Submersible Investigations of the Mid-Ocean Ridges near the Triple Junction in the Indian Ocean

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The first submersible investigations of the mid-ocean ridges in the Indian Ocean were carried out in September-October 1998 by using the submersible *Shinkai 6500* and the R/V *Yokosuka*. It was confirmed that magmatic supply to the Southwest Indian Ridge (SWIR) about 64°E is concentrated on an exceptionally big axial volcano Mt. Jourdanne, leaving the other segments in magma starved condition. A probable detachment fault surface of a "megamullion" (FUJI Dome) was investigated. Although gabbro and serpentinized peridotite samples were recovered, most of the surface was covered with sediment and basaltic debris. An extinct hydrothermal site was found on Mt. Jourdanne, where we collected the first sulfide chimneys along the ultra-slow spreading SWIR. We observed a strong transmission anomaly and collected dead shells in the first segment of the Central Indian Ridge (CIR) north of the Rodriguez triple junction.

Key words : Indian Ocean, mid-ocean ridges, Southwest Indian Ridge, sulfide chimney, detachment fault

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1. Introduction

The submersible *Shinkai 6500* and the R/V *Yokosuka* carried out the first expedition in the Indian Ocean in the fall of 1998 during the legs 3 and 4 of the Mid-Ocean ridge Diving Expedition '98 (MODE'98). The target area of the first submersible diving surveys in the Indian Ocean was the mid-ocean ridge extending southwestward from the Indian Ocean triple junction (the Southwest Indian Ridge: SWIR, see Fig. 1). The red closed circles in Fig 1 show the sites of diving surveys. While Leg 4 was focused on the Atlantis II fracture zone (ca. 57°E), Leg 3 targeted the axial volcanic ridges (AVR) between 59°E and 70°E.

The SWIR, separating the African and Antarctic plates, opens at the ultra-slow half rate of 7 to 8 mm/year, and represents therefore an end member of the global ridge system in terms of spreading rate. For this reason, it has been selected by the InterRidge program as an important target of global ridge studies. The eastern portion of the SWIR was intensively investigated in 1997 during two cruises on the French R/V *Marion Dufresne*. The EDUL cruise comprised a systematic sampling of the axis between 49°E and 68°E, and confirmed that the amount of melting is particularly low in this spreading center (Mével et al., 1997). During the FUJI cruise, a TOBI deeptow sidescan survey was conducted for the mapping of magmatic and tectonic activity (Mével, Tamaki et al., 1998). A series of transmissometers mounted on the TOBI and the tow cable documented several strong signals interpreted as hydrothermal plumes (German et al., 1998).

Although many active hydrothermal vent fields with biological communities have been found and sampled on the Mid-Atlantic Ridge (MAR) and on the East Pacific Rise (EPR), no active sites have been located in the Indian Ocean yet (cf. Plüger et al., 1990). The species of vent fauna on the MAR are different from those on the EPR (Tunnicliffe, 1991). The Indian Ocean Ridges are important from the viewpoint of vent biology; the spreading centers can be a main propagation pathway or a barrier between the Atlantic and the Pacific vent fauna.

Main objectives of Leg 3 were to get detailed information about accretionary processes along the ultra-slow spreading ridge and to locate hydrothermal vent sites for the first time in the Indian Ocean. We named this cruise "INDOYO" cruise. We carried out diving surveys firstly on the SWIR based chiefly on the TOBI images and the transmission anomalies observrd during the FUJI cruise. We also surveyed a site near geochemical anomalies found in 1993 on the first segment of the Central Indian Ridge north of the triple junction (Gamo et al., 1996). This is a brief report of the "INDOYO" diving cruise.

2. Crustal accretionary processes at the ultra-slow spreading ridge

To characterize by submersible observations the accretionary processes in the ultra-slow spreading center, we concentrated 7 dives on the SWIR Segment 11 (approx. 64° E), two on the axial volcanic ridge (AVR), three on a "megamullion", and two in the non-transform discontinuity (NTD) (see Figs. 2 and 3). Two dives were devoted to a small AVR (ca. 64° 30' E) of segment 10, and three dives to the eastern edge of an old AVR (59°E) of segment 17 (Fig. 2). These five dives had another objective to find a hydrothermal vent site; strong transmission anomalies were observed near these AVRs in 1997 (German et al., 1998). Three-component magnetic field was measured during most of the dives.

