La dissolution progressive des carbonates induit les phénomènes suivants : précipitation d'hydroxydes de Fe-Mn, puis formation de smectites riches en fer à partir de la dissolution des organismes siliceux et finalement formation de micronodules et de zéolites.

Les sédiments « métallifères » du bassin de Tiki présentent beaucoup d'analogies avec ceux décrits dans la dépression de Bauer. La grande extension géographique de ce type de sédiments conduit à reconsidérer l'hypothèse hydrothermale souvent admise et à envisager pour l'origine des éléments constitutifs de ces dépôts une source à l'échelle de l'océan.

Les conditions de genèse des sédiments « métallifères » dans ce domaine du Pacifique sud nous semblent les suivantes :
- zone où l'apport terrigène est très réduit;
- zone où la productivité organique est faible;
- zone de dissolution intense des organismes calcaires, c'est-à-dire sous la lysocline;
- zone de dissolution intense des organismes siliceux dans le sédiment de surface;
- zone où l'influence volcanique est réduite au niveau du sédiment.

Une même origine peut être proposée pour les sédiments du bassin de Tiki et de la dépression de Bauer qui répondent tous deux à ces conditions. Ces dernières différencient également les conditions de genèse des nodules du Pacifique sud de ceux du Pacifique nord et peuvent ainsi expliquer leur différence de composition.

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INTRODUCTION

Several local studies of the sedimentary environment of polymetallic nodules have been made in the north Pacific (Bezrukov, 1970; Horn et al., 1972, 1973; Greenslate et al., 1973). These works clearly point out the fact that there exists a relationship between the nature and the age of sediments on the one hand, and the proportion as well as the composition of the nodules on the other hand. In the south Pacific, due to somewhat limited sampling, such studies have not been carried out until now. However, the existence of polymetallic nodules in the S.E. Pacific as well as their association with sediments described as « deep-sea red clays » is a well established fact (Menard, 1964; Mero, 1965; Horn et al., 1972; Frazer and Arrhenius, 1972; Cronan, 1977). Since 1972, oceanographic cruises by C.N.E.X.O. have resulted in structural and sedimentological studies between Tuamotu archipelago and the Marquesas archipelago. Bathymetric maps have been published by Monti and Pautot (1974) and a structural interpretation proposed by Pautot (1978). Definition of the distribution of nodules with respect to their sedimentary environment and the influence of deep current has been studied (Pautot and Hoffert, 1974; Pautot and Melguen, 1975). It appears, in particular, that the area between 4200 and 4300 meters is the one where the nodules rich, from an economical point of view, are located.

A local study of the sedimentological, mineralogical and geochemical composition of sediments in a zone situated between 4000 and 4500 meters depth has been made in order to know if this bathymetric zone favorable for nodules corresponds to some particularities of the sediment and consequently to try to establish a relationship between the genesis of the nodules and the sedimentary phenomenon of the surface deposits.

GEOLOGICAL SITUATION AND SAMPLING

Such a study of the surface deposits has been undertaken in the Tiki basin, as defined by Pautot and Melguen (1975) (Figure 1). It is a vast depression (Figure 2) limited to the North by the Marquesas fracture zone, to the west and south by the Tuamotu archipelago that rises progressively in its eastern part towards the jump delimiting the zone of the old crust from the modern one (Anderson and Sclater, 1972).

The sea floor depth in the Tiki basin varies from 4000 to 4500 meters. A hundred samples of surface sediments (0 to 5 cm depth) gathered by free-fall grabs and evenly distributed throughout the area, have helped to establish the characteristics of this zone. The cores have been taken by Kullenberg type corer.

VARIATIONS OF THE COMPOSITION OF THE SURFACE SEDIMENTS

The characteristics of the surface sediments of this area have been established by Hoffert et al., 1978 (unpublished report). Schematically the sediments of the shallower zones are foraminiferal calcareous oozes and those of the deeper zones are red clays (or pelagic clays). Here, we shall present exclusively the components of these sediments that vary according to the depth.

1. – $CaCO_3$ CONTENT AND DISSOLUTION OF CALCAREOUS BIOGENIC SEDIMENTS

The relations between $CaCO_3$ content and bathymetry are presented on figure 4. We can see that the

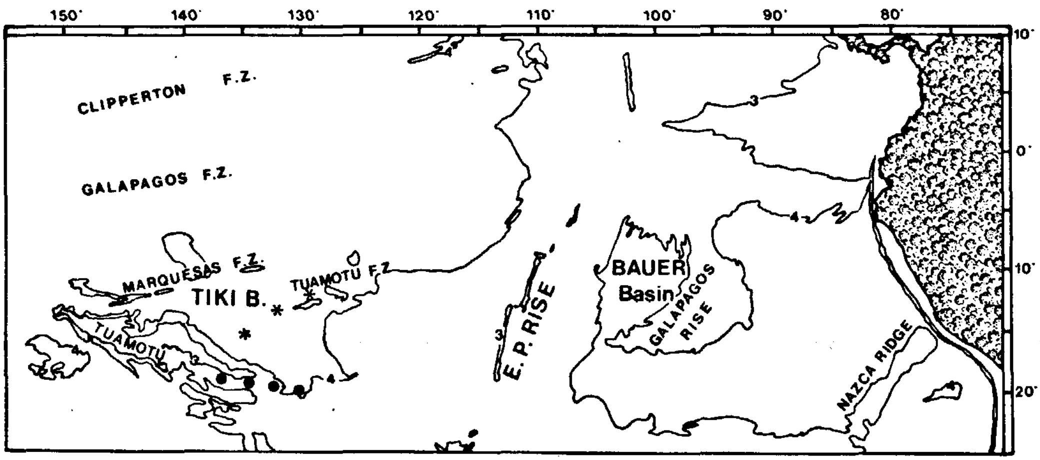

FIG. 1. – Situation of the studied area.
Number correspond to units of 1000 m. Stars indicate from E to W, the position of TKS 08, TKS 09 and TKS 10 cores. Black spots indicate position of other cores wich are composed of metalliferous sediments (from W to E : T2K1, T2K2, T2K3).

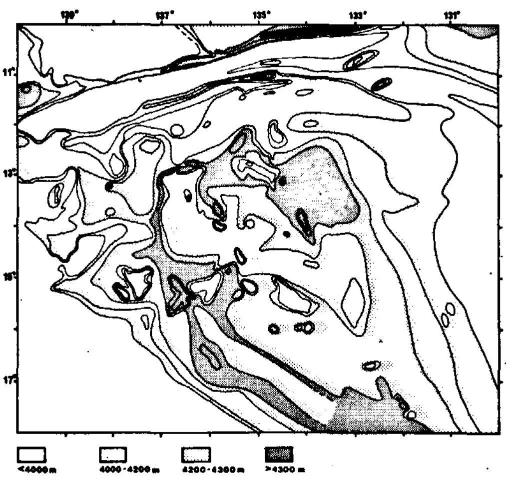

FIG. 2. – Bathymetric map of Tiki Basin.
In order to get better the physionomy of the Basin, all depths within 2000 and 4000 m have been grouped into single unit.

