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Takeshi MATSUMOTO Jiro NAKA
Yoshiharu NAGAYA Kei OKAMURA

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Jean-Marie AUZENDE[*1] Tetsuro URABE[*2] Etienne RUELLAN[*3] David CHABROUX[*3] Jean-Luc CHARLOU[*1] Kaul GENA[*4] Toshitaka GAMO[*5] Katell HENRY[*1] Osamu MATSUBAYASHI[*2] Takeshi MATSUMOTO[*6] Jiro NAKA[*6] Yoshiharu NAGAYA[*7] Kei OKAMURA[*5]

The Manus Basin spreading system consists of three main ridge segments separated by Wuillaumez, Djaul and Weitin Fracture Zones. The aim of Manusflux cruise of the R/V "Yokosuka" and the submersible "Shinkai 6500" was the *in situ* exploration of the Central and Eastern ridge segments and the study of the associated hydrothermal activity. On each segment active hydrothermal sites have been explored and sampled. They show all types of activity from low temperature diffusion up the black smoker stage. They are located on the fault zones which affect the basaltic or dacitic rocks constituting respectively the Central and Eastern ridge segments.

Key words : South-West Pacific, Manus Basin, Geology, Hydrothermal processes, Submersible.

* 1 IFREMER/CB, France (Present : BPA 5 Nouméa cédex, Nouvelle Calédonie)
* 2 Geological Survey of Japan
* 3 CNRS, Géosciences Azur, France
* 4 University of Papua New Guinea (Present : Akita University)
* 5 Ocean Research Institute, University of Tokyo
* 6 Deep Sea Research Department, Japan Marine Science and Technology Center
* 7 Hydrographic Department, Maritime Sefety Agency

1. Introduction

The Manus basin is one of the intra-arc or back-arc basins aligned along the Australian and Pacific Plates boundary (Fig. 1). It is limited by Manus island to the north, New Ireland to the east, Papua New Guinea to the west and New Britain to the south (Fig. 2). The whole domain constitutes the Bismarck plate. Structurally the Manus basin is bounded by the fossil Manus subduction zone to the north and to the south by the tectonically active system formed by the New Britain trench and the folded and overthrusting suture of Papua New Guinea. The emerged areas surrounding the Manus basin constitute an ancient tertiary volcanic arc (Francis, 1988 ; Stewart and Sandy, 1988), part of the unique arc separating the Australian and Pacific plates (Gill and Gorton, 1973 ; Falvey, 1975 ; Coleman and Packham, 1976 ; Taylor, 1979 ; Kroenke, 1984 ; Auzende et al., 1988) at that time and dismembered during the opening of Manus basin about 4Ma ago (Falvey and Pritchard, 1985). Different models have been proposed to explain the Manus basin creation, from diffuse accretion (Hamburger and Isacks, 1988) up to a complex system combining accretion, rotation of microplate and stretching (Martinez and Taylor, 1996) passing trough a simple oceanic spreading (Taylor, 1979 ; Taylor and Karner, 1983).

The present day spreading in the Manus Basin is located on 3 successive NE-SW trending ridge segments (Fig.3) offset by N120 transform faults, Weitin