The center of Segment 11 is characterized by the presence of a large magmatic construction that fills the axial valley (Mt. Jourdanne). A series of extrusive units, principally alternating sheet flows and pillow/lobate flows, comprise the main outcrop of the eastern AVR of Mt. Jourdanne. Pillow mounds and flow units are more common on the uppermost, shallowest parts of the summit (Dive 446 in Fig. 3). Most of the seafloor was covered with sediment of varied thickness. The eastern AVR is cut by faults, and in some cases, pervasive fissures with E-W strikes; some of them were associated with hydrothermal mounds as mentioned below (Dive 454).

The results of the observation of a small volcanic Segment 10 AVR show some differences to those of Mt. Jourdanne. While fresh pillow basalts were observed in some area, pillow fragments and basaltic talus covered most of the AVR. Sheet flows were not observed (Dives 448 and 449). The AVR is cut by a series of approximately E-W scarps and grabens reflecting extensional plate motion in the N-S direction. In contrast to Segment 11, tectonic processes look more dominant in this segment. Although the eastern end of the segment 17 AVR was located near a non-transform discontinuity, old basalts with thick sediment covered the seabed.

The R/V *Yokosuka* is well equipped with geophysical mapping system: HS-10 multi-beam system, a LaCoste & Romberg sea gravimeter, and a shipborad three-component magnetometer as well as a proton precession magnetometer. To determine the evolution of the crustal accretion processes in the SWIR, we extended sea surface geophysical mapping to anomaly 5 in Segment 11 as shown in Fig. 2. The mapping was also carried out in Segment 9, where TOBI image indicates least magmatic supply. Off-axis topographic data across Segment 9 show striking asymmetry across the spreading axis (Fig. 2).

3. The first sulfide chimneys from the SWIR

Some of the larger fissures on the eastern AVR of Mt. Jourdanne show a strong spatial relationship to the location of extinct hydrothermal sites (Münch et al., this volume). Favored by both volcanic (heat source) and tectonic activity (pathways for fluid convection) several extinct hydrothermal sites were found within an area of approx. 0.5 km^2 at a water depth of about 2940m (27° 50.97' S/63° 56.15' E) (Dives 446 and 454).

