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DEEP BOTTOM CURRENTS, SEDIMENTARY HIATUSES AND POLYMETALLIC NODULES

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Abstract

—Recent studies undertaken by the Centre National pour l'Exploitation des Oceans have focused some attention on the environment of nickel- and copper-bearing iron-manganese nodules in the Tuamotu Archipelago region of the South Pacific. The results indicate that the distribution of the nodules is closely linked to that of deep currents in the area. We attempt to show that these currents are associated mainly with the Antarctic Bottom Water and we attribute the episodical character of nodule formation in this region to major pulsations of the Antarctic Bottom Water. A synthesis of what are considered to be primary factors in the nodules formation are incorporated into a tentative model which is presented as a guide for future exploration for polymetallic nodules. —

INTRODUCTION

Numerous works have underlined the local importance of bottom currents on sedimentation in the Pacific (Johnson *et al.*, 1970; Johnson, 1972), the presence of outcrops of pre-Quaternary sediments and of sedimentary hiatuses (Bramlette, 1961; Riedel and Funnell, 1964; Moore, 1970; Tracey *et al.*, 1970; Hays *et al.*, 1972), the relationship existing between bottom topography, sedimentary facies, submarine volcanism and the distribution of polymetallic nodules (Menard, 1964; Mero, 1965; Barnes, 1967; Horn *et al.*, 1972; Glasby 1973a; Friedrich and Plüger, 1974; Beiersdorf and Wolfart, 1974; Andrews, 1974). However, most of these works deal almost exclusively with the North Pacific and only rarely emphasise the relationship existing between the structural and sedimentological situation and the distribution of polymetallic nodules. Further, these works consider polymetallic nodules in a global fashion, without dissociating those nodules whose high contents of nickel and copper justifies an economic interest. The aims of the present article are as follows:

1. To propose a course of the Antarctic Bottom Current to the latitude of the Tuamotu Archipelago and the Marquesas Islands.
2. To establish in this zone the relationship existing between erosion structures, sedimentary hiatuses and the passage of the Antarctic Bottom Current;
3. To illustrate the role played by the Antarctic Bottom Current on the genesis of polymetallic nodules;
4. To illustrate in the light of recent research carried out in the South Pacific (Glasby, 1972, 1973b; Glasby *et al.*, 1974; Hollister *et al.*, 1974) and, especially, from our own observations (Pautot and Melguen, 1975), a "model" for the formation of polymetallic nodules rich in nickel and copper. This "model", integrating the principal factors controlling the formation of nodules of economic interest, is proposed as a "guide for exploration".

I. Proposals for a traverse of the Antarctic Bottom Current in the Tuamotu-Marquesas Islands (South Pacific)

The Tuamotu Archipelago, bounded in the north by the fracture zone of the Marquesas, is interpreted (Pautot, 1975) as a volcanic structure comparable to an undeveloped oceanic ridge. The Marquesas Islands Archipelago is composed of a modern volcanic mass (Plio-Pleistocene) (Pautot and