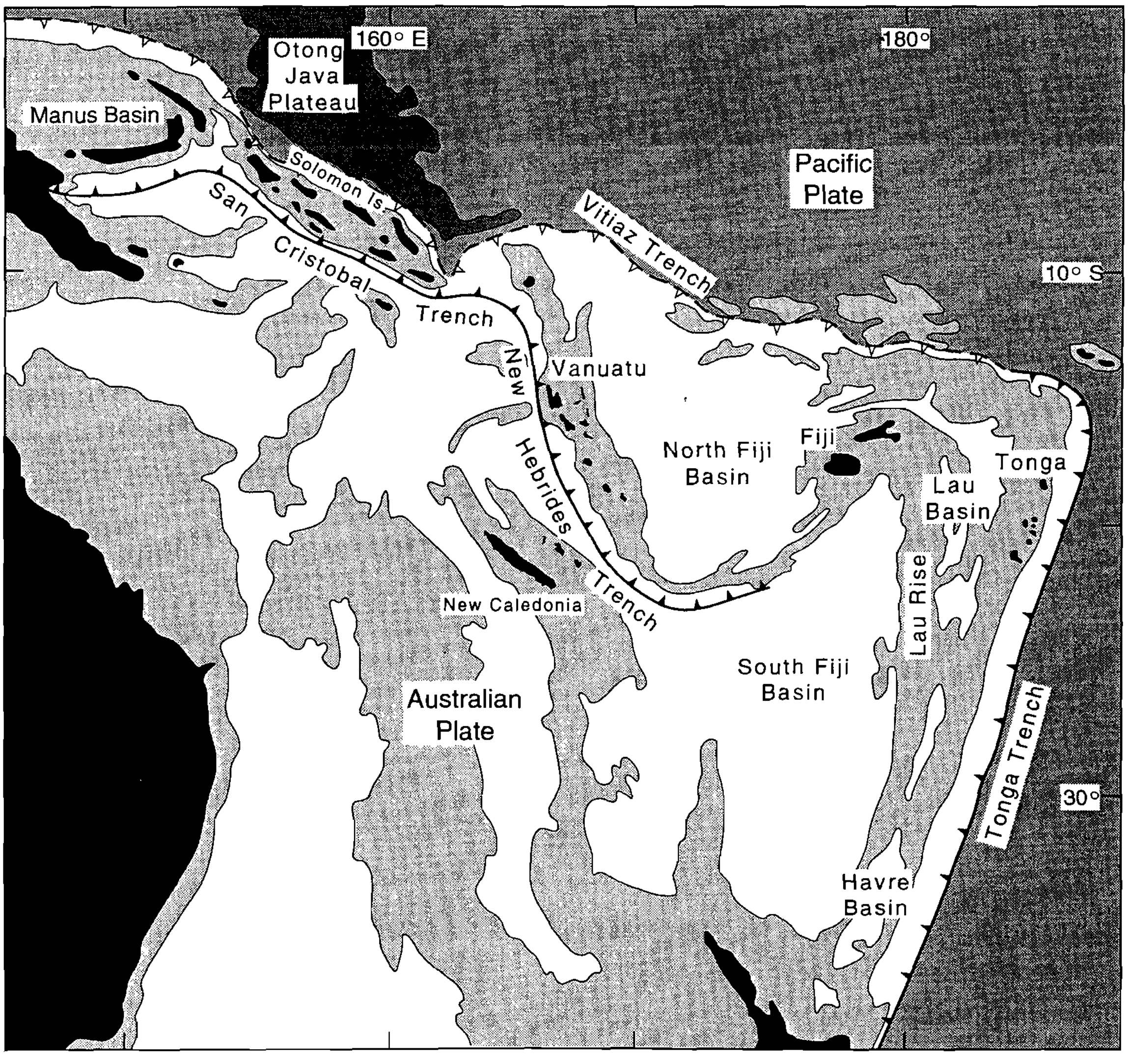

Fig. 1 General map of the South West Pacific area (from Auzende et al., 1996).

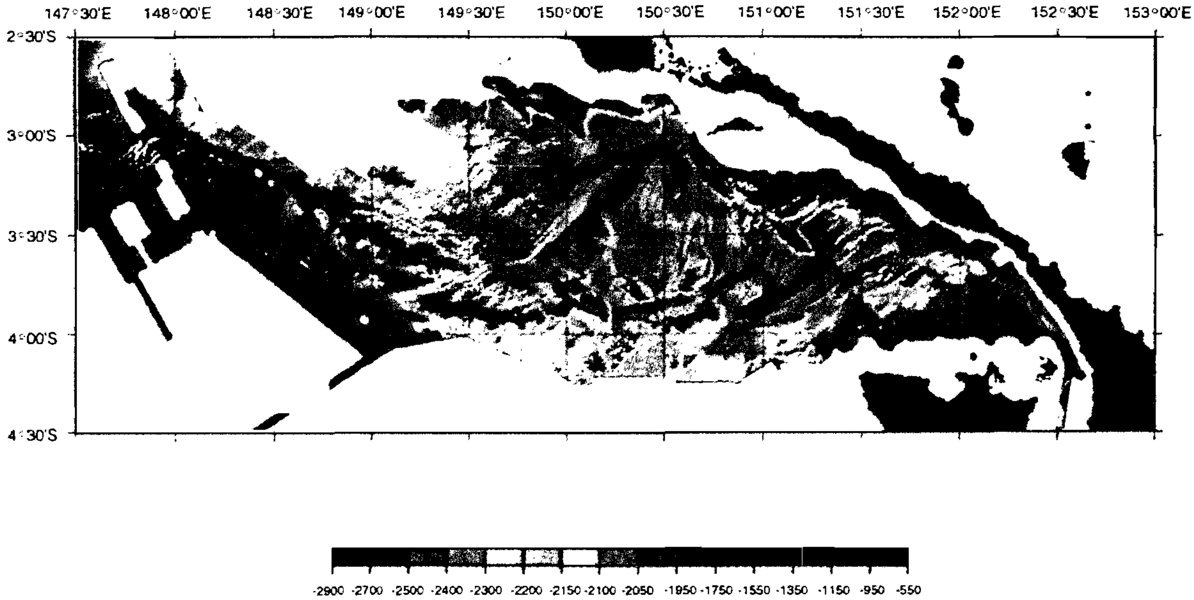

Fig. 2 General bathymetric map of the Manus Basin. This map is a compilation of SeaMark II data from University of Hawaii, Hydrosweep data from Metal Mining Agency of Japan and Furono multibeam survey of ManusFlux Cruise.

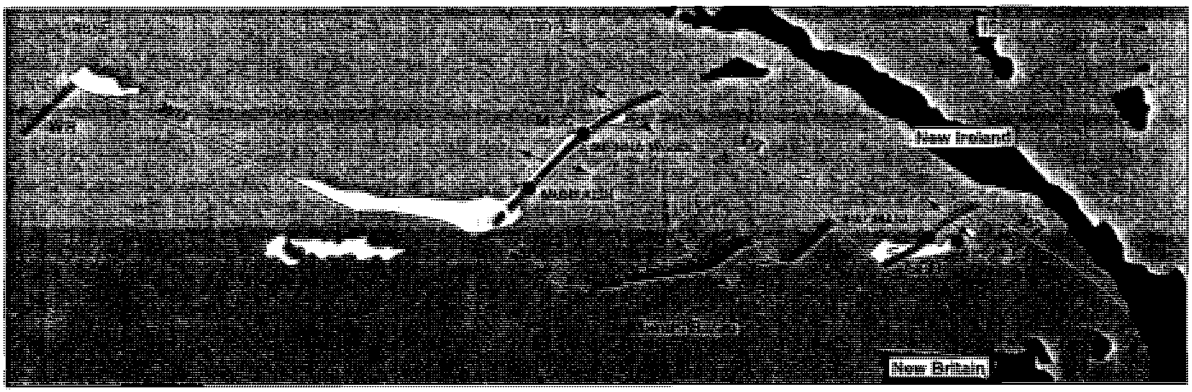

Fig. 3 Geodynamic sketch of the Manus Basin accretionary system. (modified after Martinez and Taylor, 1996).

and Djaul FZ to the east and Willaumez to the west (Taylor, 1979 ; Tufar, 1990 ; Taylor et al., 1991 ; Binns and Scott, 1993 ; Martinez and Taylor, 1996). The main surveyed segments are the Manus Spreading Center (MSC) in the central part between 3°and 3°40'S, centered on 150°E and the Southeastern rift (SER) abutting toward the east against New Ireland. Both segments have been covered by bathymetry, imagery and geophysics (Tufar, 1990 ; Taylor et al., 1991) and also by deep towed photographs, dredging, and indirect measurements in order to identify hydrothermal activity (Binns and Scott, 1993). The MSC geometry is relatively simple. It is a 120km-long ENE-WSW linear ridge culminating in its southern tip at less than 1,900m-deep showing a change from a ridge morphology in the south to a graben morphology in the north. Its spreading rate calculated from magnetic lineation analysis varies from 100mm/y in its southern part to zero in its northeastern one (Martinez and Taylor, 1996). The SER is made of an "en échelon" succession of segments comprised between Djaul and Weitin FZ. Due to the lack of associated magnetic lineations, Martinez and Taylor (1996) interpret this segment as a stretching zone better than a spreading zone.

