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Extensive Magmatic and Hydrothermal Activity Documented in Manus Basin

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In 1995, a joint French-Japanese cruise (ManusFlux) explored the Manus Spreading Center and some sites of the South Eastern Rift in the Manus Basin off the coast of Papua New Guinea (Figure 1) with the Japanese submersible [*Auzende et al.*, 1996; *Gamo et al.*, 1997]. In the framework of this joint project, called New STARMER, the French and Japanese teams completed the Manaute cruise with the R/V *LAtalante* and the Ifremer submersible *Nautile* in April and May 2000.

The Manaute cruise explored and sampled volcanic and hydrothermal sites in the eastern part of Manus Basin and on the spreading axis of the Western Ridge (WR). The eastern part of the Manus Basin (Figure 2) was interpreted as a stretched-back arc basin crust showing alternatively elongated ridges and isolated volcanoes where accretion and hydrothermal activity are distributed [*Martinez and Taylor*, 1996; *Binns et al.*, 1993].

Alternatively, oceanic accretion could be present in the eastern part of the Manus Basin, restricted to localized zones, with the main part of the extensional processes being absorbed on the volcanoes and volcanic ridges. The most plausible interpretation is that the spreading sensu stricto is confined on two N45-trending grabens and ridges; one to the east of Pual Ridge and one perpendicular to the Susu Knolls system (Figure 2).

The junction between both features is marked by a succession of *en echelon* ridges and volcanoes aligned along a wide transverse zone trending N110. However, it is now clear that the volcanic material supply and the hydrothermal activity of this zone is not only concentrated on spreading axes, but is distributed on numerous active volcanoes, the origin of which likely results from the subduction along the Manus and New Britain Trenches. The nature of rocks sampled on the volcanoes confirms this interpretation. They are essentially constituted of dacitic bodies piercing andesitic substratum [*Binns et al.*, 1993].

Six *Nautile* dives and thirteen dredges have been carried out in the South Eastern Rift to evaluate the areas volcanic and hydrothermal activity. One diving site was located on a spreading axis and five others on non-spreading features. All of the dredge sites were located on isolated volcanoes and ridges (Figure 2). The Manaute cruise made several discoveries.

First, the two N45 features (Eastern Rift Graben and Kalivuvur - Figure 2) that were interpreted as resulting from the stretching of the Manus arc crust [*Martinez and Taylor*, 1996] are active spreading axes. *Nautile* exploration of the Kalivuvur shows active faulting and accretion in an axial graben similar to a medio-oceanic ridge axis.

Second, a major part of the volcanoes and ridges constituting the N110 volcanic line (see above) are active.

Three Active Volcanoes

It was known that the Pacmanus and Desmos sites were active with fresh magmatism and active hydrothermal venting [*Craig*