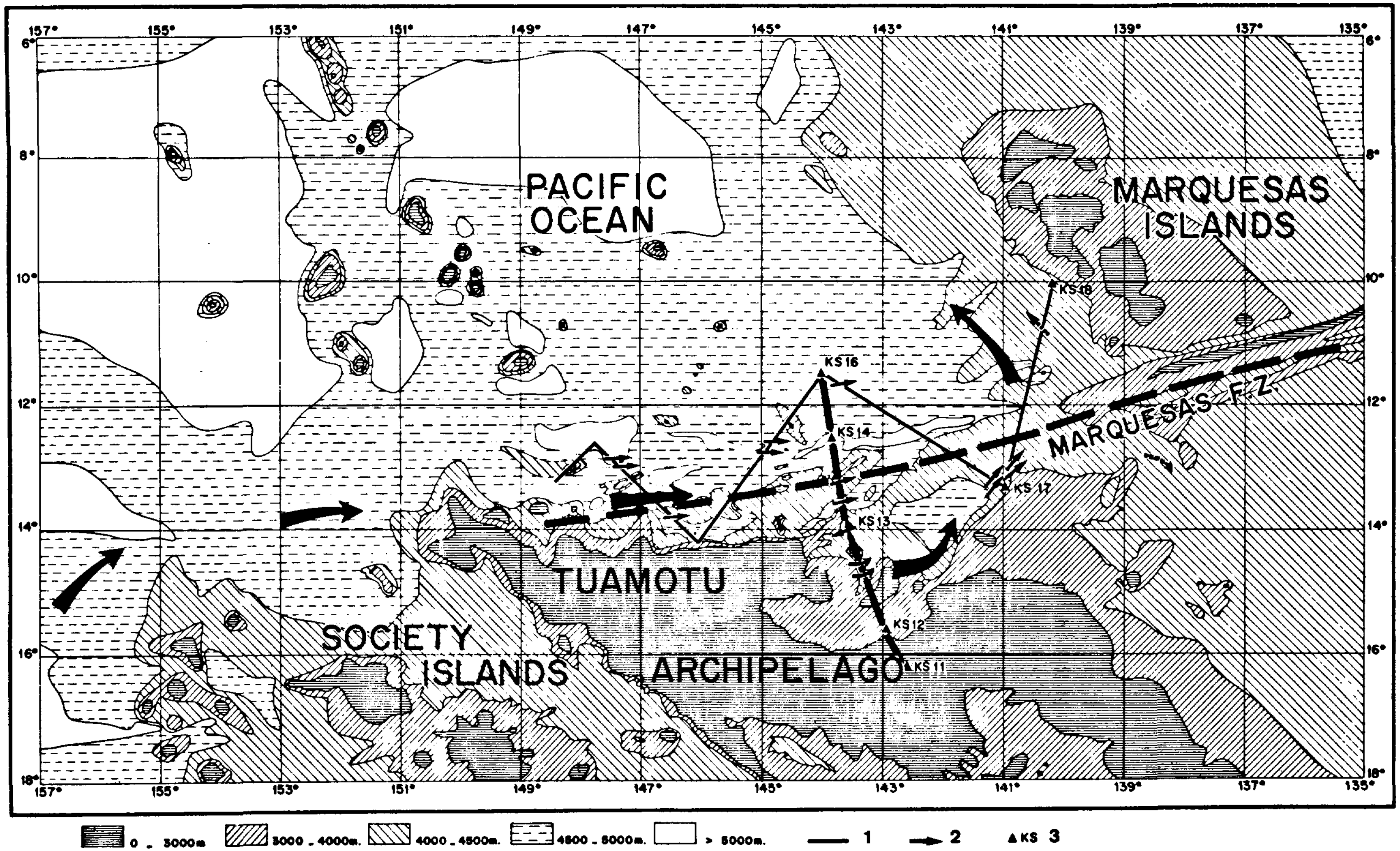

Fig. 1. Regional setting and general bathymetry of the Tuamotu Marquesas islands in the central south Pacific ocean:

1. seismic profiles
2. principal directions of the near-bottom current, deduced from the observation of the erosional structures
3. piston core

Dupont, 1974). The region studied is situated between the Tuamotu Archipelago and the Marquesas Islands (Fig. 1). This zone has been the subject of detailed bathymetric and structural research (Monti and Pautot, 1974; Pautot and Dupont, 1974; Pautot, 1975).

The course of the Antarctic Bottom Current in the South Pacific has been described, at least partially, by Wooster and Volkman (1960), and more recently by Hollister *et al.* (1974). The Antarctic Bottom Current enters the Pacific south of Tasmania, at the latitude level of the Pacific ridge, and flows in fracture zones through channels or basins at a depth greater than 4,000 m. From the Tonga-Kermadec trench, it flows into the Samoan Basin and then into the North Pacific through the Samoan Passage. Nevertheless all the Antarctic Bottom Water reaching the Samoan Basin do not flow through the Samoan Passage. A second passage exists. It was brought to light on the new bathymetric chart by Mammerickx *et al.* (1974) and named the Aitutaki Passage (Pautot and Melguen, 1975).

It seems that the Antarctic Bottom Water masses flowing through the Aitutaki Passage reach the Tuamotu-Marquesas zone. In effect, some hydrological measurements taken during the Transpac I cruise suggest the presence of a bottom current along the north flank of the Touamotou Archipelago. The Antarctic Bottom Current flows towards the east along Marquesas fracture zone (Pautot and Dupont, 1974), and reaches the Tiki Basin where it is probably stopped by the ridge. The Antarctic Bottom Water then flows towards the NW, overflowing into the Tapu Basin (Fig. 1).

