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NAUDUR Explorers Discover Recent Volcanic Activity Along the East Pacific Rise

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Surveying an ultra-fast spreading ridge along the East Pacific Rise (EPR), explorers aboard the submersible *Nautilé* examined features such as lava pillows and tubes, sulfide chimneys, black smokers, hot shimmering waters, and animal colonies living in hydrothermal vents to learn more about the processes of accretion and tectonics on the ocean floor. Taken together, the observations of the EPR between 17°S and 19°S from the 1993 NAUDUR cruise (a French acronym for *Nautilé* on Ultra-fast Ridge) indicate recent volcanic eruptions occurring as frequently as every few years.

The NAUDUR cruise was designed to study the interaction between magmatic, tectonic, and hydrothermal processes at an ultra-fast spreading axis of the EPR. Researchers performing twenty three dives in five regions (Figure 1) along the axis of the Garrett fracture zone collected more than 150 rock samples and made 52 gravity measurements [Auzende *et al.*, 1994]. The Garrett fracture zone (13°S) and the Easter Microplate limit a large segment of the East Pacific Rise where the accretion rate is near the upper limit for present-day spreading values (141 to 162 mm/yr) [Perram *et al.*, 1993]. The five dive regions with distinct morphological characteristics represent different stages in the accretion process.

Evidence for Recent Volcanism

Very thin layers of sediment on lava flows signify recent volcanic eruption. Though the sedimentation rate in this area is unknown, published estimates suggest a value close to 2 cm per 1000 years. Thus lavas lying under 1 mm of sediment or less are estimated to be younger than about 50 years old. Many flows covered by much less than 1 mm of sediment probably result from eruptions that occurred within the last decade or so.

The presence of fresh lava around recently extinct hydrothermal chimneys also in-

dicates recent volcanic activity. The researchers observed that between 17°09'S and 17°12'S, lava encompassed extinct hydrothermal chimneys that were several meters high. The chimneys, which were apparently inactive and covered with vent animals, had probably only recently stopped vigorous hydrothermal venting. Animal communities tend to disappear within a few years of the cessation of active venting; therefore vol-

canic eruption probably occurred within that time frame.

In the 17°10'S region, lava had invaded a colony of anemones and other vent animals. Because the younger lava flow was not colonized with animals, eruption probably occurred within the last few months to years.

Filamentous enteropneusts (hemichordate) worms and bacteria covered much of the freshest unsedimented lava between 17°09'S and 17°27'S. The only other species inhabiting the area were crabs. Recent observations of bacteria being replaced by other organisms near 9°50'N suggest that eruptions in this area have occurred within the last few months [Haymon *et al.*, 1993].

In 1984, the *Cyana* crew, mapping an extensive collapsed lava lake near 17°25'S that was devoid of hydrothermal activity, sighted a deep-towed survey vehicle lost in the lava lake (See Figure 2). When researchers on *Nautilé* revisited this site, the large lava lake had disappeared—as well as the survey vehi-