On both MSC and SER segments, active hydrothermalism has already been described (Lizitsin et al, 1990 ; Binns and Scott, 1993 ; Gamo et al., 1993) respectively at Vienna Wood, PACMANUS and DESMOS sites.

The aim of the Manusflux cruise of the R/V "Yokosuka" and the submersible "Shinkai 6500" (16 October-13 November 1995) was, within the New Starmer French-Japanese joint programme, the in situ exploration and sampling of the Manus ridge segments and active hydrothermal sites previously surveyed by indirect measurements and the exploration of the MSC in order to detect new hydrothermal sites. This multidisciplinary cruise involved geophysicists, geologists, chemists and biologists from Japan, France, Papua New Guinea, Australia and Canada.

2. Results of ManusFlux Cruise

Both the Central Spreading Center (MSC) and the Eastern Spreading Ridge (SER) were explored during the 15 dives of ManusFlux Cruise.

2.1 The Manus Spreading Center (MSC)

The present spreading axis shows a linear structuration with a N45 trending ridge in its southern part up to 3°15′ S changing to N65 northward (Fig. 4). Acccompanying this change of trend, the morphology also changes from a ridge in the south to a double graben in the north.

On the Manus Spreading Center (MSC), two zones have been selected :

In the southern part of the ridge axis, one dive was performed on a peculiar feature represented by a volcano, located in the axial part of the ridge. This volcano shows very steep walls and culminates at less than 2,000m-deep (Fig. 5 a). Due to its shape it has been named Munkalin (Razor-back in Papuan dialect). The explored slope (Fig. 6) of Munkalin is mainly constituted by N-MORB pillows, as already suggested by Lisitsin et al. (1990). The major part of the pillowed slope is covered by sediments and few fractures and fissures trending NW-SE have been observed. In the upper part of the slope around 2,200 to 2,100m-depth, white material covers the rocks and is probably constituted by bacteria accu-

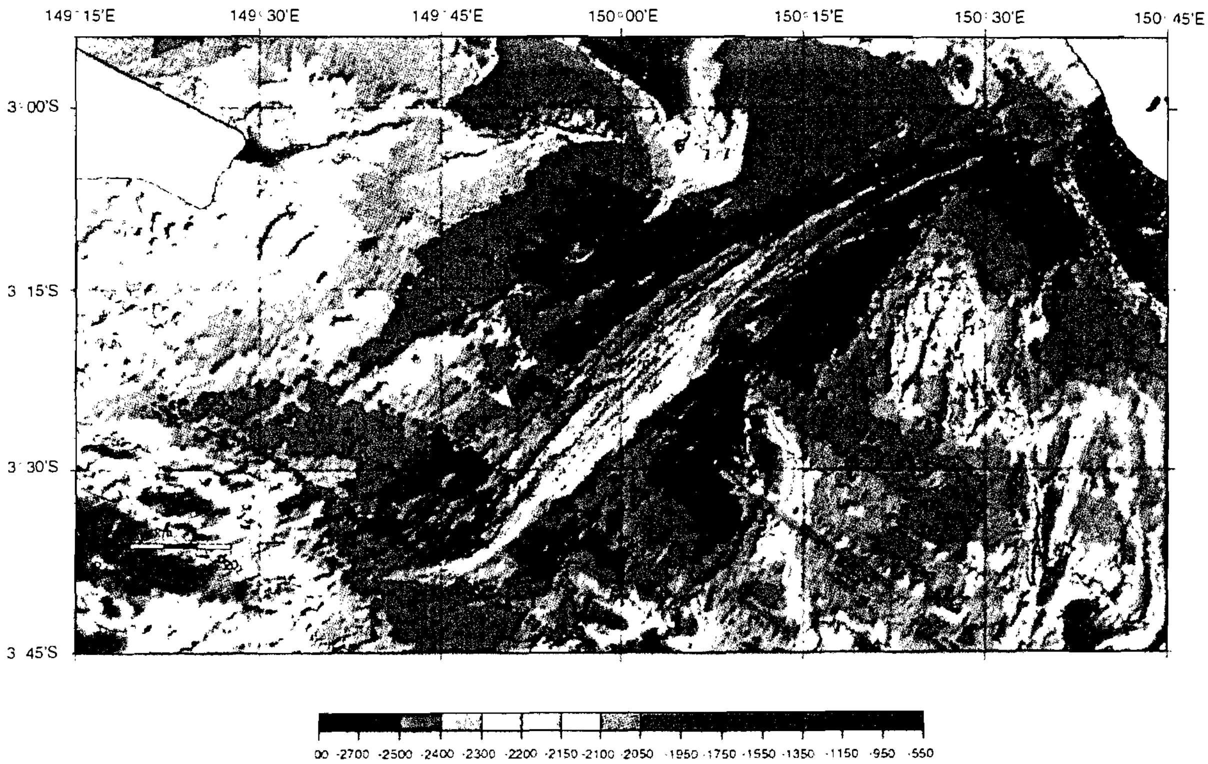

Fig. 4 Bathymetric map of the Manus Spreading Center obtained by the compilation of SeaMark, Hydrosweep and Furono multibeam data.