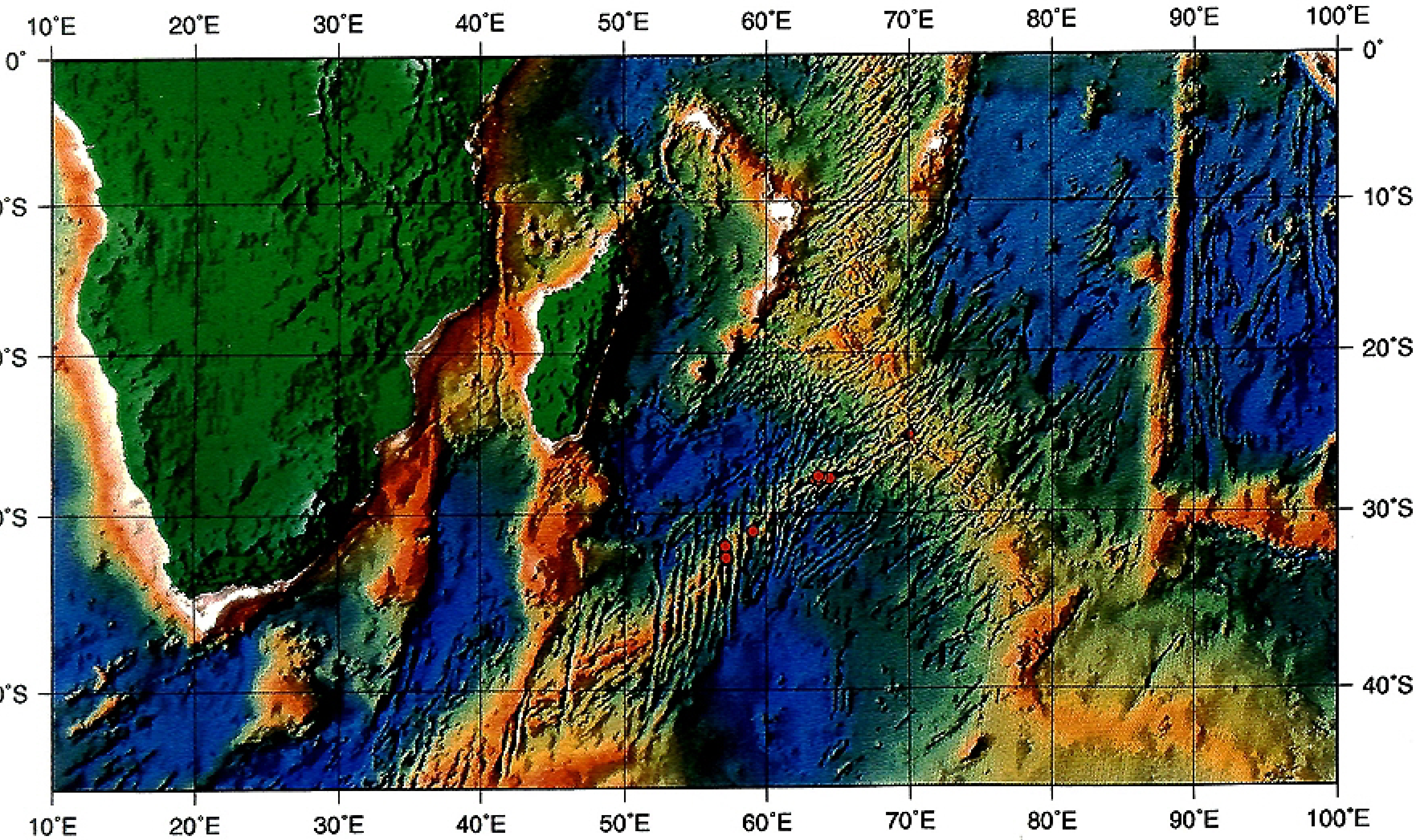

Fig. 1 Topographic map showing the mid-ocean ridges in the Indian Ocean (National Geophysical Data Center, 1994). Closed red circles show the sites of diving survey during the MODE'98 Leg3 and Leg 4 in 1998.