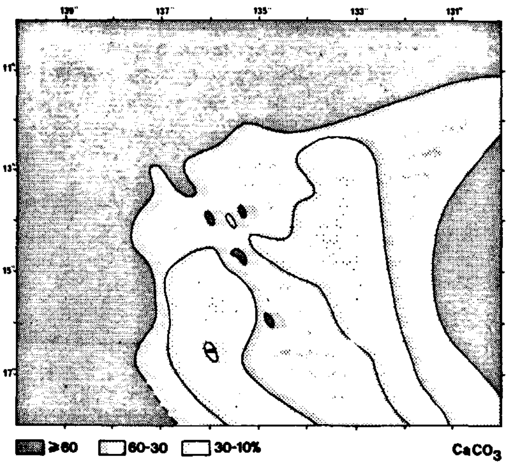

FIG. 3. – Repartition of $CaCO_3$ content (%) into surface sediments of Tiki Basin. Limits are those used by DSDP.

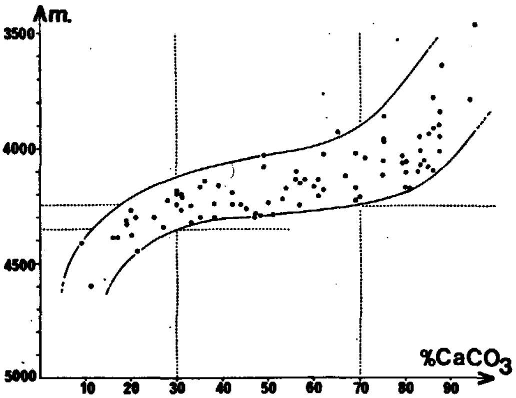

FIG. 4. – Varying $CaCO_3$ content to depth (Tiki Basin).

$CaCO_3$ rich contents (more than 70 %) are generally located at depth shallower than 4100 m. In contrast, the values inferior to 30 % are located at greater depths than 4300 m. The zone in between those two levels is therefore characterized by very important variations in $CaCO_3$ content. The laying down of the curve thus obtained must also reflect influence of deep-sea currents or other local factors which can modify the rate of dissolution of the calcareous biogenic sediments (Parker and Berger, 1971; Edmond, 1971; Berger et al., 1976; Pautot et al., this volume). A map of the distribution of the $CaCO_3$ content of the surface sediments of the Tiki basin is presented in figure 3.

2. – SILICEOUS BIOGENIC SEDIMENTS AND THEIR DISSOLUTION

The proportion of siliceous microfossils (Radiolarian and Diatoms) is small. It is always lower that 10 % (on the surface of smear slides) when these organisms are most abundant, viz in the north-west high zone of the basin. The distribution of radiolarians and diatoms as well as their state of preservation is shown in figures 5 and 6. The progressive dissolution of the calcareous biogenic material is accompanied by a very important dissolution of the siliceous material. Kastner et al. (1977) have shown that the alkalinisation of the environment, caused by the dissolution of the calcareous organisms, results in the dissolution of the siliceous organisms. The nearly complete disappearance of siliceous microfauna in the southern part of the basin may be equally a consequence of its geographic position. In fact, Van Andel et al. (1975) as well as Renz (1976) have shown that the highest productivity of siliceous organisms in the present plankton is situated around 5°N and decreases on the north and south sides.

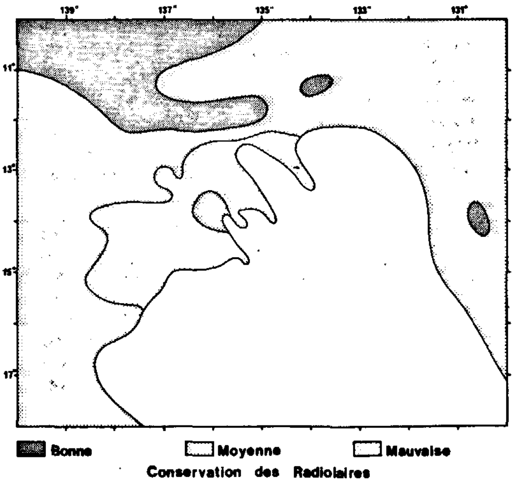

FIG. 5. – Repartition and conservation of Radiolarians into surface sediments of Tiki Basin.

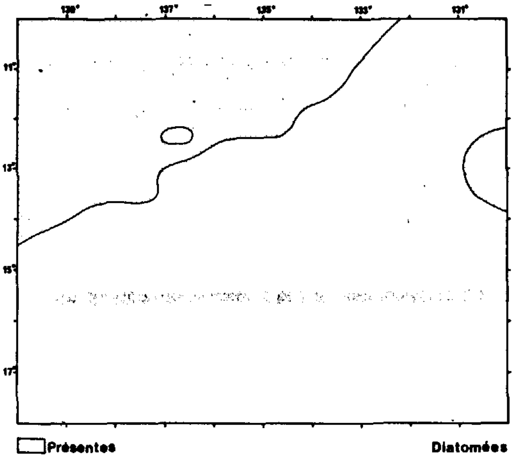

FIG. 6. – Repartition of Diatoms into surface sediments of Tiki Basin.

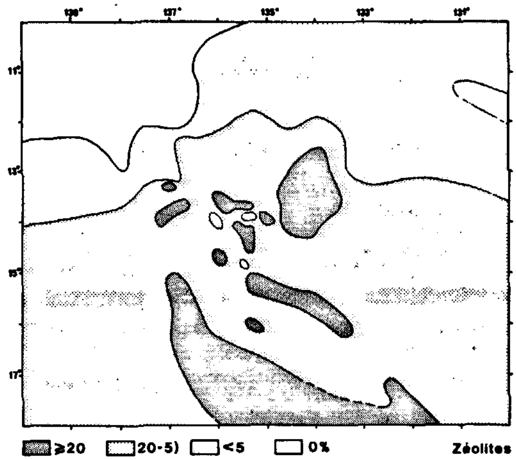

FIG. 7. – Repartition of phillipsite into surface sediments of Tiki Basin.

Thus, three phenomenons : geographic position, dissolution of siliceous biogenic material and dissolution of calcareous biogenic material (which leads to a decrease of the accumulation rate) contribute to one of the most important characteristics of the Tiki basin : the low proportion of siliceous organisms, their instability and, consequently, the « solubilisation » of silica of biogenous origin. We can also note that this characteristic is parallel to that of the surface deposits of Bauer deep, a basin located roughly at the same latitude as the Tiki basin and at an analogous depth (Sayles and Bischoff, 1973; Dymond et al., 1973).