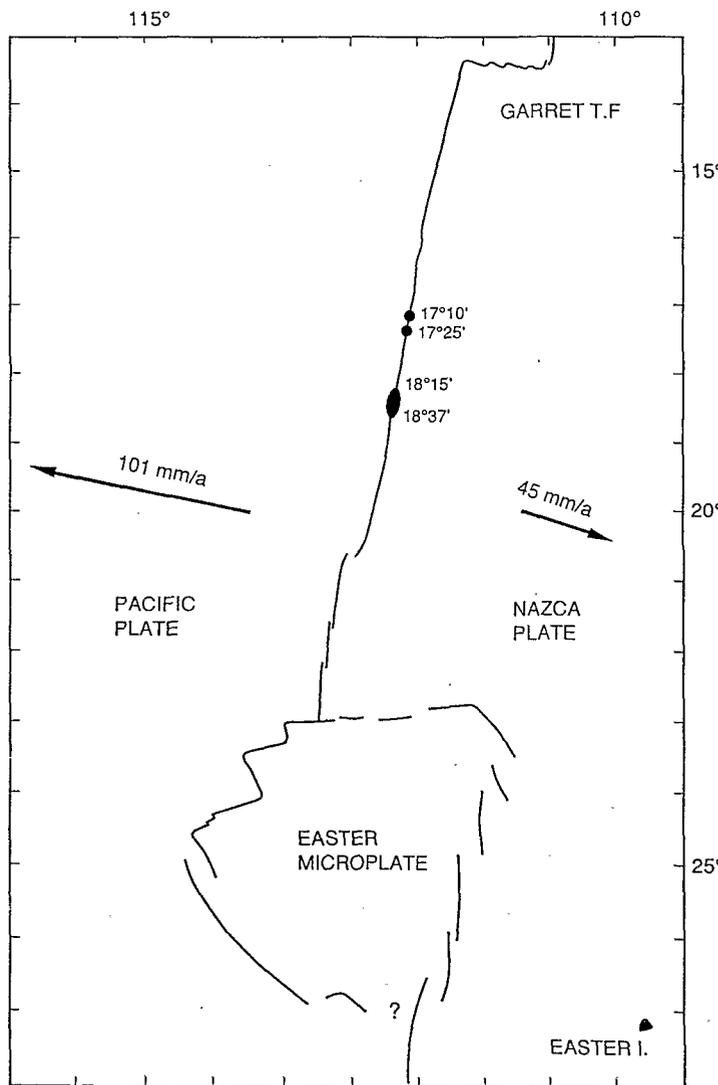


Fig. 1. Location map of the NAUDUR cruise dives. Sketch of the East Pacific Rise [after Cormier and Macdonald, 1994].

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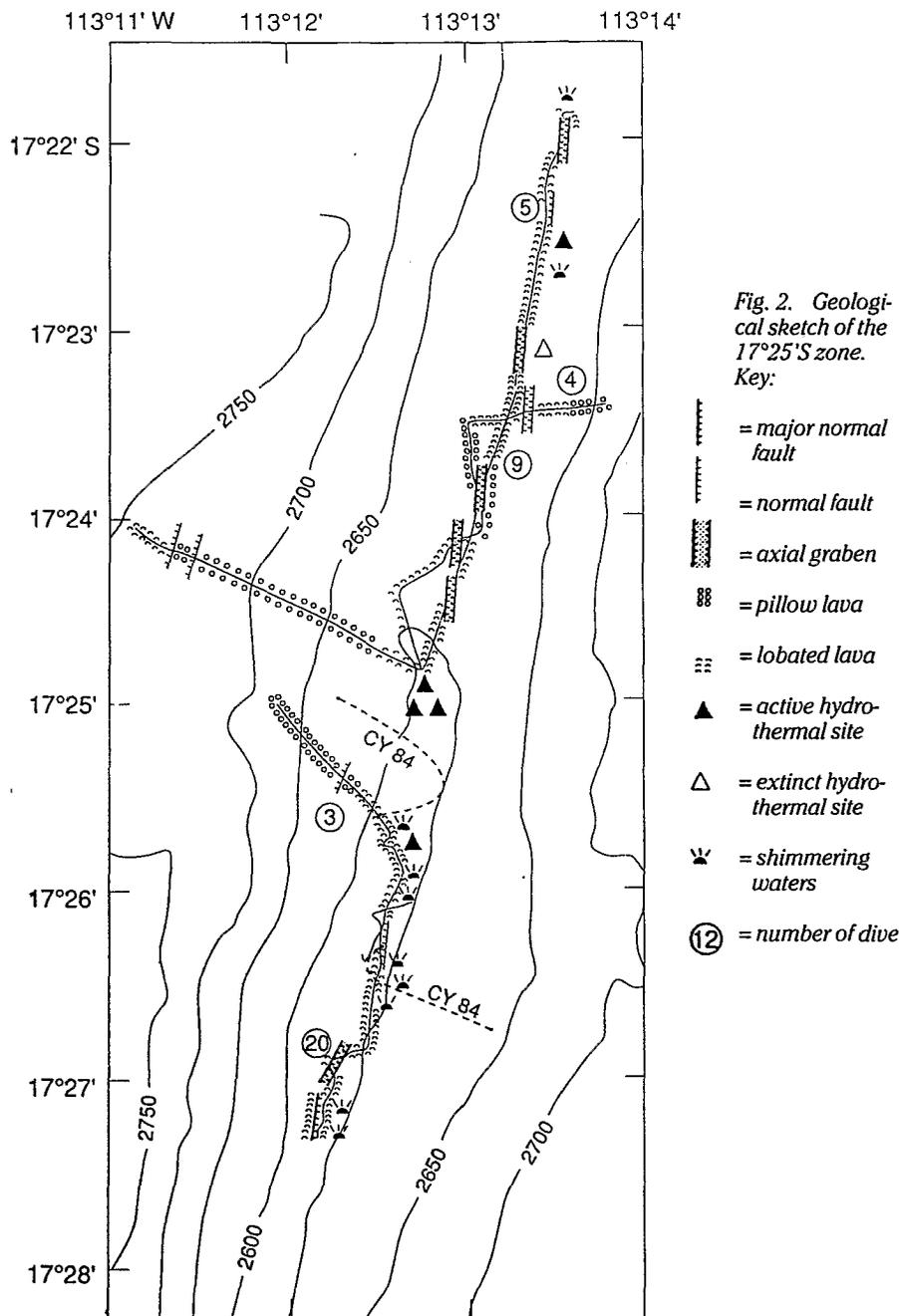