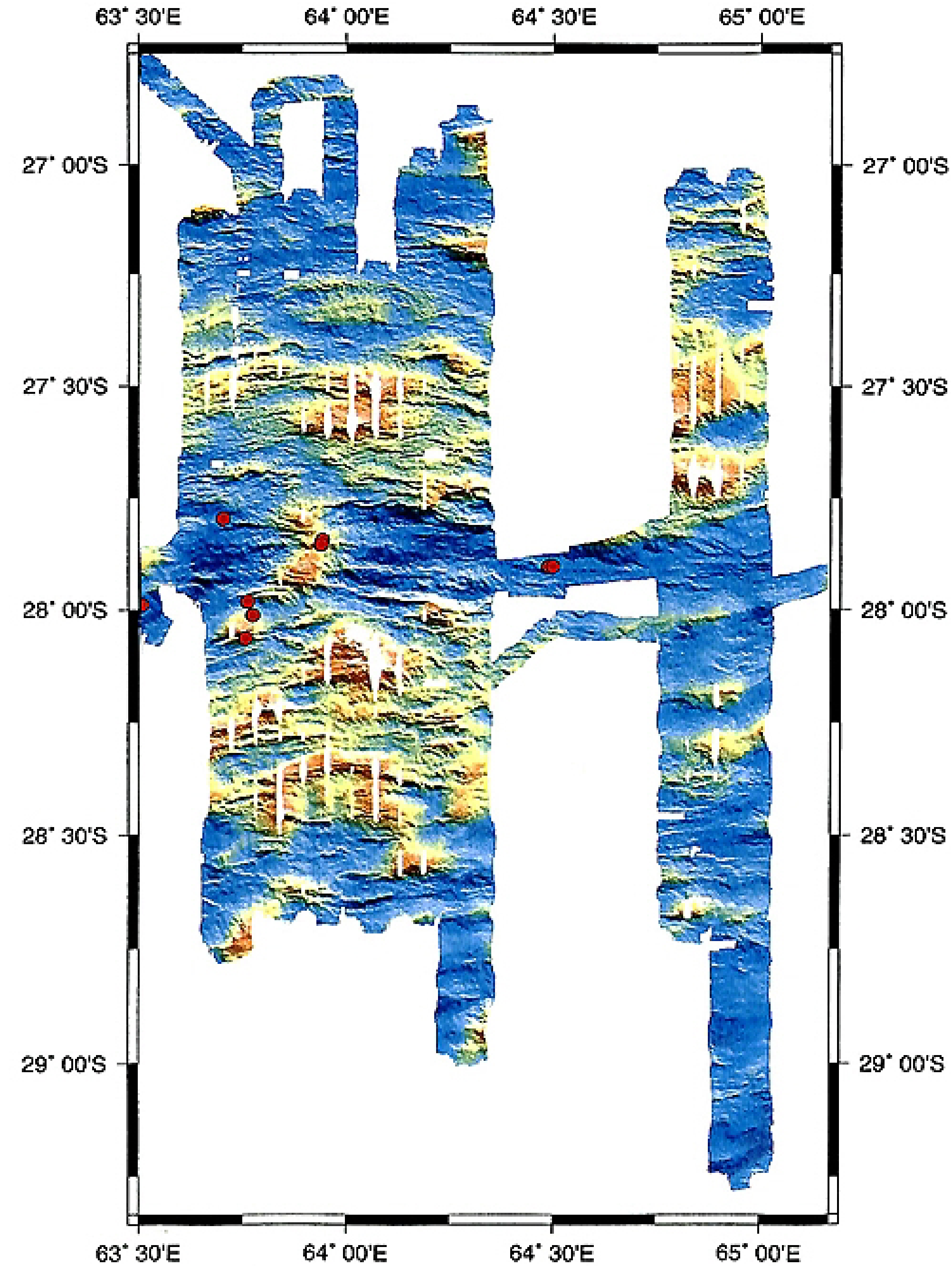

Fig. 2. Map of off-axis topography of segments 9 and 11 of the SWIR obtained by the multi-beam system HS-10 on board the Yokosuka. Closed circles show the dive sites of the Shinkai 6500. See Fig. 3 and the text.

All of them were spatially related either to the graben or to smaller fissures. They are the first known sulfide deposit along the ultra-slow spreading SWIR. These chimneys have a tube-like shape and consist possibly of sphalerite, some chalcopyrite as well as pyrite and minor amounts of sulfates. Silica seems to be more or less absent in chimney samples, which might explain the fragility of chimney edifices. Chimneys are totally encrusted by manganese (Münch et al., this volume).

4. Detachment fault surface (FUJI Dome)

The TOBI image also showed a large striated surface ("megamullion") 20 km south of the axis in Segment 11, inferred to be a major detachment surface resulting from long-lasting asymmetric extension (Fig. 2). Three dives (Dives 444, 445, and 450 in Fig. 3) were carried out to cross this topographic high called "FUJI Dome". The detachment surface represents a distinct formation that is different from those adjacent to it. Except at the steep southern slope near the inferred breakaway, they revealed a very smooth, sediment-covered surface with frequent deposits of basaltic debris. Two gabbro samples were recovered from the crest of the dome, and one serpentinite peridotite boulder (not in-situ) was recovered from