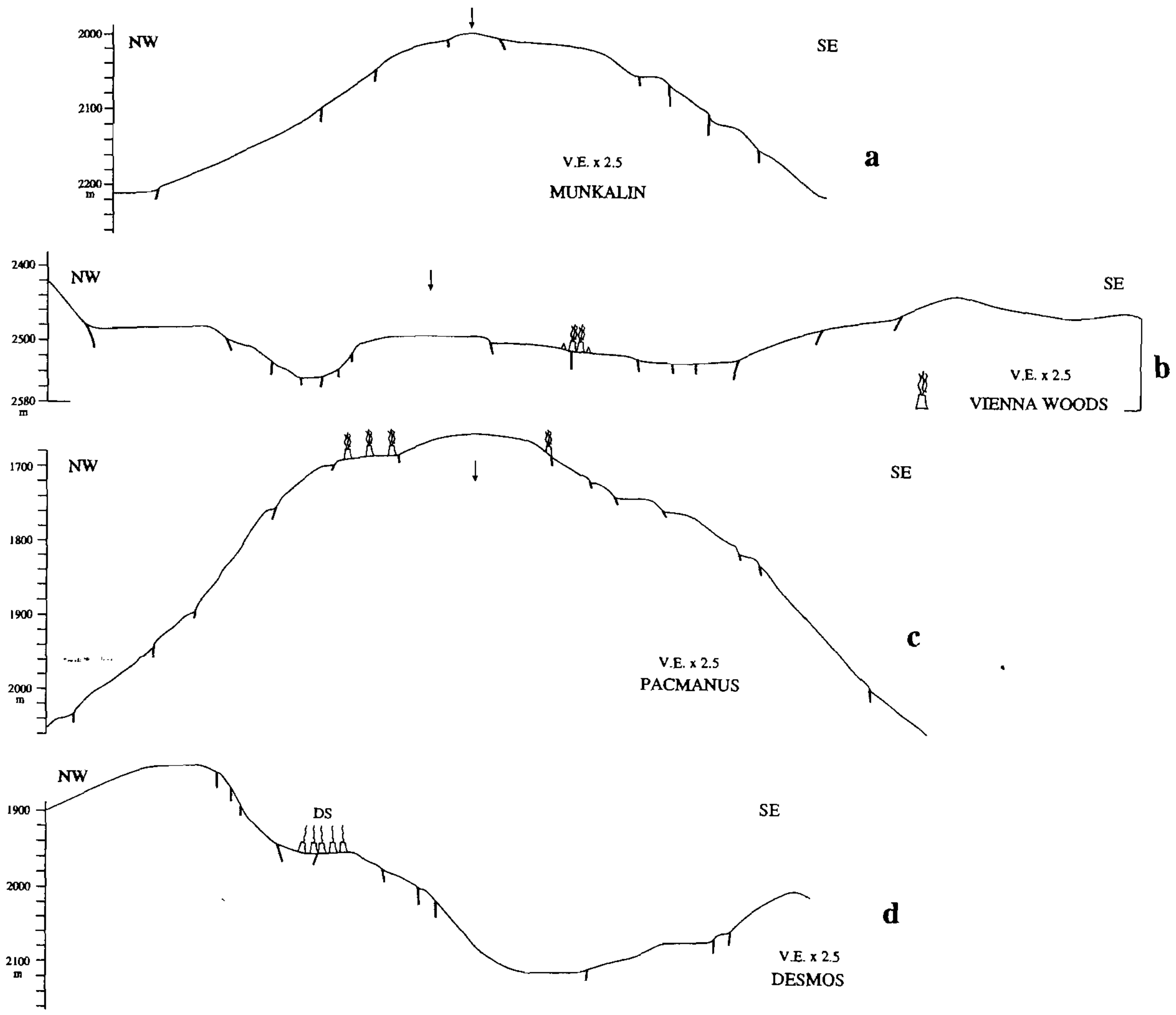

Fig. 5 Topographic sections of the different areas explored during the ManusFlux Cruise dives. a)-Munkalin volcano, b)-Vienna Woods zone, c)-PACMANUS zone, d)-DESMOS zone.

mulation. The top of the massive from 2,100 to 1,980 m is occupied by very fresh ropy lava and sheet flows imbricated in successives flows. The extreme top of the volcano is fracturated by NE-SW faults and fissures which represent the beginning of graben formation in which have been observed very fresh, glassy, scoriated lava flows. A preliminary onboard analysis shows that the lava sampled on the upper slope and the top of Munkalin are of andesitic type.

The second explored zone on the MSC, is located in the northeastern part of the ridge where a drastic change occurs in the ridge morphology from a dome-shape axis to a central graben cut in its axial part, by a neovolcanic ridge (Fig. 5 b). Five dives were carried out around the Vienna Woods area discovered in 1989 (Tufar, 1990) and already explored by Russian submersible MIR (Lisitsin, unpublished report, 1990). It is located at 2,500m-depth in the axial graben at 3°09′45″S and 150°17′E on a fault bounding to the SE the neovolcanic ridge. The area of lobated lava and pillows located in the vicinity of Vienna Woods site shows an intense N60 and N120-140 fissuration. The Vienna Woods hydrothermal site is an important field of active and fossil chimneys about 300m in diameter (Fig. 7). The main explored chimneys, 10 to 15m-high on the top of a sulfides mound, expell a 285° to 300°C shimmering fluid. The chimneys are made of anhydrite, sulfides, oxydes and silica. The associated fauna is essentially constituted by gastropods (*Alviniconcha Hessleri,*