II. Antarctic Bottom Current, erosional structures and sedimentary Hiatuses

The evidence given of the Antarctic Bottom Current flowing along the north flank of the Touamotou Archipelago explains the presence of erosional structures (for example: channel of erosion, Fig. 2, I and II) and of sedimentary hiatuses (for example: core KS 13, Fig. 2, III). The cores sampled a water depth of about 4,200 m. in the basins bordering the volcanic reliefs (Fig. 2, I) show a superposition of greatly differing facies and a stratigraphic gap (for example: sample KS 13, Fig. 2, III). At the top of the cores a few cms. of chocolate-brown mud ("Red clay" or mud) is Quaternary in age. Below this and separated by a very sharp contact is a white Upper Oligocene calcareous ooze.

The origin of this sedimentary hiatus, with a stratigraphic gap of almost 30 million years, has been discussed in detail (Pautot and Melguen, 1975). The Antarctic Bottom Current appears to be the major factor controlling the presence of this gap, by its influence on the "abyssal fractionation" of carbonates (Berger, 1970: Berger and Winterer, 1974) and on sediment erosion. The upper limit of the Antarctic Bottom Current corresponds, in the South Atlantic (Melguen and Thiede, 1974) as in the Pacific (Berger, 1974), with the water depth of the calcite lysocline. Towards 4,000-4,200 m. water depth, calcareous sediments and more particularly planktonic foraminifera are subject to a drastic increase in the degree of dissolution. Because of its relationship with the presence of the Antarctic Bottom Water masses, this water depth (4,000-4,200 m.) is also called "hydrographic lysocline" (Berger, 1974). The passage along the core KS 13 (Fig. 2) from a white calcareous ooze to a brown mud much poorer in carbonate reflects a great fluctuation of the hydrographic lysocline at the end of the Oligocene. Furthermore, it seems that the fluctuations of the lysocline (during Oligocene, upper Miocene, Pliocene, and Quaternary) (Berger, 1973, 1974)is linked to the pulsations of the Antarctic Bottom Water masses during the major Cenozoic glaciations (Watkins and Kennett, 1971; Weisell and Hayes, 1972). In effect, at the end of the Cenozoic, the intensity of the Antarctic Bottom Current fluctuated in response to worldwide climatic variations and particularly to the major oscillations of glacial and interglacial periods (Hayes *et al.,* 1969; Kennett, 1970). The corrosive flow of the Antarctic Bottom Current has played a role of primary importance in the presence of sequences of