3. – THE CLAY FRACTION AND BROWN AGGREGATES

The clay fraction of the Tiki basin sediments is essentially composed of Fe-rich smectites around 0.5 μm in size. Their authigenic character has been confirmed by the R.E.E. analysis (Courtois and Hoffert, 1978). These clay particles are often found as aggregates whose size can reach a few tens of microns, and which increase in number in he deepest part of the basin.

We have observed by T.E.M. the direct authigenesis of Fe-smectites on dissolving siliceous organisms. These observations confirm the hypothesis of Johnson (1974) as well as the works of Heath and Dymond (1977) Lyle et al. (1977), Dymond and Eklund (1978).

This biogenous silica dissolution induces the formation of Fe-rich clay and thus points out one of the mechanisms that can explain iron retention in deep sea sediments.

4. – PHILLIPSITE

The distribution of this zeolite is presented in figure 7. Generally, phillipsite is very rare in surface deposit, however we have been able to differenciate between the distribution of two types : twinned phillipsite crystals in the deepest part of the Tiki basin, and spheric piles of a few dozen microns present in the NW-SE rise which crosses the Basin. The latter phillipsite is similar to that associated with weathered volcano-sedimentary materials of this area (Hoffert et al., 1978). Consequently, it seems possible to differenciate two phillipsite occurences : the isolated crystals, characterizing the deeper zones poor in $CaCO_3$, the spheric piles, independant of $CaCO_3$ content, perhaps, indicating more significant volcanism.

5. – OXIHYDROXIDES AND Fe-Mn MICRONODULES

The observation of smear-slides and of the coarse fraction (< 63μm) has permitted us to make the following assertions :

- the oxihydroxides are already present, but their proportion is very low in the $CaCO_3$ rich sediments. This proportion increases with decreasing $CaCO_3$ content.
- micronodules appear only in the deeper zone of the basin. Their distribution is nearly the same as that of the first type of phillipsite described above.

6. – THE VOLCANIC ENVIRONMENT

The importance of volcanism in this area of the Pacific is a well known fact (Pautot, 1978). Inside the Tiki basin, this volcanic influence manifests itself in two sedimentary features :

- basalt fragments and volcanic glass have been recovered from the NW-SE line described above. This structure must, consequently, correspond to a volca-

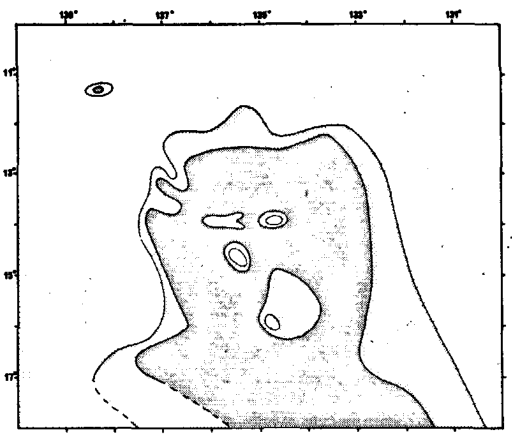

FIG. 8. – Repartition map of Titanium (total analysis, %) into surface sediments of Tiki Basin.

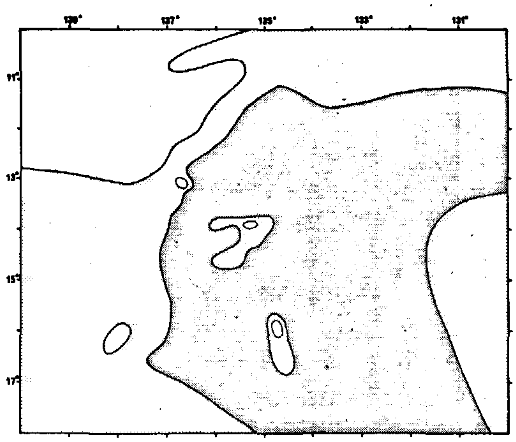

FIG. 9. – Repartition of Fe contents (% on CaO free basis) into surface sediments of Tiki Basin.

nic alignment, and confirms the observation of the second type of phillipsite.

- the surface sediments always contain little palagonite. This discret volcanic phase can also be seen when comparing the distribution of titanium and iron (Figure 8).

Thus, it may be seen that the relative importance of volcanic material increases when the $CaCO_3$ content decreases. Or, there is a concentration of the volcanic material which will modify the chemical composition of these sediments. Moreover, the sedimentation rate being low, the alteration of the volcanic material is easier. For example, the formation of smectites starting from palagonite will be possible. No sign of hydrothermalism has been observed in this region.

7. – GEOCHEMICAL VARIATIONS

The major part of the geochemical data are grouped in figures 9 and 10 and in table 1. From these we can draw the following conclusions :

- The Fe and Mn contents increase with depth. The values calculated on CaO free basis are higher than the average oceanic sediment content, in the deeper part of the basin (Goldberg and Arrhenius, 1958; El Wakeel and Riley, 1961). These metal concentrations reach the values found in sediments termed " metalliferous " such as those described in the surface deposits of the Bauer Deep (Sayles and Bischoff, 1973; Sayles et al. 1973; Mc Murty, 1975). We have agreed to consider as metalliferous the carbonate poor sediments having Fe contents higher than 10 % and Mn contents higher than 3 % (on CaO free basis). In order to make clearer the comparison between the $CaCO_3$ (or CaO) content and Fe and Mn contents (on a CaO free basis) we have drawn curves linking those two factors (Figure 11). In this manner we can see that it is in sediments with very high CaO contents (more than 40 % CaO or 70 % $CaCO_3$) that Fe and Mn increase when CaO decreases. It appears as if the values of these two elements stabilize or at least decrease much more slowly. Finally, the distribution map of Fe/Mn ratio (Figure 12) permits us to point out a gradual variation : the Fe/Mn ratio is higher in carbonate oozes (where it is representative of oxihydroxides) than in the metalliferous sediments (which are characterized by their high amount of Fe-smectites and occurence of micronodules).
- The behaviour of trace elements (Ni, Cu, Co) is more difficult to define; in figures 13 to 15, we see that the contents of these elements increase with

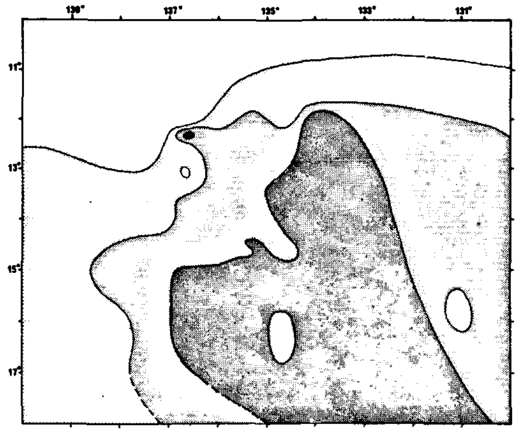

FIG. 10. – Repartition of Mn contents (% on CaO free basis) into surface sediments of Tiki Basin.