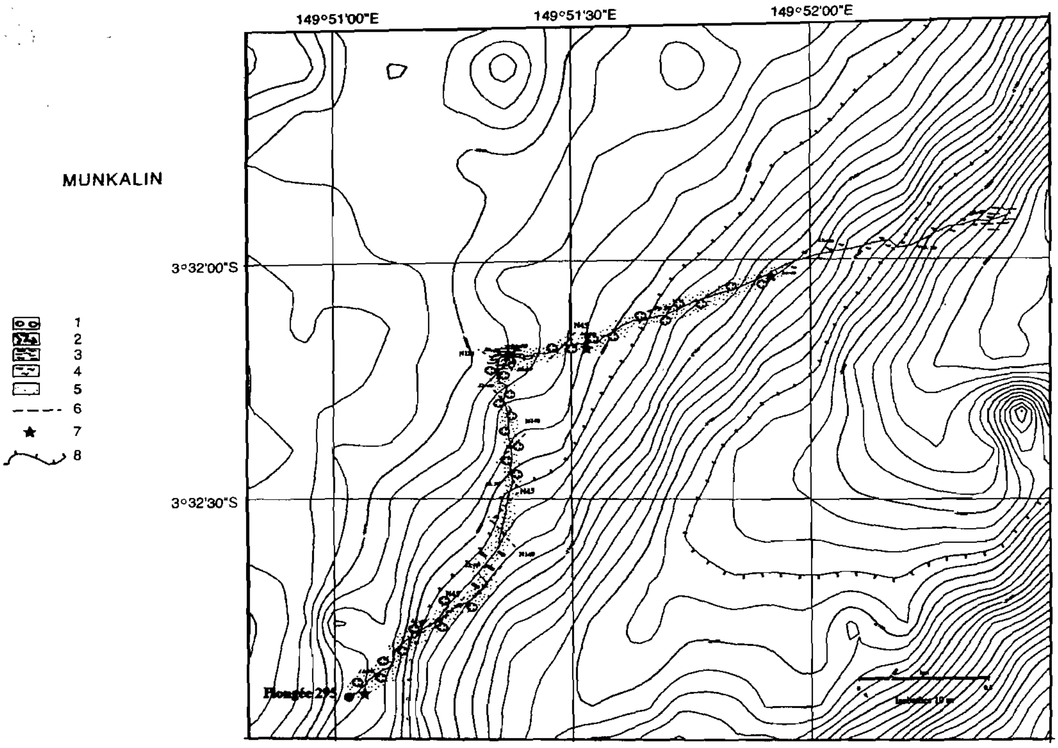

Fig. 6 Geological map of the Munkalin volcano resulting from dive observations (after Chabroux, 1996) : 1-Pillow lava ; 2-Lava tubes ; 3-Sheet flows ; 4-Ropy lava (Aa type) ; 5-Uniform sedimentary cover ; 6-Fissure ; 7-White bacterial mat ; 8-Bathymetric contours.

Ifremeria Nautilei and a new specie), bythograeids crabs, galatheids, shrimps and cirripeds. These petrological and biological characteristics combined with the temperature and nature of the fluids, are close to those observed on White Lady site, on the Central Spreading Ridge of the North Fiji Basin, discovered and studied during the STARMER project (Auzende et al., 1991 ; Desbruyères et al., 1994).

2.2 The Southeastern Rift (SER)

In the eastern corner of the Manus basin, east of the Djaul transform zone, the SER is a more complex system closer to an extensional zone rather than a typical oceanic spreading zone. The spreading is probably concentrated along an axial rift but occurs also, for a minor part, on a series of parallel ridges (Fig. 8). Some of these ridges are tectonically and hydrothermally active. That is, for example, the case of Pual Ridge on which is located the PACMANUS Site explored during ManusFlux dives. Pual ridge is a Y shaped ridge with steep flanks (Fig. 5 c) culminating at less than 1,700m-deep. It shows a sucession of mounds, 50m-height aligned along a N 65 trend and separated by NS-structurated saddles. It is mainly in these saddles and along the summit edge of the massive that are located the active hydrothermal vents of PACMANUS site.

The PACMANUS site was discovered in 1990 (Binns, Wheller et al., 1991) during a deep-towed video-photographs profile. During the five dives carried out in this area, five active sites and four inactive deposits have been explored (Chabroux, 1996) (Fig. 9). Different zones have been distinguished in the PACMANUS site. The first one at 1,654m-depth on the top of the Pual Ridge shows inactive chimneys made of sulfides and active vents characterised by white-shimmering fluids, the temperature of which varies from 85 to 104℃. East of this first zone in a saddle separating two mounds, another site is characterised by 2 to 3 m-height chimneys expelling shimmering waters, the temperature of which varies from 220 to 268℃. The last explored zone, north of the previous one is made of numerous