Fig. 2. Geological sketch of the 17°25'S zone.

Key:

-  = major normal fault
-  = normal fault
-  = axial graben
-  = pillow lava
-  = lobated lava
-  = active hydrothermal site
-  = extinct hydrothermal site
-  = shimmering waters
-  = number of dive

cle. The region was covered with fresh lava that is only locally collapsed along a discontinuous fissure zone. Hence substantial volcanic activity appears to have occurred in this area in the last decade.

Warm to hot water shimmering directly off the lava also indicates that the lava is not very old. For example, the temperature was approximately 150°C in a crack in a sheetlike lava that filled the axial graben floor near 18°34'S. Warm water shimmered off the surface of this flow, which was not yet colonized

by vent animals (although many crabs were crawling on it). An external temperature sensor mounted on *Nautilie* recorded a temperature anomaly of approximately 2.50°C, 2 to 3 m above the flow surface. In the 17°26'S zone, the axis was covered by a lobate lava completely devoid of sediment, with shimmering water rising directly from the flow surface. Shimmering water also rose from the surface of a sheet flow near 18°37'S. However, this flow is presumably somewhat older because it was heavily colonized by anemo-

nes, mussels, crabs, gastropods, and other vent animals.

Very recent volcanic activity had occurred along the axis between 17°-19°S. The youngest activity was located between 17°09'S-17°27'S, and also near 18°34'S and 18°37'S. Whether or not any of the young lava was flowing under the consolidated basaltic upper crust at the time of our program is unclear. Nevertheless, if observations made from *Nautilie* are representative for the area, volcanic eruptions along this superfast spreading ridge occur with a frequency of every few years.

Other Findings of the NAUDUR Cruise

A variety of geological morphologies, hydrothermal manifestations and diverse animal colonizations observed during the NAUDUR cruise demonstrate that different stages of volcanic and tectonic activity on the EPR axis have occurred within a distance of a few kilometers and a time span of a few years.

Asymmetric spreading occurs along the southern East Pacific Rise (EPR), with generally faster spreading for the eastern flank [Naar and Hey, 1989; Cormier and Macdonald, 1994]. Between 18° and 19°S, this asymmetry is largely explained by the transfer of Pacific lithosphere to the Nazca plate through the southward, ultrarapid migration of small left-stepping discontinuities. Between 17°S and 18°S, the spreading axis consists of a ridge that is 2600 m deep. Three ridge segments, which are 25 to 40 km long and separated by relatively small offset overlapping spreading centers (OSC) at 18°22'S and 18°37'S, form the Hump zone between 18° and 19°S.

Since 1982, French, German, and American institutions have surveyed the area extensively with *Seabeam* and *Seamark II*. Multichannel seismic surveys identified a very shallow (less than 1 km deep) seismic reflector, regarded as the top of the magma chamber, at 17°22'S [Detrick et al., 1993].

The spreading ridge in the 17°10'S zone is a dome culminating at less than 2600 m depth and devoid of summital tectonic graben. Two types of lavas predominate: pillows and tubes on the flanks of the ridge, and more fluid, draped or lobated lavas at the axis. The present-day active accretion is located in a narrow fissure, 30-50 m deep and less than 100 m wide, running parallel to the ridge, or distributed into two fissures of similar size. This area contains very few traces of active faulting.