TABLE I

Chemical analysis (%) of some surface and core sediments of Tiki Basin

	TKS 07 (0-2 cm)	TKS 08 (0-2 cm)	TKS 08 (291-292 cm)	TKS 09 (0-2 cm)	TKS 09 (98-100 cm)	TKS 10 (0-2 cm)	TKS 10 (43-45 cm)	T2 K1 (0-2 cm)	T2 K1 (60-62 cm)	T2 K2 (0-2 cm)	T2 K2 (50-52 cm)
Major elements (%)											
SiO_2	3.7	9.7	30.5	28.4	36.7	16.3	36.2	10.5	29.5	26.8	24.1
Al_2O_3	0.4	2.0	7.2	8.4	10.8	4.8	10.5	3.1	9.9	8.8	8.4
MgO	0.46	1.09	2.81	1.98	2.46	1.27	2.58	1.16	3.32	2.95	2.84
CaO	48.7	33.1	4.9	14.4	2.9	32.4	4.7	34.8	6.5	4.7	4.5
Fe_2O_3	1.4	5.4	22.9	12.9	16.4	7.3	15.5	5.4	20.7	23.5	31.1
Mn_3O_4	0.34	1.43	4.80	4.16	4.42	2.35	4.49	1.91	4.93	6.0	5.55
TiO_2	0.04	0.15	0.32	0.70	0.76	0.45	1.06	0.24	1.15	0.92	0.85
Na_2O	0.16	1.30	5.53	3.33	5.69	0.45	5.70	0.60	4.01	4.47	3.84
K_2O	0.08	0.44	2.69	1.15	3.45	0.07	2.91	0.23	2.08	1.88	1.99
Ignition loss (1000°C)	42.35	40.34	13.94	20.65	10.99	33.56	12.18	34.65	14.72	15.96	13.96
Total	98.0	95.35	96.21	96.57	94.71	99.52	96.45	93.21	97.00	96.22	97.16
Major elements (%) recalculated on CaO = 0 basis											
SiO_2	33.56	26.77	34.87	40.08	40.99	39.13	41.11	33.80	34.54	30.5	27.04
Al_2O_3	3.62	5.51	8.23	11.85	12.06	11.52	11.92	9.90	11.59	10.01	9.42
MgO	4.17	3.0	3.21	2.79	2.74	3.04	2.92	3.73	3.88	3.3	3.18
Fe_2O_3	12.70	14.9	26.18	18.20	18.31	17.52	17.60	17.38	24.20	26.7	34.89
Mn_3O_4	3.09	3.94	5.48	5.87	4.93	5.64	5.09	6.14	5.77	6.8	6.2
TiO_2	0.36	0.41	0.36	0.98	0.84	1.08	1.20	0.77	1.34	1.04	0.95
Na_2O	1.45	3.58	6.32	4.69	6.35	1.08	6.47	1.93	4.69	5.08	4.30
K_2O	0.72	1.21	3.07	1.62	3.85	0.16	3.30	0.74	2.43	2.14	2.23
Minor elements (ppm)											
Sr	1348	1325	442	714	365	916	513	1799	736	703	470
Ba	2775	2758	4030	3386	1368	3491	3522	6719	2099	2197	934
V	< 5	< 5	303	143	309	44	241	48	371	378	492
Ni	35	64	739	713	800	450	798	363	711	785	782
Co	< 2	15	266	251	300	167	299	135	316	373	263
Cr	< 5	< 5	9	19	32	10	55	22	67	30	29
B	< 5	< 5	158	34	130	< 5	120	26	182	217	191
Zn	86	45	173	67	209	43	59	239	219	195	226
Ga	< 2	< 2	18	7	23	< 2	19	< 2	25	25	19
Cu	46	88	525	194	539	219	366	253	441	474	497
Pb	< 2	15	187	120	72	25	47	24	92	93	85
Sn	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5

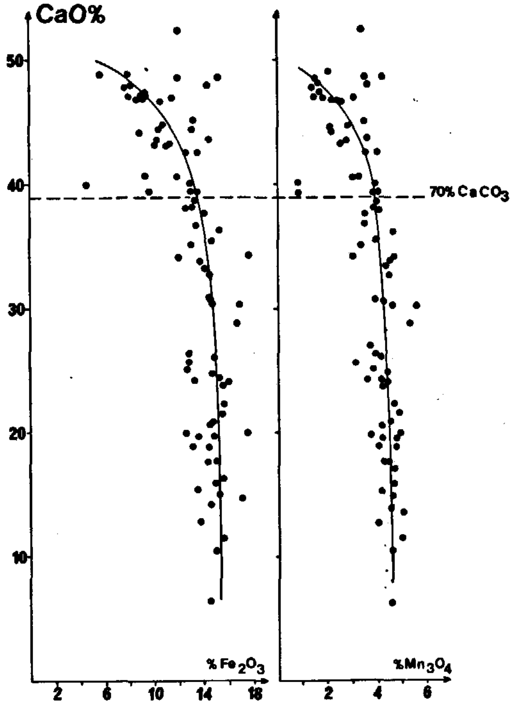

FIG. 11. – Correlation between CaO content (%) and Fe and Mn contents (% on CaO free basis).

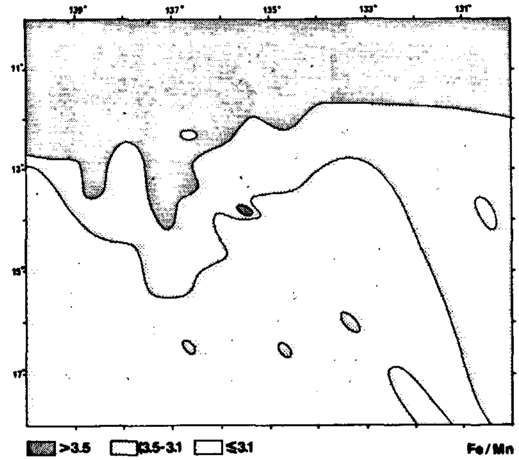

FIG. 12. – Repartition map of Fe/Mn ratio into surface sediments of Tiki Basin.

decreasing $CaCO_3$ content and that no limit can be clearly defined.