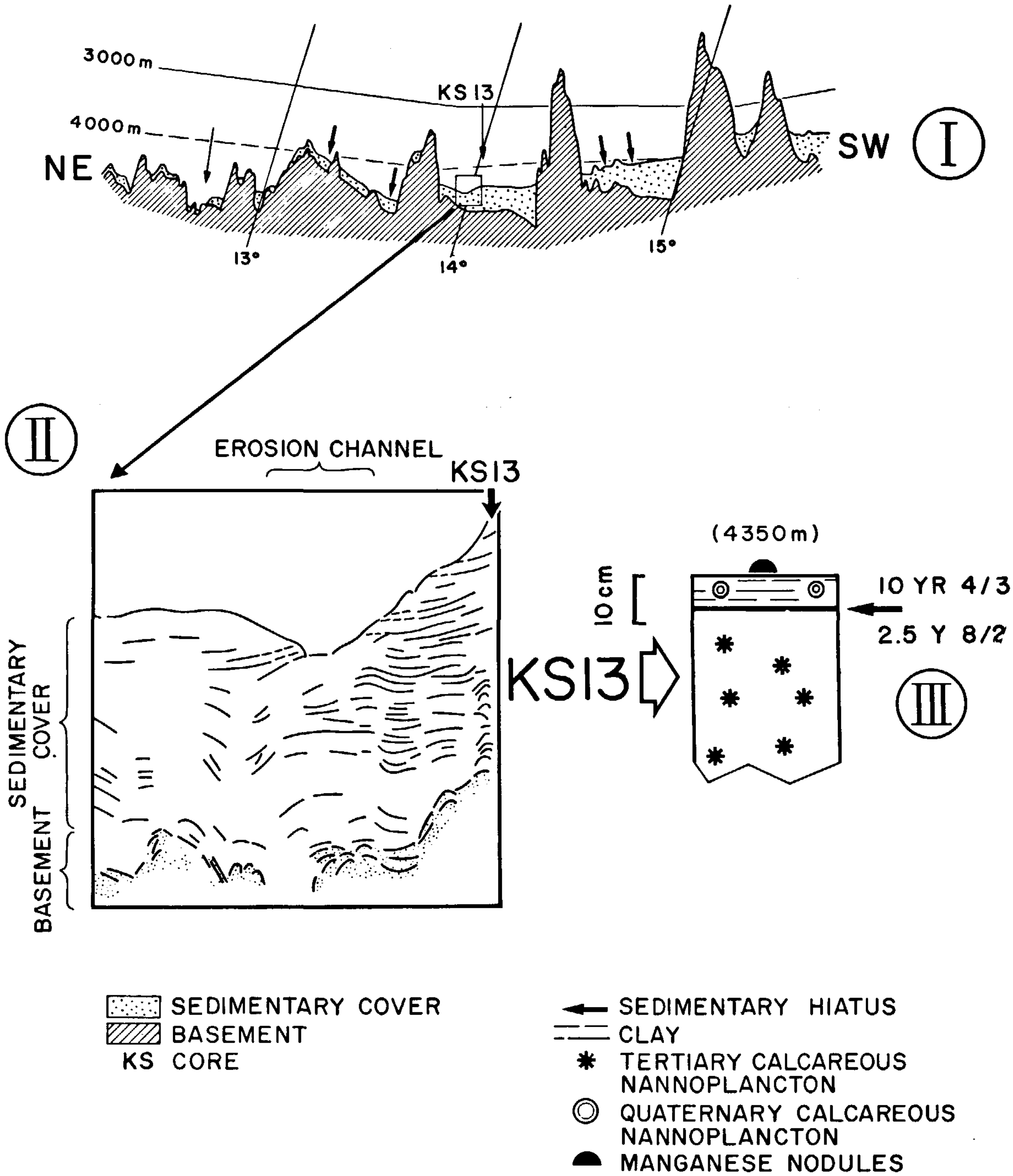

Fig. 2. Example of an erosional channel, cut through sedimentary strata by a near-bottom current, flowing in the Marquesas fracture zone. We suggest that the current corresponds to a branch of the Antarctic Bottom Current. Note the obvious asymmetry of both flanks of the channel and the location of core KS 13.

very low sedimentation rates (< 2 m./m.y., i.e. less than the normal sedimentation rate of abyssal clay) and of sedimentary hiatuses. The same observations were made in the South-west Atlantic, where Eocene, Oligocene, upper-Middle Miocene and Pliocene hiatuses were brought to light (Hayes *et al.*, 1973; Melguen and Thiede, 1974b; Perch-Nielsen *et al.*, 1975). The localisation of these hiatuses in the oceans is of primary importance for the reconstruction of the palaeocirculation of the deep water masses and, consequently, for the exploration of polymetallic nodules.

III. Antarctic Bottom Current, sedimentary hiatuses and polymetallic nodules

The analysis of results (put at our disposal by our colleagues from the Nodules Project) from the nodules-prospecting cruises in the South Pacific leads to the following observations:

(i) the ocean floor situated at depths less than 4,000 m. is poor in nodules and the nodules encountered there are economically uninteresting.

(ii) the ocean floor rich in economically interesting nodules is found at water depths greater than 4,000 m. (for example: the Tiki and Tapu Basins), that is, below the hydrographic lysocline, which itself, as previously indicated, marks the upper limit of the Antarctic Bottom Water masses, and also coincides with the distribution of sedimentary hiatuses. Similar observations have been made in the South Atlantic in the Vema Channel, where indurated beds rich in manganese nodules have been encountered. They are present in the zone of the Antarctic Bottom Current passage, at a depth of more than 4,200 m. They are associated with non-calcareous sedimentary facies (abyssal clay or "red clay" showing at least locally a Miocene-Lower Pleistocene sedimentary hiatus (Melguen and Thiede, 1947a, 1947b; Pautot and Melguen, 1975).

If, however, the present hydrographic lysocline delimits potentially rich zones of polymetallic nodules on the ocean floor, it is important to note that it has varied during the geological periods, correlating to the pulsations of Antarctic Water masses. Thus, in the Vema Channel, for example, it has undergone fluctuations in depth of 800 m. or more in the Miocene and Pleistocene (Melguen and Thiede, 1975). Therefore all polymetallic nodules exploration must take into account not only the present depth, but also the palaeo-depths of the hydrographic lysocline and the palaeo-bathymetry of the considered oceanic region: palaeo-bathymetry depending notably on the relative mobility of ocean plates, on subsidence, on tectonics, on major oceanic transgressions and regressions.