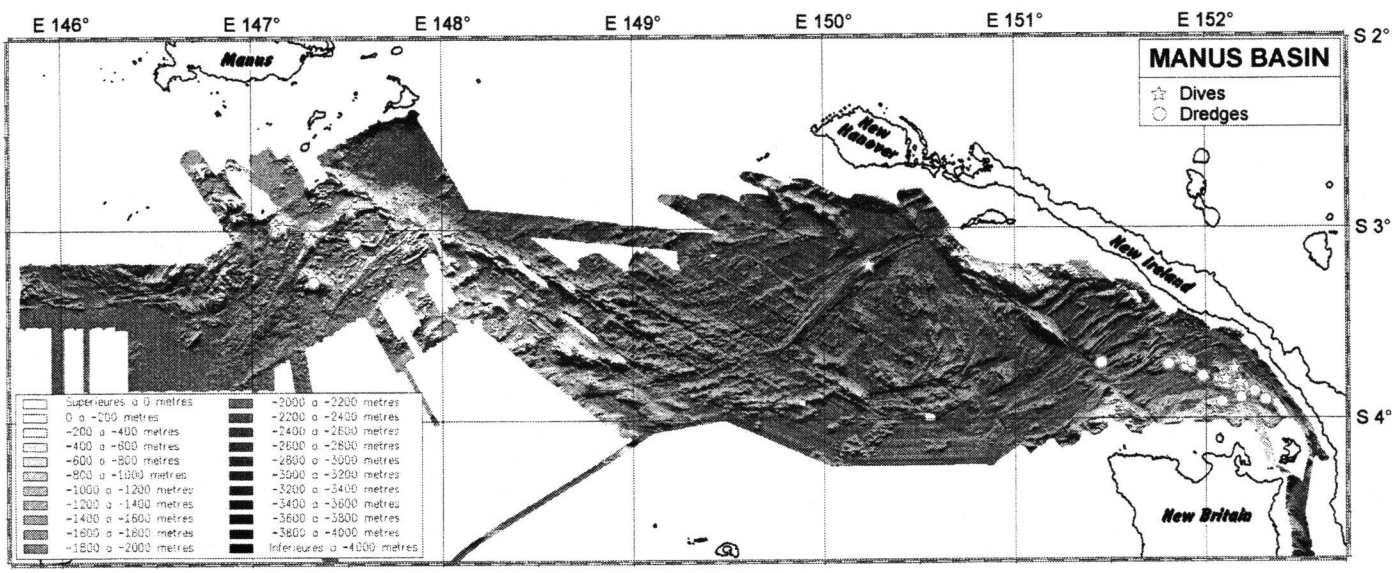

Fig. 1. General bathymetric map of Manus Basin derived from swath-mapping surveys carried out during the ManusFlux and Manaute cruises. The central part of the Basin was surveyed by Sea Mark [Martinez and Taylor, 1996].

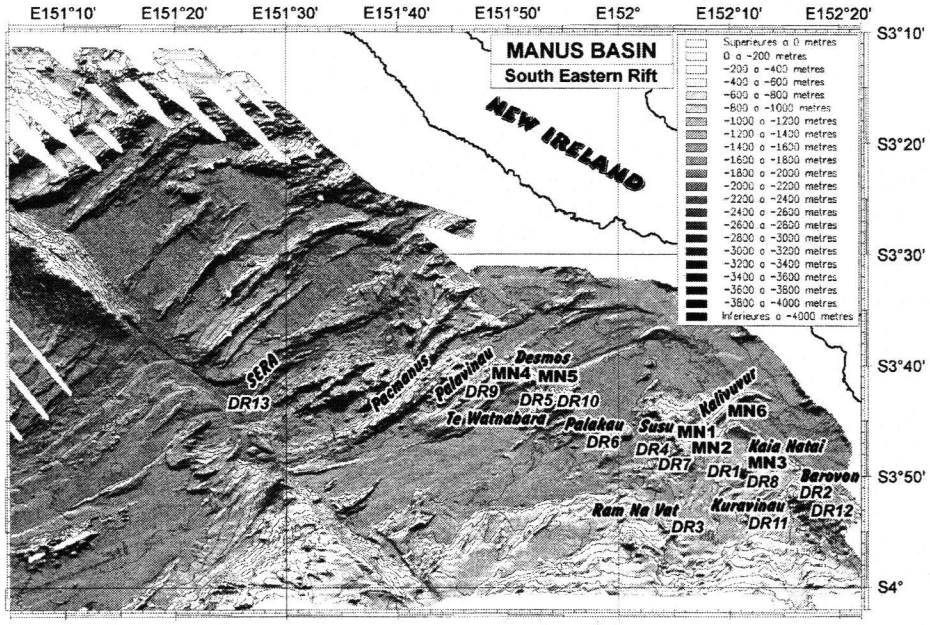

Fig. 2. Simplified swath-map of the eastern part of Manus Basin. The contour interval is 50 m; MN: number of Nautile dives; DR: number of dredgings. The names given to the volcanoes and ridges are in the Tolai language of New Britain. Kaia Nata: undersea volcano ; Kalivuvur: tempest ; Barovon: dream ; Kuravinau: chaotic vines ; Ram navat: stone clubs ; Palakau: footprints ; Te Watnabara: coconut boy ; Palavinau: chaotic vines.

and Poreda, 1987; *Both et al.* 1986; *Binns et al.*, 1993; *Auzende et al.*, 1996; *Gamo et al.*, 1997]. During the cruise, active sites such as Susu knoll and Kaia Natai volcano (Figure 3) were explored. Susu knoll is characterized by three volcanoes (called Suzette, North-SU, and South-SU, respectively) aligned on a N140 direction that is close to the direction of fracture zones.