8. – CONCLUSIONS TO THE STUDY OF SURFACE DEPOSITS

In an area characterized by a low organic productivity, a constant but low-grade volcanic influence on the

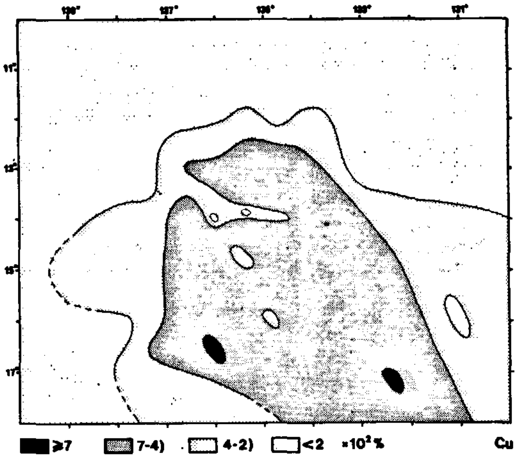

FIG. 13. – Repartition map of Cu (% x 10^2) into surface sediments of Tiki Basin.

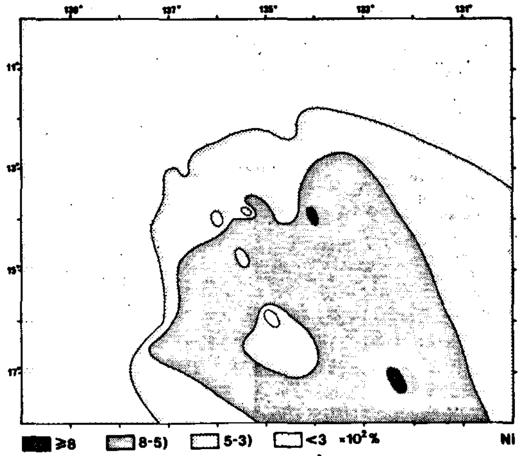

FIG. 14. – Repartition map of Ni (% x 10^2) into surface sediments of Tiki Basin.

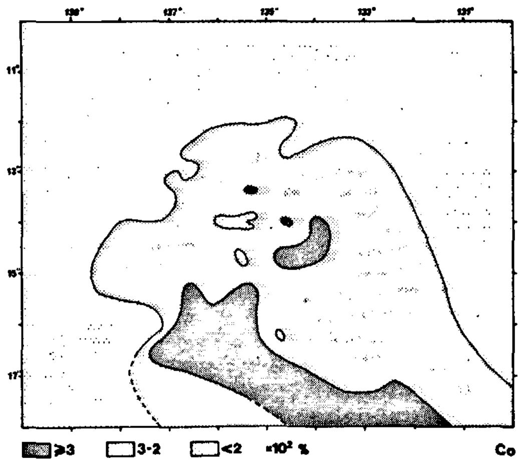

FIG. 15. – Repartition map of Co (% x 10^2) into surface sediments of Tiki Basin.

sediments, as well as by an almost non existent detrital contribution, we have been able to point out the variation in the composition of sediment depending on depth, and also to differenciate well defined zones. Here are the principal aquired facts :

a) In $CaCO_3$-rich sediments (more that 70 % – or 40 % CaO) generally located at depths greater than 4250 m, the Fe and Mn contents of the non carbonate phases increase when CaO content decreases. These elements are present as oxihydroxides. The rather rare siliceous biogenous material is dissolved and acts as a support for the formation of Fe-smectites. Zeolites and micronodules are absent.

b) The sediments whose $CaCO_3$ content is between 70 and 30 % are located in an area with a rather variable depth (about 4100 to 4350 m). The Fe and Mn contents remain stable when $CaCO_3$ content decreases, and these elements are present as Fe-smectites, oxihydroxides and micronodules. Fe and Mn tend to dissociate from one another as is shown by the variation of Fe/Mn ratio.

c) The sediments having a $CaCO_3$ content lower than 30 % characterized by the abundance of smectites, and presence of zeolites and micronodules. These are deposits with intermediate characteristics between those of " metalliferous " sediments and those of the zeolitic red clays of this Pacific area.

Thus it appears that :

- In sediments that are poor in siliceous organisms, the progressive decrease of $CaCO_3$ content makes the calcareous ooze pass gradually into metalliferous sediments with an enrichment of Fe and Mn contents higher than residual contents only.
- It is in the depth interval where $CaCO_3$ content is still high (70 to 30 %) but where Fe and Mn contents remain stable in the non-calcareous phase of the sediments that nodules seem to occur preferentially.

REMARKS : The data that we have at our disposal do not allow us to establish the origin of either Fe and Mn in sediments nor that of the trace elements (volcanism, dissolved ions in sea water, or resulting from the dissolution of calcareous organisms). Nevertheless, variation of Fe/Mn ratios as well as the existence of an enrichment of Fe and Mn content indicate that the transformation of the sediment through progressive dissolution of $CaCO_3$ does not end in a purely residual deposit. We may propose the following mechanism : the progressive dissolution of carbonate leads to a gradual alkalinisation of the solution which favours Fe then Mn precipitations (Krauskopf in Garrels and Christ, 1967) which continues until a certain level of Fe and Mn contents in sediments is reached. The excess of these elements may contribute to the formation of nodules and polymetallic crusts. The fact that a part of Fe is used to form smectite induces a parting of Fe and Mn that were initially linked to oxihydroxides. A similar mechanism is described by Lyle et al. (1977) to explain the genesis of nodules in the Bauer deep.

The spacial variations brought out in the study of the surface deposits (related to bathymetry), can be extended

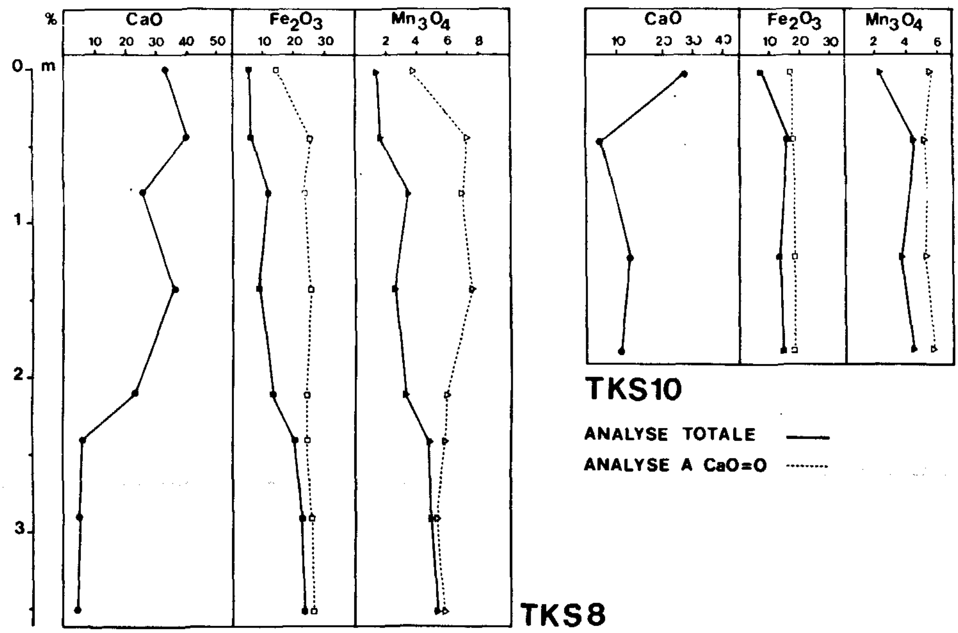

FIG. 16. – CaO, Fe_2O_3, Mn_3O_4 contents (%) into sedimentary column.

to a temporal scale by the studies of cores taken in the same area.