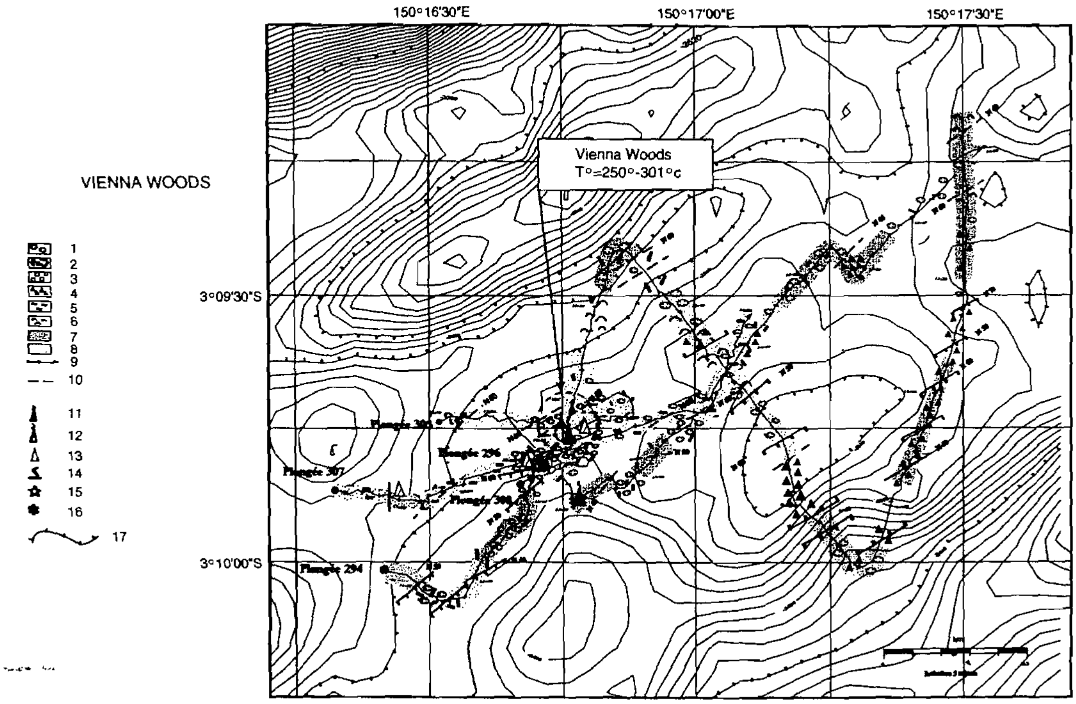

Fig. 7 Geological map of the Vienna Woods zone resulting from dive observations (after Chabroux, 1996) : 1-Pillow lava ; 2-Lava tubes ; 3-Blocky lava ; 4-Volcanic breccia ; 5-Ropy lava ; 6-Lobated lava ; 7-Thick sedimentary cover ; 8-Thin sedimentary cover ; 9-Fault scarp ; 10-Fissure ; 11-Black smoker ; 12-Shimmering fluids ; 13-Dead chimneys ; 14-Fissural venting ; 15-Bacterial mat ; 16-Iron oxide deposits ; 17-Bathymetric contours.

active and inactive chimneys at a depth ranging from 1,693 to 1,703m. The active chimneys expell either shimmering water or black fluids with a temperature close to 180℃ and a low pH ranging from 2.6 to 3.1.

The associated fauna is composed, for all the different sites of colonies of gastropods, mussels (*bathymodiolus*), crabs and fishes. The sampled rocks are of dacitic type as already shown by Binns and Scott, (1993).

The last explored zone is DESMOS, discovered in 1990 during the Aquarius cruise of the R/V Hakuho Maru (Gamo et al., 1993). It is a cauldron about 1.5 km in diameter, 300m-deep, slightly elongated in NS direction and crowned by a discontinuous circular ridge, 200m-high (Fig. 5 d). Hydrothermal deposits (Both et al., 1986) and methane, maganese, alumina and pH anomalies in the water column have been already reported by Craig and Poreda (1987) and Gamo et al. (1993).

The dives data (Fig. 10) show that the cauldron is cut through a thick layer of lava flows. These lava flows are essentially lava tubes and small pillows. A preliminary onboard analysis indicates that they are of andesitic type. The faulted walls of the cauldron are cut through the lava tubes section and are covered with alteration products (oxydes, staining, etc.). At the foot of the fault large blocky talus reach more than 50m-high. On the northwestern flank of the cauldron an active hydrothermal area has been observed. It is characterised by low temperature shimmering fluids associated with sulfides, oxydes and a poorly developped animal colonisation made of galatheids, mussels and spaghetti-worms. One very large part of the site is covered by a continuous layer of white bacteria mats. On the eastern side of this hydrothermal zone, a very robust site (the Onsen) has been discovered and sampled on an EW fault cutting the northwestern edge of the cauldron. It is a white smoker, the measured temperature of which is 118℃, the pH : 2.1 and the H_2S content very high (more than 9mmol/*l*). These peculiarities in the fluids composi-