The three volcanoes are hydrothermally active, with small vents expelling waters with temperatures ranging from 50°C on the southern mound (South-SU) up to 220-280°C on the two other mounds (Suzette and North-SU). Above these three mounds, the methane and nephelometric sensors detected large methane and nephelometric anomalies.

In the same area, the Kaia Natai isolated volcano shows fresh acidic lavas at its base and a thick coverage of iron-rich hydrothermal sediments, barite, and polymetallic sulfides between 1300 m-depth and its summit at 1035 m. The Kaia Natai volcano is cut by N140 faults on which active hydrothermal vents are located. These vents are characterized by small yellow domes that expel shimmering water through a relatively thick (several centimeters) cover of bacteria mats, which are the only evidence of animal colonization of the area. Temperature measurements in this water show a 38°C elevation, which is low and could explain the nature of animal colonization.

Dredges on the volcanoes and ridges indicated on the map of Figure 2 have all shown that they are built by acidic rocks, as already demonstrated for the Pacmanus and Desmos sites. Most of them suggest the presence of hydrothermal venting and alteration (oxides, manganese coating, sulfides, sulfates, etc.).

Until now, the Western Ridge axis (Figure 4) was very poorly known. Except for a multibeam bathymetric map drawn by Metal Mining of Japan (unpublished, 1995) no other data or sampling were available in this area. Five dives and four dredges allowed us to confirm that it is an active ridge axis system that is schematically constituted by two ridge axes propagating rapidly to the southwest. These ridges are characterized by an extremely shallow depth, the top of the eastern one being less than 200 m deep, and the top of the western one being about 600 m deep.

In addition to the spreading system, the entire area is dotted by tens of isolated volcanoes, several of which have calderas on their summits. The eastern axis is characterized by a succession of N45-trending shallow ridges and depressions propagating to the southwest up to 3° 30 S. The western-propagating axis cuts volcanoes and calderas as shown on Figure 4. The very large caldera, about 40 km in diameter, centered on 2° 50 S, has been spectacularly divided in two halves by the present-day axis. The same figure is observed at Mata na Taru site, where the present-day axis cross-cuts a large axial volcano.

The five dives and four dredges carried out in the Western Ridge region (Figure 4) permitted the confirmation of the present-day accretion along the two axes defined above, but also the present-day activity of volcanoes located close to the axes. The two axes are characterized by extremely fresh lava supply with vesicular, glassy rocks and pumices. Considering the thickness of the observed glass and the abundance of in situ pumice, the samples are probably very acidic. Active hydrothermal venting has been observed on the Mata na Kul site, where it is marked by low-temperature (28-30°C) shimmering water and bacteria mats more than 30 cm thick.

During all the other dives on the axis, although no direct observation of venting was made, the CTD and in situ Mn analyzer installed on the submersible *Nautile* detected large manganese anomalies up to several tens of nanometers on the bottom, which indicates the proximity of vents. Dredging has confirmed this hydrothermal activity; numerous pieces of barite and silica-rich chimneys, manganese, iron and silica crusts, oxides, and sulfides were sampled, especially on sites Vat na Ingiet, Mata na Taru, and Mata na Kul.

This cruise in the Manus Basin confirms the magmatic and hydrothermal activity on the South Eastern Ridge. Furthermore, it allows one to identify with precision the location of this activity, which is distributed on the active spreading axis, but also along volcanic ridges and a series of isolated volcanoes. The major result of the cruise is the first demonstration of the so-far unknown, intense, recent magmatic and hydrothermal activity of the Western Ridge.

In these two regions the South Eastern Ridge and the Western Ridge the magmatism and hydrothermalism are related to the felsic nature of the crust in these parts of the Manus Basin, which is still considerably contaminated by arc volcanism related to subduction in the New Britain Trench.

Meanwhile, as already known in the central part of the Basin, rocks in the Manus Spreading Center exhibit N-morb properties and related hydrothermal characteristics. We expect that the rocks erupted at active spreading axes in the South Eastern Ridge (SERA and Kalivuvur) and that the Western Ridge (Limana Kaia, Nat na Vavina, and Mata na Taru) may have signatures intermediate between typical N-morb and the felsic rocks sampled on isolated volcanoes.