VARIATIONS INTO THE SEDIMENTARY COLUMN

A study of composition of the upper few meters of three cores (TKS 08, TKS 09 and TKS 10) taken respectively at 4090 m, 4453 m and 4322 m depth (Figure 1) in Tiki Basin, permits us to point out the following observations :

- The most superficial deposits of the three cores are calcareous ooze, followed by a decrease in $CaCO_3$ content. The $CaCO_3$ content of the most superficial deposits decreases even more quickly in the cores taken at the deeper sites. The siliceous biogenic material always present on the sediment surface are dissolved in the first centimeter of the core.
- The carbonate rich deposits contain oxihydroxides, followed with a decrease in $CaCO_3$, by brownish clay aggregates, micronodules and zeolites.
- The Fe and Mn contents which vary in surface deposits stabilize progressively in the first meters of sediment (Figure 16), whereas the Cu, Ni and Co show more continuous variations all through the sedimentary column.

One can establish that this information is similar to that obtained in the study of surface deposits. We see that the same sequence of processes is again exhibited, but in this case as a function of time instead as a function of bathymetry. The speed of these processes is related to the depth of the sediment, in fact, to the accumulation rate of calcareous and siliceous biogenic sediments falling on the sediment-water interface. Nevertheless, it must be noted that the process of mobilization of elements in the sedimentary column, such as the one described by Michard (1975) is in addition to those that we have described. The importance of such mechanisms is linked to the position of the oxidized zone at the top of the sedimentary column and also to the sedimentation rate.

Deposits similar in mineralogical and chemical composition to those described in the Bauer Deep have been taken in other areas of the Tiki Basin on the western side of the East Pacific Rise (positions are given in Figure 1). This indicates the great horizontal distribution of metalliferous sediments in the South Pacific and leads us to a discussion about their genesis.

DISCUSSION

The major points that have been brought out are the following :

1 – The sediments studied are characterized by three factors : an almost non-existent detritical contribution, a biogenous phase with a low proportion of siliceous biogenic material, and a present but low volcanic influence on sediments.

2 – Calcareous oozes develop towards Fe and Mn rich sediments in a similar fashion to those described in the Bauer Deep. This evolution occurs in areas where calcareous biogenic material is unstable, i.e. at depth beneath the lysocline.

3 – The process of enrichment in Fe and Mn are :
- Fe-hydroxides precipitation, favored by the alkalinization of solutions
- Fe-smectites authigenesis
- Fe and Mn micronodules formation.

4 – According to the type of surface sediments, it seems that a limit of Fe and Mn content in the non-calcareous phase of the sediment might be defined and that nodules might occur in zones where this limit is reached.

5 – Origin of Fe and Mn is not clearly defined, yet the widespread distribution of metalliferous sediments shown, leads us to hypothesize a source on an oceanic scale. This last point seems all the more important because, as already stated, the sediments studied are similar from all points of view to those of the surface of Bauer Deep. It appears to us that the hydrothermal origin, often proposed for the genesis of Bauer Deep deposits (Piper, 1973; Dymond et al. 1973; Mc Murty, 1975) is not sufficient to explain their widespread distribution. Sayle and Bischoff (1973) observed that the Bauer Deep metalliferous sediments are always present below 4200 m depth and that they have a different composition from hydrothermal deposits on the East Pacific Rise described by Bostrom and Peterson (1969), and they also conclude that it might be necessary to consider other possible origins for the genesis of these sediments. Heath and Dymond (1977) consider also the importance of other processes than hydrothermalism, such as hydrogeneous and biogenous factors in the origin of metalliferous deposits. From the study of site DSDP 319, Dymond et al. (1977) also concluded that hydrogeneous influence is presently stronger than hydrothermal influence on the surface deposits of this area.

6 – The association of sediments of metalliferous character with nodules has been established in the Tiki Basin. These same observations have been made for the Bauer Deep by Lyle et al. (1977). The zones in which sediments with metalliferous character can form are therefore potential " noduliferous " sites.

- The conditions for genesis of metalliferous sediments appear to be the following :
- Zone in which detritic contribution is very low
- Zone with low organic productivity
- Zone of important dissolution of siliceous organisms at the sediment surface.
- Zone of dissolution of calcareous organisms below the lysocline
- Zone where the volcanic influence on the sediment is weak.

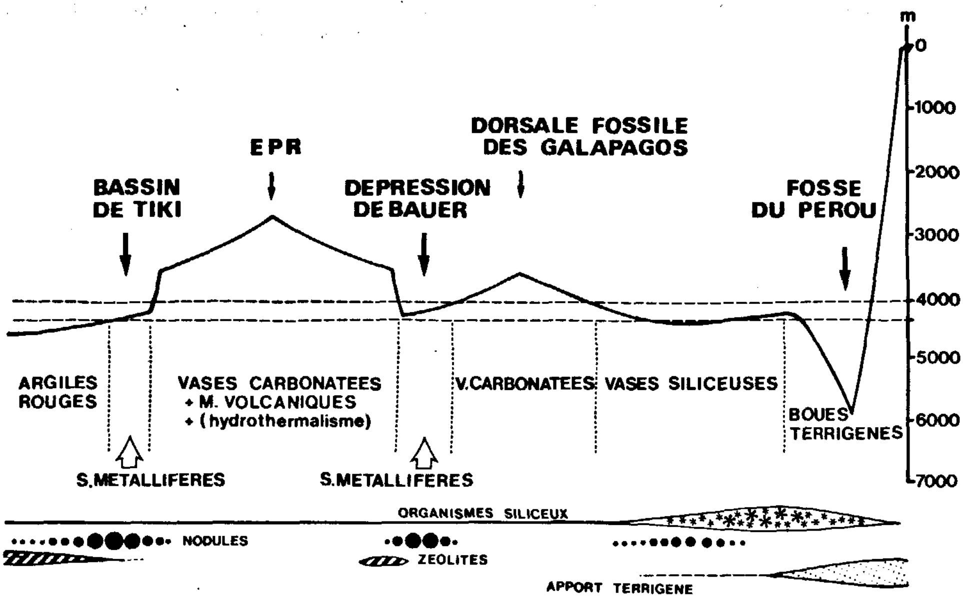

FIG. 17. – Shematic synthesis of localisation of differents types of sediments, and in particular metalliferous sediments, along a E-W line in South Pacific.