IV. Proposal for a "model" of formation and distribution of polymetallic nodules rich in nickel and copper

It is well known at present that polymetallic nodules form around a nucleus consisting of volcanic debris, of indurated clay, of fish teeth or of any other organic or inorganic debris exposed on a well-oxygenated sea floor with a low sedimentation rate (deep basins far away from continents) and situated near active volcanic zones (mid-oceanic ridge, volcanic chains). The bottom topography also controls the nature and the distribution of nodules (Menard, 1964; Barnes, 1967; Friedrich and Plüger, 1974) i.e. nodules rich in nickel and copper are concentrated in the basins, while nodules rich in cobalt are more frequent in higher regions. In spite of considerable number of dating studies undertaken on manganese nodules (isotopes, potassium-argon, biostratigraphy of nuclei of organic origin), the rate of formation of the nodules seems to remain an open question. Therefore no discussion on the subject is presented in this article. A particular emphasis is put on the episodic character of the nodules formation.

The cortex of manganese nodules, consisting of rings of growth, strongly suggests an episodic formation. Consequently, this reflects the presence of episodic factors in the environment of formation of the manganese nodules, factors such as volcanism and bottom currents. The proposed model (Fig. 3) is very largely based on these two factors.

The role of volcanic activity in the genesis of nodules was first studied at the level of the axis of the East-Pacific Rise (Transpac cruise): a zone where transition metals can be released in an ionic state in the sea water. But in the samples taken in the immediate proximity of the emissive zones of the ridge, we have found only fragments of manganese-rich crust. Furthermore, it seems that enrichment in nickel and copper must be looked for, not along the axis of an oceanic ridge but, above all, in the neighbourhood of the fracture zones cutting across this ridge. In the fracture zones, in effect, the bottom water is enriched in transition elements (enrichment confirmed by the results of the Geosecs programme). The enrichment of the water comes about either by weathering of outcropping ultrabasic rocks or from hydrothermal sources. At the outlet of the fracture zones the flow of water enriched in metallic ions meets the cold bottom current. Low temperatures and an oxygenated environment are favourable to the precipitation of metallic ions and the crystallisation of solid phases. Nickel and copper can not only be transported in an ionic state but also be fixed on biogenic fragments, organic matter or shells. The fixation of these metals on calcareous micro-organisms certainly plays an important role in the genesis of nodules. In the abyssal depths, at the level of the hydrographic lysocline, calcareous organisms, abruptly dissolved by corrosive cold water masses, free metallic ions, which precipitate on a substrate: a fragment of volcanic rock, erratic rock fragment or indurated argile. The precipitation of transition metals seems to take place preferably between the hydrographic lysocline and the carbonate compensation depth or approximately between 4,100 and 5,000 m. At greater water depths, their amounts diminish. The enrichment of