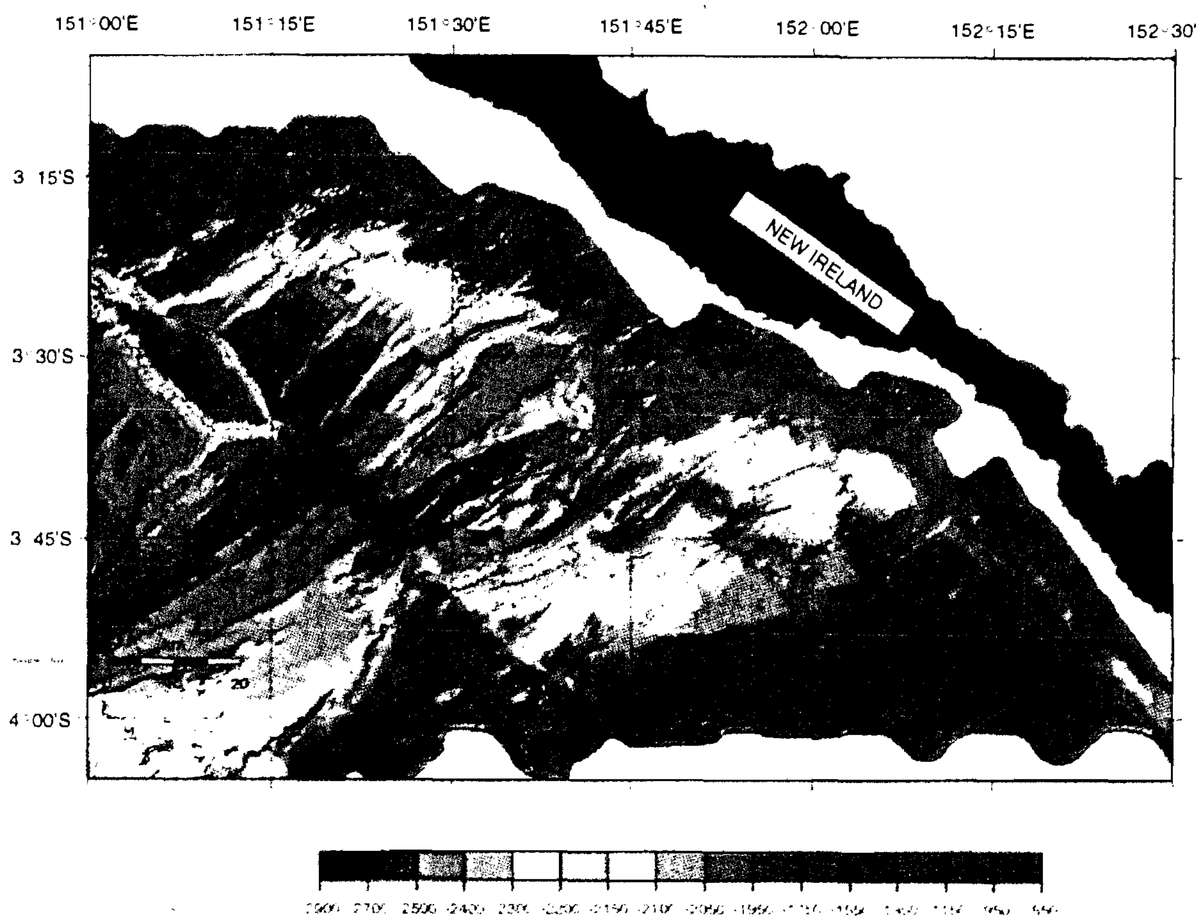

Fig. 8 Bathymetric map of the Southeastern Rift obtained by the compilation of SeaMark, Hydrosweep and Furono multibeam data.

tion (Gamo et al, in press) could be related either to nature of the outcropping rocks or/and the geodynamic context of DESMOS site which is a volcano intruded within a transverse fault (transform fault) linking the SER to the easternmost extensionnal ridge of the Manus Basin (Fig. 8).

3. Rocks and sulfides sampling

Outcropping rocks have been sampled on each of the explored ridge segments. On the MSC, the Vienna Woods area shows pillows on the graben edge and lava tubes in the present-day spreading zone. Both are basaltic in composition. A preliminary onboard analysis indicate MORB affinities. The samples taken on Munkalin volcano which recently intruded the MSC axis are basalts with andesitic affinities.

On the SER, all the collected rocks, either on PACMANUS site or DESMOS site are acidic rocks mainly represented by dacites on the top of PACMANUS and at DESMOS and andesites in the deeper part of PACMANUS.

4. Fluids chemistry

In situ water samples have been taken on about 15 different hydrothermal vents on the three active zones. As seen for the rock samples their content varies depending of the considered site and the nature of the outcropping rocks (see also Gamo et al., in press, for detailed description and analysis of water samples). In Vienna Woods area the fluids are hot temperature shimmering-grey fluids (285 to 300℃) expelled by sulfides chimneys. The anhydrite chimneys observed on the site have not been sampled. The measured pH of the fluids is 4.5 in average and the H_2S content relatively low. On

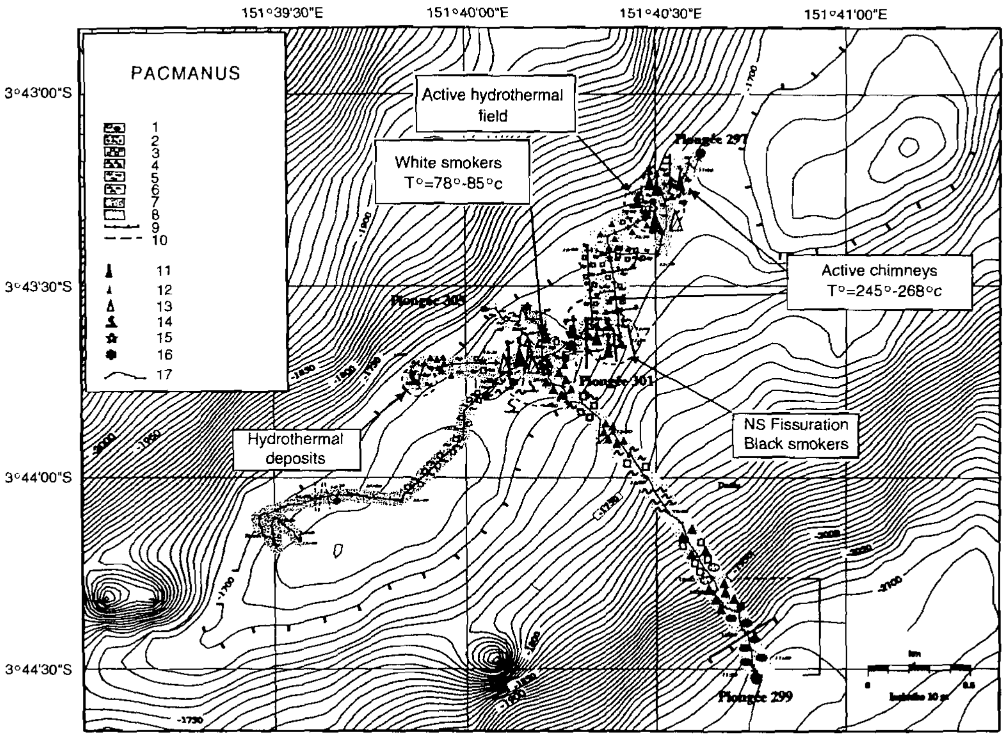

Fig. 9 Geological map of the PACMANUS zone resulting from dive observations (after Chabroux, 1996) : 1-Pillow lava ; 2-Lava tubes ; 3-Blocky lava ; 4-Volcanic breccia ; 5-Ropy lava ; 6-Lobated lava ; 7-Thick sedimentary cover ; 8-Thin sedimentary cover ; 9-Fault scarp ; 10-Fissure ; 11-Black smoker ; 12-Shimmering fluids ; 13-Dead chimneys ; 14-Fissural venting ; 15-Bacterial mat ; 16-Iron oxide deposits ; 17-Bathymetric contours.

PACMANUS site the fluids which have been sampled are shimmering to dark-grey fluids. They show a high temperature (260℃) and a relatively low pH (2.7 to 3.1). On DESMOS site, the collected fluids are extremelly peculiar. Their measured temperature does not exceed 118℃, their pH value is very low (less than 2), their H_2S content very high (more than 9 mmol/l) and their SO_4^{++} content extremely rich. These characteristics (Fig. 11) combined with the preliminary chemical analysis operated onboard (Gamo et al., in press) indicate a very new type of hydrothermal waters, up to now unknown in the world ocean.