– A similar origin can be proposed for both the deposits of the Tiki Basin and those of the Bauer Deep, both exhibiting the conditions stated above (Figure 17). These latter differenciate the conditions of genesis of the south Pacific nodules from the north Pacific ones, such as those of the Clarion and Clipperton fracture zones, and the associated siliceous oozes.

– The proposed hypothesis will have to be confronted with other observations, such as metalliferous sediments from other areas, or with later samplings which will be done in this region of the south Pacific.

Presently, however, it may explain one aspect of the sedimentological observations made in this area of the Pacific ocean and justify the particularities of nodules taken in the same area.

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REFERENCES

ANDERSON R.N. and SCLATER J.G. (1972). – Topography and Evolution of the East Pacific Rise between 5° S and 20° S. *E.P.S.L.*, *14*, p. 433-441.

BERGER W.H., ADELSECK C.G. and MAYER L.A. (1976). – Distribution of Carbonate in Surface sediments of the Pacific Ocean. *Journal of Geophysical research*, *81*, p. 2617-2627.

BEZRUKOV P.L. (1970). – Nodules de manganèse de l'Océan Pacifique. *in* Sedimentation in the Pacific Ocean, traduction *B.R.G.M.* du chapitre nodule, vol. V, t. 1 et 2, Acad. of Sciences, Moscou URSS (en russe).

COURTOIS C. and HOFFERT M. (1978). – Distribution des terres rares dans les sédiments superficiels du Pacifique Sud-Est. *Bull. Soc. Géol. Fr.*, 7, p. 1245-1251.

CRONAN D.S. (1977). – Deep-Sea nodules : distribution and geochemistry. *in* Marine Manganese Deposits (Glasby G.P. ed.). *Elsevier Oceanography Series*, p. 11-44.

DYMOND J., CORLISS J.B., HEATH G.R., FIELD C.W., DASCH E.J. and VEEH H.H. (1973). – Origin of metalliferous sediments from the Pacific Ocean. *Geol. Soc. of Amer., Bull.*, *84*, p. 335-337.

DYMOND J., CORLISS J.B. and HEATH G.R. (1977). – History of metalliferous sedimentation at Deep Sea Drilling Site 319 in the South Eeastern Pacific. *Geochim. Cosmochim. Acta*, p. 741-753.

DYMOND J. and EKLUND W. (1978). – A microprobe study of metalliferous sediment components. *Earth and Planetary Science Letters, 40*, p. 243-251.

EDMOND J.M. (1974). – On the dissolution of carbonate and silicate in the deep ocean. *Deep-Sea Research, 21*, p. 455-480.

EL WAKEEL Sk. and RILEY J.P. (1961). – Chemical and mineralogical studies of deep sea sediments. *Geochim. Cosmochim. Acta, 25*, p. 110-146.

FRAZER J.Z. and ARRHENIUS G. (1972). – World-wide distribution of ferromanganese nodules and element concentration in selected Pacific nodules. *Tech. Rep. Off. Int. Decace Ocean Explor., 2*, 52 p.

GARRELS R.M. and CHRIST C.L. (1967). – *Équilibres des minéraux et de leurs solutions aqueuses*. Gauthier-Villars, Paris, 335 p.

GOLDBERG E.D. and ARRHENIUS G.O.S. (1958). – Chemistry of Pacific pelagic sediments. *Géochim. Cosmochim. Acta, 13*, p. 153-212.

GREENSLATE J., FRAZER J.Z. and ARRHENIUS G. (1973). – Origin and deposition of selected transition elements in the seabed. *in* The origin and distribution of manganese nodules in the Pacific and prospects for exploration (Morgenstein M. ed.) Honolulu, Hawaii, *International Symposium by the R/V VALDIVIA manganese Exploration Group of West Germany and the Hawaii Institute of Geophysics*, p. 45-70.

HEATH G.R. and DYMOND J. (1977). – Genesis and transformation of metalliferous sediments from the East Pacific Rise, Bauer Deep and Central Basin, northwest Nazca Plate. *Geol. Soc. of Amer. Bull., 88*, p. 723-733.

HOFFERT M., KARPOFF A.M., CLAUER N., SCHAAF A., COURTOIS C. and PAUTOT G. (1978). – Néoformations et altérations dans trois faciès volcano-sédimentaires du Pacifique Sud. *Oceanologica Acta, 1*, p. 187-202.

HORN D.R., HORN B. and DELACH M.N. (1972). – Worlwide distribution and metal content of deep-sea manganese deposits. *in* Manganese Nodule deposits in the Pacific, *Symposium/Workshop Proc.*, Honolulu, p. 46-60.

HORN D.R., HORN B.M. and DELACH M.N. (1973). – Copper and nickel content of ocean ferro-manganese deposits and their relation to properties of the substrate. Reprinted from *International Symposium by the R/V Valdivia Manganese Exploration Group of West germany and the Hawaii Institute of Geophysics*, p. 77-83.

JOHNSON T.C. (1974). – The dissolution of siliceous microfossils in surface sediments of the eastern equatorial Pacific. *Deep Sea Research, 21*, p. 851-864.

KASTNER M., KEENE J.B. and GIESKES J.M. (1977). – Diagenesis of siliceous oozes. I. Chemical controls on the rate of opal-A to opal-CT transformation – an experimental study. *Geochim. Cosmochim. Acta, 41*, p. 1041-1059.

LYDE M., DYMOND J. and HEATH G.R. (1977). – Copper-nickel-enriched ferromanganese nodules and associated crusts from the Bauer Basin, Northwest Nazca Plate. *Earth Planet. Sci. Letters, 35*, p. 55-64.

McMURTRY G.M. (1975). – Geochemical investigations of sediments across the Nazca Plate at 12° S. Contributions to the geochemistry of Nazca Plate sediments, southeast Pacific, *Hawaii Institute of Geophysics, University of Hawaii HIG-75-14*, p. 1-40.

MENARD H.W. (1964). – *Marine Geology of the Pacific*. Mc Graw-Hill, New-York, 271 p.

MERO J.L. (1965). – *The mineral ressources of the Sea*. Elsevier, Amsterdam, 312 p.

MICHARD G. (1975). – Chimie du manganèse à l'interface eau-sédiment. Application à la formation des dépôts manganésifères des fonds océaniques. *Mineral. Deposita, 10*, p. 315-322.

MONTI S. and PAUTOT G. (1974). – Cinq cartes bathymétriques au 1/1.000.000 : Tahiti, Raroia, Marquises, Hao, Mururoa. Cartes éditées par le CNEXO, Paris.