Active and fossil vents, observed and sampled on the eastern side of the axial domain near the 17°10'S zone, contained shimmering water and colonies of clams, serpulids (large marine polychaete worms), and vestimentifers (worms with an outer structure like a vest-

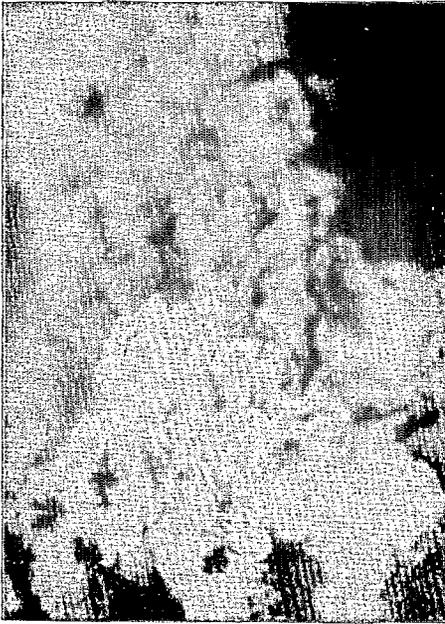


Fig. 3. Black smoker at 17°25'S without animal colonization. The water temperature in the vent was 318°C.

ment). The researchers observed colonies of clams and serpulids living on now-extinct vents that were probably recently active.

In 1984, researchers performing eight dives in the submersible *Cyana* between 17°30' and 21°30'S discovered fossil hydrothermal deposits in an axial alignment of narrow lava lake collapses; active black smokers (hydrothermal vents releasing 250–340°C water) were absent [Renard *et al.*, 1985]. Observations made on 6 dives of the NAUDUR cruise in the same area suggest that important changes in morphology and in magmatic and hydrothermal activity, which are probably related to a recent volcanic eruption, have occurred since 1984. Hydrothermal vents, which are common in the axial domain, displayed diffusion of shimmering water from many areas of the most recent lava surfaces and black smokers in older regions (Figure 3). Abundant animal colonies contained a diversity of species [Geistdoerfer *et al.*, 1994].

Observations of the 17°25'S region from *Nautille* allowed the differentiation of two main domains (Figure 2): the top of the axial dome, culminating at less than 2600 m and lacking an axial graben; and the northern part of the segment where the bathymetry deepens to 2650–2700 m. In the first domain, present-day expansion of oceanic crust was focused in meter-sized fissures. Fresh lobated and draped lava flows occupied the oceanic bottom in this area, with shimmering waters expelled from the top of the lava lakes or from the pillars.

In the second domain, the axial graben 50–100 m wide and 20–50 m deep results in

the foundering of the lava lakes. In this area the lobated lava alternated with pillows. The hydrothermal vents were more evolved, with chimneys, sulfide deposits and fauna colonization.

The northernmost Hump segment (17°56'S to 18°22'S) is characterized by a wide graben bounded by walls culminating at 2650 m. Dive results showed that the graben had a maximum width of 800 m and included a secondary axial graben with a maximum depth of 80 m, bounded by two steps. The main boundary faults of the graben had a total vertical offset of 30–40 m. The bottom of the central valley was intensely fissured. Open fissures, some meters wide, separated small horsts that are only a few meters wide and 10 m high. These very fragile features were locally tilted. Chaotic, brecciated, draped lavas flanked the axial graben. Thick pillow lavas lined the inner edge. Collapsed lava lakes containing relict pillars up to 10–15 m high and associated pillows occupied the graben center.

The Hump segment between 18°22'S and 18°34'S exhibited a complex morphology. A median graben 200–500 m wide displayed two asymmetrical walls. The eastern wall culminated at less than 2600 m and the western wall at less than 2700 m. Six dives were conducted along this segment. In the northern part of the area, the present-day accretion was located in a 500 m-wide, ~100 m deep graben, filled by lobated lava flows. In the 18°30'S region to the south, intense tectonic activity affected the entire median graben, as shown by pillowed horsts separated by numerous open fissures with widths up to 10 m. A uniform sedimentary cover with a thickness of a few millimeters was observed throughout the entire domain. At the southern tip of the Hump zone, the axial graben narrows, and its aspect resembles the 17°25'S segment aspect.