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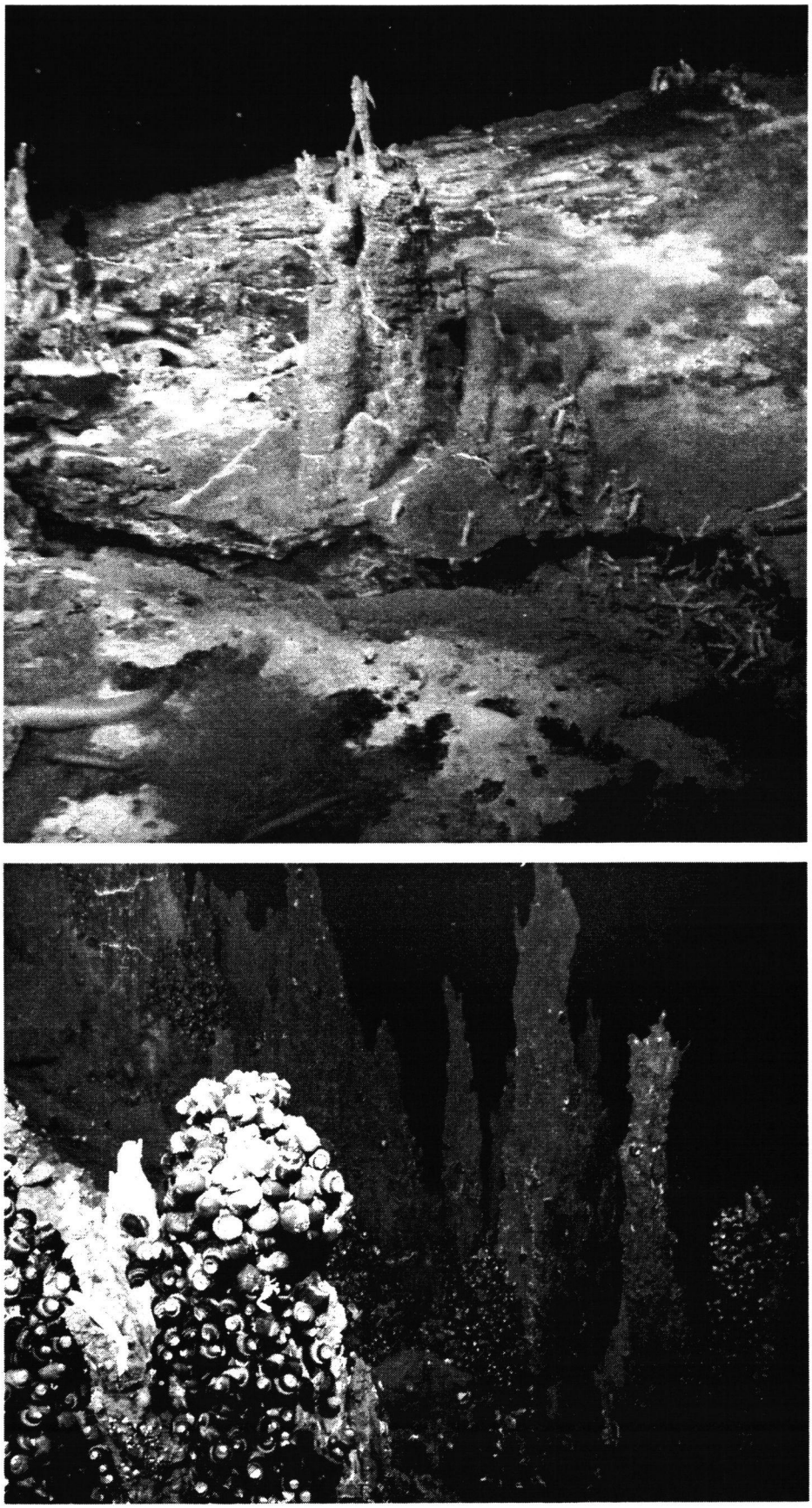

Fig. 3. (top) Susu north active site; (bottom) Suzette active site.