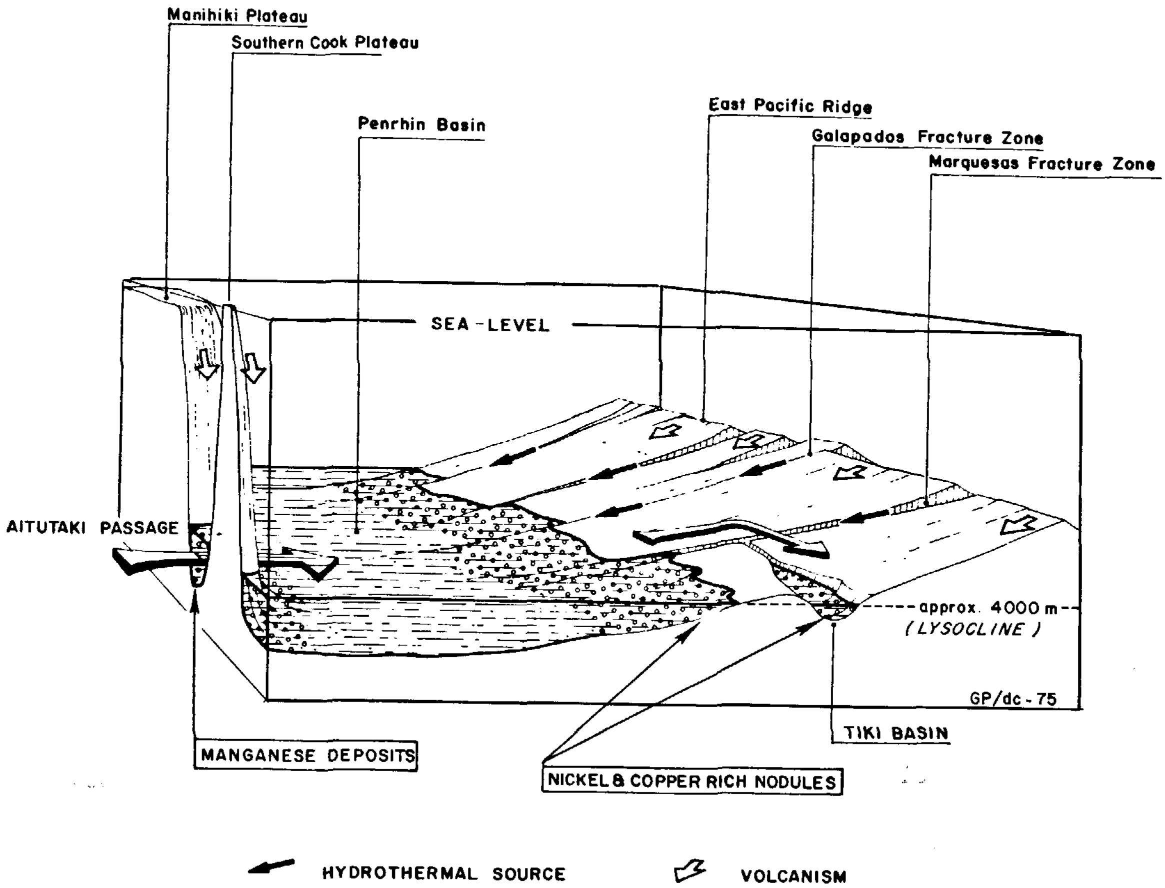

Fig. 3. Model proposed as "guide" for future exploration of nickel and copper rich manganese nodules. This model is a tentative synthesis of the primary factors interfering in the polymetallic nodules distribution.

nodules in nickel and copper is a function not only of the availability of metallic ions in the water and their rate of precipitation but also of the rate of precipitation of the manganese. In a well oxygenated environment (*i.e.* zones with local acceleration of a bottom current: channels, base of a great depth), the precipitation of manganese is rapid and the dilution of transition metals by the manganese is important. Consequently, the manganese nodules which are the richest in nickel and copper are found on sea floor swept by bottom currents but more in zones of deceleration (and therefore less oxygenated) then in those of acceleration of these currents. The example of the Tiki and Tapu basins is significant.

CONCLUSIONS

From the evidence presented on the study of a bottom current and its relationship with the sedimentary environment surrounding it and the distribution of polymetallic nodules, we are trying to establish the importance in the genesis of polymetallic nodules of currents and bottom palaeocurrents, of fluctuations in the hydrographic lysocline, of the distribution of zones of volcanic activity and of oceanic fracture zones. In integrating previously known criteria with these deductions from our observations in the South Pacific, we propose (Fig. 3) a model of formation and distribution of "nickel- and copper-rich nodules", that is to say of nodules of economic interest. In brief, in the South Pacific, a field of "nickel- and copper-rich nodules" will be found:

(i) far from continents (in order to avoid dilution of metallic ions by a too rapid rate of sedimentation);

(ii) in an area with a thin sedimentary cover (showing the absence of reworking of sediments, and of turbidity currents);

(iii) in the proximity of an active oceanic ridge, cut by fracture zones (a source of metallic ions and a circulation area for waters enriched in metals towards the abyssal depths);

(iv) not far from active volcanic relief (a source of metallic ions and of nuclei of crystallisation);

(v) on the course of bottom currents, but even more in a zone of deceleration of these currents (a zone sufficiently oxygenated to allow the precipitation of nickel and copper, but not favourable to a too rapid precipitation of manganese);

(vi) at a greater depth than that of the hydrographic lysocline (4,100-4,200 m., a zone of intensive dissolution of carbonates).

In the context of nodule exploration, these criteria may serve as a "guide". This guide, however, must depend not only on knowledge of the present oceanic environment but also on that of the palaeo-environment: palaeobathymetry, palaeo-currents, and palaeolysocline.

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