5. Conclusion

The Manusflux cruise allows to confirm the magmatic, tectonic and hydrothermal activity of two segments, MSC and SER of the Manus basin spreading system.

The MSC shows, along strike, the change of morphology from ridge to the south to graben to the north. The ridge morphology is associated with a recent magmatic episode while the graben morphology reflects a tectonic stage. The intense hydrothermal activity observed on Vienna Woods site is associated with this stage. The SER is a more complex system closer to an extensional zone rather than a typical oceanic spreading zone. Active hydrothermal sites are numerous (PACMANUS and DESMOS zones) due to the fact that tectonism is predominant against magmatism. The sampled rocks illustrate the peculiarity of the geodynamical context of the whole area and the arc affinity. They are MORB basalts on the northern part of the MSC, andesitic basalts on the Munkalin volcano and acidic rocks on the SER. The hydrothermal sites cover the whole range from low temperature shimmering waters up to high temperature shimmering or black-smokers. Their chemical content is closely linked with the basic or acidic nature of the outcropping

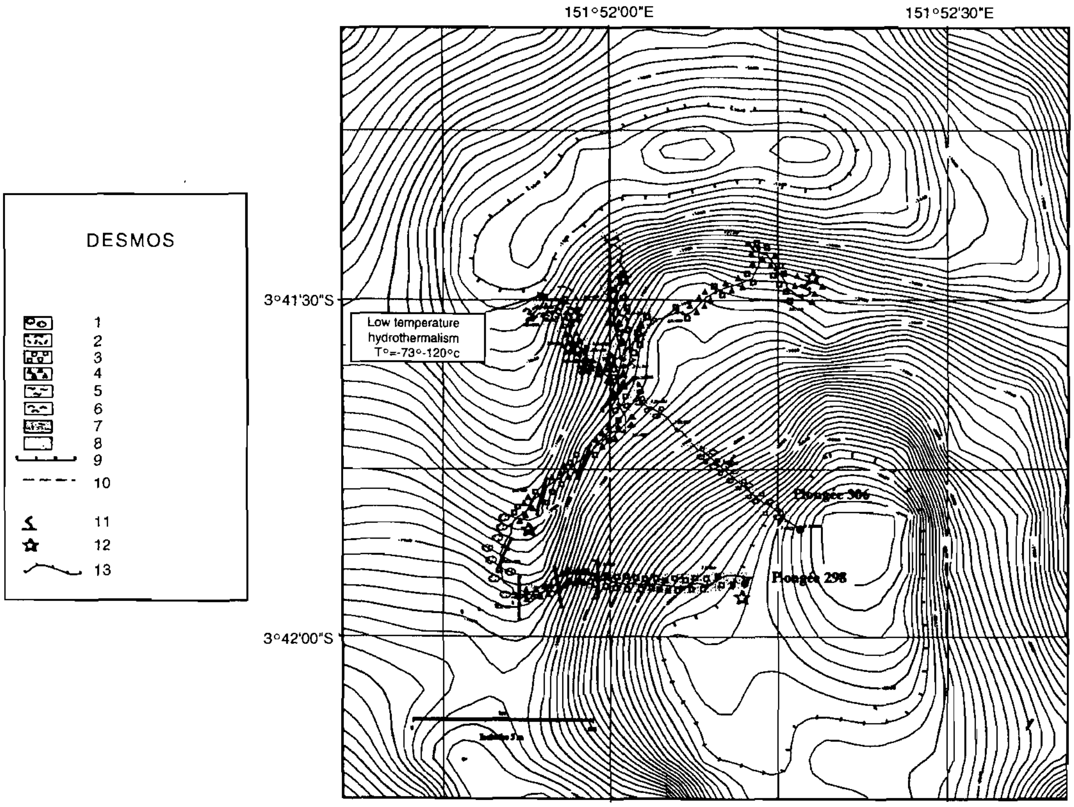

Fig. 10 Geological map of the DESMOS zone resulting from dive observations (after Chabroux, 1996) : 1-Pillow lava ; 2-Lava tubes ; 3-Blocky lava ; 4-Volcanic breccia ; 5-Ropy lava ; 6-Lobated lava ; 7-Thick sedimentary cover ; 8-Thin sedimentary cover ; 9-Fault scarp ; 10-Fissure ; 11-Fissural venting ; 12-Bacterial mat or native sulphur ; 13-Bathymetric contours.

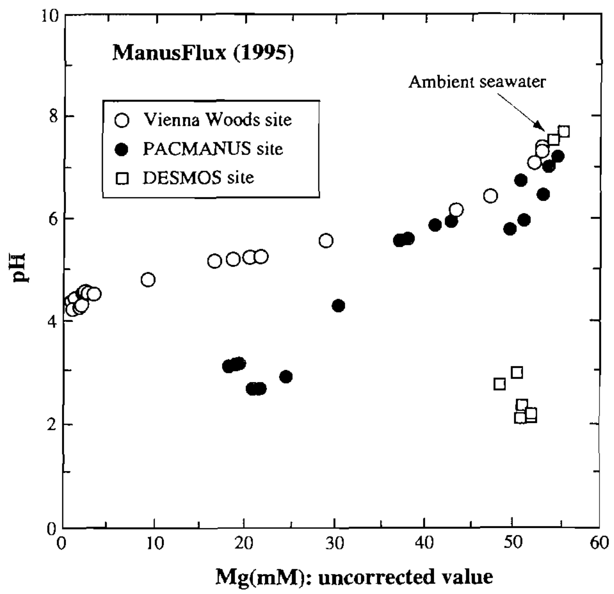

Fig. 11 Values of pH and Mg for fluids collected at Vienna Woods, PACMANUS, and DESMOS hydrothermal sites during the cruise.

rocks.

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