PIPER D.Z. (1973). – Origin of metalliferous sediments from the East Pacific Rise. *Earth and Planetary Science Letters, 19*, p. 75-82.

PARKER F.L. and BERGER W.H. (1972). – Faunal and solution patterns of planktonic foraminifera in surface sediments of the South Pacific. *Deep Sea Res., 18*, p. 73-107.

PAUTOT G. and HOFFERT M. (1974). – Pacifique sud-est : cadre structural, morphologique et sédimentaire. Relation avec les nodules polymétalliques. *II[e] Colloque Intern. sur l'Exploitation des Océans*, Bordeaux, 4, BX202, 8 p., 3 fig.

PAUTOT G. and MELGUEN M. (1975). – Courants profonds, hiatus sédimentaires et nodules polymétalliques. *IX[e] Congr. Intern. de Sédimentologie, Nice*, p. 57-64.

PAUTOT G. (1978). – Tuamotu Archipelago and adjacent areas : hot spot or not ? in press.

RENZ G.W. (1976). – The distribution and ecology of Radiolaria in the Central Pacific : plankton and surface sediments. *Bull. of the Scripps Institution of Oceanography*. University of California, San Diego, La Jolla, 22, 267 p.

SAYLES F.L. and BISCHOFF J.L. (1973). – Ferromanganoan sediments in the equatorial East-Pacific. *Earth and Planetary Science Letters, 19*, p. 330-336.

SAYLES F.L., KU T.L. and BOWKER P.C. (1975). – Chemistry of ferromangoan sediments of the Bauer Deep. *Geol. Soc. of Amer., Bull., 86*, p. 1423-1432.

VAN ANDEL T.H., HEATH G.R. and MOORE T.C. Jr. (1975). – Cenozoic history and paleoceanography of the central equatorial Pacific Ocean. *Geol. Soc. of Amer., Mem. 143*, 134 p.

DISCUSSION

K. BOSTRÖM : I think there is a problem of terminology here. You use the term metalliferous for any sediment poor in $CaCO_3$ and rich in Fe and Mn. However, the $CaCO_3$ content is mostly dependant on the position of the lysocline that is, anywhere close to the spreading where the depth is sufficiently large, you should expect to find sediments resembling the Bauer deep-type.

M. HOFFERT : Nous précisons, dans notre communication, que nous considérons que les « sédiments métallifères » de la dépression de Bauer ainsi que nos propres échantillons ont une origine commune, halmyrolytique, et que leurs caractères minéralogiques et géochimiques sont différents de ceux prélevés sur les dorsales océaniques. Il se pose donc effectivement un problème de nomenclature. Il nous semble qu'il y a, au moins, deux types de sédiments « métallifères » :

– ceux nés à partir de processus hydrothermaux et qui sont donc localisés à proximité des dorsales océaniques, des failles transformantes ou d'autres zones de volcanisme actif. Dans ce type de sédiments, nous mettons ceux prélevés durant la campagne FAMOUS (Hoffert et al. 1978) ou encore ceux prélevés près du Rift des Galapagos (Hekinian et al. 1978, Corliss et al. 1978, Hoffert et al. en préparation);

– ceux nés lors de la dissolution des organismes calcaires et siliceux et ceci dans une zone où l'apport continental est réduit. Nous incluons dans ce second type, les sédiments de la dépression de Bauer, ceux décrits dans le Pacifique Nord (Bischoff et Rosenbauer, 1977, Bischoff et al. ce volume), ainsi que ceux que nous venons de présenter.

W. NESTEROFF : Votre exposé soulève un problème de nomenclature des sédiments de mer profonde. Quelle est la différence entre les argiles rouges (red clays) et les sédiments métallifères ? Où se place la limite et comment définissez-vous les deux types de sédiments ?

M. HOFFERT : La question que vous posez est très vaste. Nous limiterons la réponse au Pacifique Sud-Est. Dans cette région nous considérons que le passage depuis les vases carbonatées aux « sédiments métallifères » puis aux « argiles rouges » est continu en fonction de la profondeur. La limite entre ces différents types est une question de convention. Nous appelons « sédiments métallifères » des sédiments pauvres en $CaCO_3$ qui se sont formés à une profondeur à laquelle organismes calcaires et siliceux se dissolvent rapidement et qui sont, de ce fait, enrichis en Fe, Mn... Nous appelons « argiles rouges » des sédiments fins qui se sont formés sous la profondeur de compensation des carbonates et qui, par voie de conséquence, n'ont pas les mêmes enrichissements en éléments comme Fe, Mn... et une composition minéralogique différente (en particulier l'abondance de zéolites).

C. LALOU : You have shown that above your metalliferous sediments you have a carbonaceous deposit which is variable in thickness. Have you an idea about the age of the carbonaceous deposit, specially at the contact with metalliferous sediments ?

M. HOFFERT : Nous constatons que les sédiments que nous appelons « métallifères » par analogie avec ceux décrits dans la dépression de Bauer se trouvent dans une zone de dissolution rapide des organismes calcaires et siliceux. Aussi la détermination de l'âge de ces sédiments est très difficile étant donné le mauvais état de préservation de ces organismes . Nous pouvons cependant donner les indications suivantes d'après les déterminations des organismes siliceux faites par A. Schaaf et celles des coccolithes faites par M. Melguen.

La carotte TKS 08 contient, dans le sédiment de surface carbonaté, une prédominance d'organismes actuels. La présence de rares discoasters est un indicateur de remaniements sédimentaires dus à des courants de fond. A 20 cm de profondeur, c'est à dire à la limite entre les vases carbonatées claires et les « sédiments métallifères » brun foncé, l'âge estimé est Pléistocène supérieur.

Dans la carotte TKS 09, prélevée à une profondeur plus grande, les vases carbonatées ne forment qu'une pellicule superficielle dont l'épaisseur est de l'ordre du centimètre et sont formées d'organismes actuels. A 7 cm de profondeur, l'âge estimé est Pléistocène supérieur.

La même observation est faite pour TKS 10 dans laquelle un âge Pléistocène supérieur a pu être déterminé à 25 cm de profondeur.

J.L. BISCHOFF : Apparently metalliferous sediments are never pure but are mixed with various proportions of red clay. The content of Al may be useful in determining the relative amount of red clay in your metalliferous rich samples. Do you have Al analyses for your sediments ?

M. HOFFERT : Vous considérez que les « sédiments métallifères » sont une phase constitutive d'un sédiment alors que nous les considérons comme un type de sédiment. Dans le Pacifique Sud où l'apport terrigène est vraiment très réduit, un des constituants qui peut faire changer la teneur en Al des sédiments est la phase volcanique qui peut être importante dans les sédiments dits « argiles rouges ». Des analyses chimiques seront jointes au texte de notre communication.