Hydrothermal activity in this part of the Hump segment appeared to be concentrated along a narrow ridge of pillow debris close to the eastern wall of the graben. The majority of the 15 sites sampled were black smokers set on active white mounds venting hot shimmering water that was up to 150°C.

One dive near 18°37'S traversed two segments separated by a small OSC that was 2 km wide. The northern ridge showed a tectonized axis. The "overlap basin" was almost entirely composed of constructional lava, and the axis of the southern segment consisted of very young expansive sheet flows.

Numerous fossil and active hydrothermal sites were observed along all the dives and in all parts of the graben. They include large sulfide chimneys, black and white smokers, and low-temperature fossil chimneys composed of silica and iron hydroxides.

At 18°45'S, one dive followed a cross section from the present-day active axis to an abandoned ridge lying approximately 2 km

to the east [Cormier and Macdonald, 1994]. The active axis was characterized by a strongly tectonized western margin and fresh lobated flows, whereas the eastern abandoned ridge was covered by a uniform sedimentary.

Conclusion

The explored segments clearly illustrate the evolution of the accretion processes and of the related hydrothermal processes and biological colonization at an ultra-fast spreading ridge. Almost every conceivable combination of lava, hydrothermal type and extent of colonization, depending on the age of the last magmatic eruption and extent of the tectonic maturation, existed along the ridge. The observed associations included young lava with low temperature and diffuse vents with large animal colonies (17°10'S); young lava with low-temperature and/or high-temperature vents with no or very little animal colonization (e.g., the central axis near 17°25'S, and at the northern tip of the southern Hump segment); older lava with high-temperature vents with no colonization (between 18°10'S and 18°21'S) or with extensive colonization (17°25'S).

Scientific Party

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References

- Auzende, J. M., V. Ballu, R. Batiza, D. Bideau, M. H. Cormier, Y. Fouquet, P. Geistdoerfer, Y. Lagabrielle, J. Sinton, and P. Spadea, Activite magmatique, tectonique et hydrothermale actuelle sur la Dorsale Est Pacifique entre 17° et 19°S (campagne Naudur), *Comptes Rendus. Acad. Sci., Paris, Ser. II*, 319, 1994.
- Cormier, M. H., and K. C. Macdonald, East Pacific Rise 18°-19°S: Asymmetric spreading and ridge reorientation by ultra-fast migration of axial discontinuities, *J. Geophys. Res.*, 99, 543, 1994.
- Detrick, R.S., A.J. Harding, G.M. Kent, J.A. Orcutt, J.C. Mutter, and P. Buhl, Seismic structure of the southern East Pacific Rise, *Science*, 159, 499, 1993.
- Geistdoerfer, P., J. M. Auzende, V. Ballu, R. Batiza, D. Bideau, M. H. Cormier, Y. Fouquet, Y. Lagabrielle, J. Sinton, and P. Spadea, Hydrothermalisme et communautés animales associées sur la dorsale Est Pacifique entre 17°S et 19°S (Campagne Naudur), *Comptes*

- Rendus. Acad. Sci., Paris, Ser. II*, 319, 1994.
- Haymon, R. M., et al., Volcanic eruption of the mid-oceanic ridge along the East Pacific Rise crest at 9°45-52': Direct submersible observations of seafloor phenomena associated with an eruption event in April, 1991, *Earth Planet. Sci. Lett.*, 119, 85, 1993.
- Naar D. F., and R. N. Hey, Recent Pacific-Easter-Nazca plate motions, Evolution of Mid-Ocean Ridges, *IUGG Geophys. Monogr. Ser.*, vol. 57, 9, 1989.
- Perram, L. J., M. H. Cormier, and K. C. Macdonald, Magnetic and tectonic studies of the dueling propagating spreading centers at 20°40'S on the East Pacific Rise: Evidence for crustal rotations, *J. Geophys. Res.*, 98, 13,850, 1993.
- Renard, V., R. Hekinian, J. Francheteau, R. D. Ballard, and H. Backer, Submersible observations at the axis of the ultra-fast-spreading East Pacific Rise (17°30' to 21°30'S), *Earth Planet. Sci. Lett.*, 75, 339, 1985.