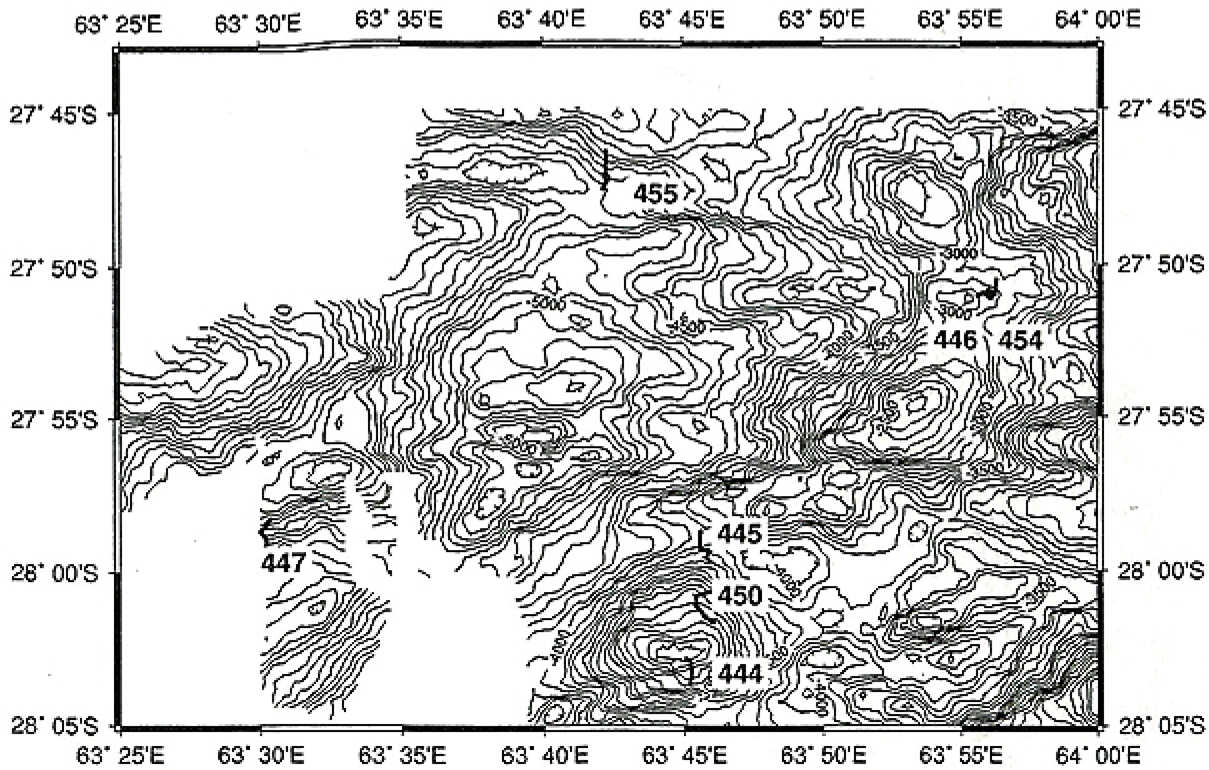

Fig. 3. Dive tracks of the *Shinkai 6500* near a small axial volcanic ridge (AVR) of the SWIR Segment 11.

its northern (younger) flank. No other evidence of lower crustal or mantle lithologies was seen (Searle et al., in preparation). In-situ metamorphosed basalt was recovered from a probable thin faulted sliver on the lower northern flank of the detachment. Preliminary analysis of seafloor gravimetry during the three dives indicates much the same subterranean density structure.

5. Extinct clam colonies near the Rodriguez Triple Junction

As is mentioned above, we carried out five dives on the AVRs of segments 10 and 17, where strong transmission anomalies were observed during the FUJI cruise. However, we were unable to find any indication of hydrothermal activities along the SWIR other than the extinct sites on the Mt. Jourdanne. We then moved to the CIR near the triple junction to examine another hydrothermal signal. Two dives (Dives 456 and 457 in Fig. 4) were focused on a spur extending to the NW from the crestal ridge at 25° 19' S, 70° 03' E, where the most fresh hydrothermal plume observed in 1993 had been expected to converge from the analysis of CH4/Mn ratio (Gamo et al., 1996).

Heaps of dead shells were found just on the landing site of the first dive. We successfully sampled shells of two species. The heaps can safely be regarded as in-situ biological communities related to former or even recent hydrothermal activity.

During the last dive, transmission anomalies amounted to 0.5% at the leaving point of the dive. This anomaly is significantly higher, about 5 times larger than that observedin 1993, probably because the surveyed area is much closer to a venting site. In addition, the CTD attached to *Shinkai 6500* detected bottom temperature anomalies of about 0.05°C at a nearby location close to the leaving point mentioned above; these observations suggest the existence of hydrothermal activity around the survey area.

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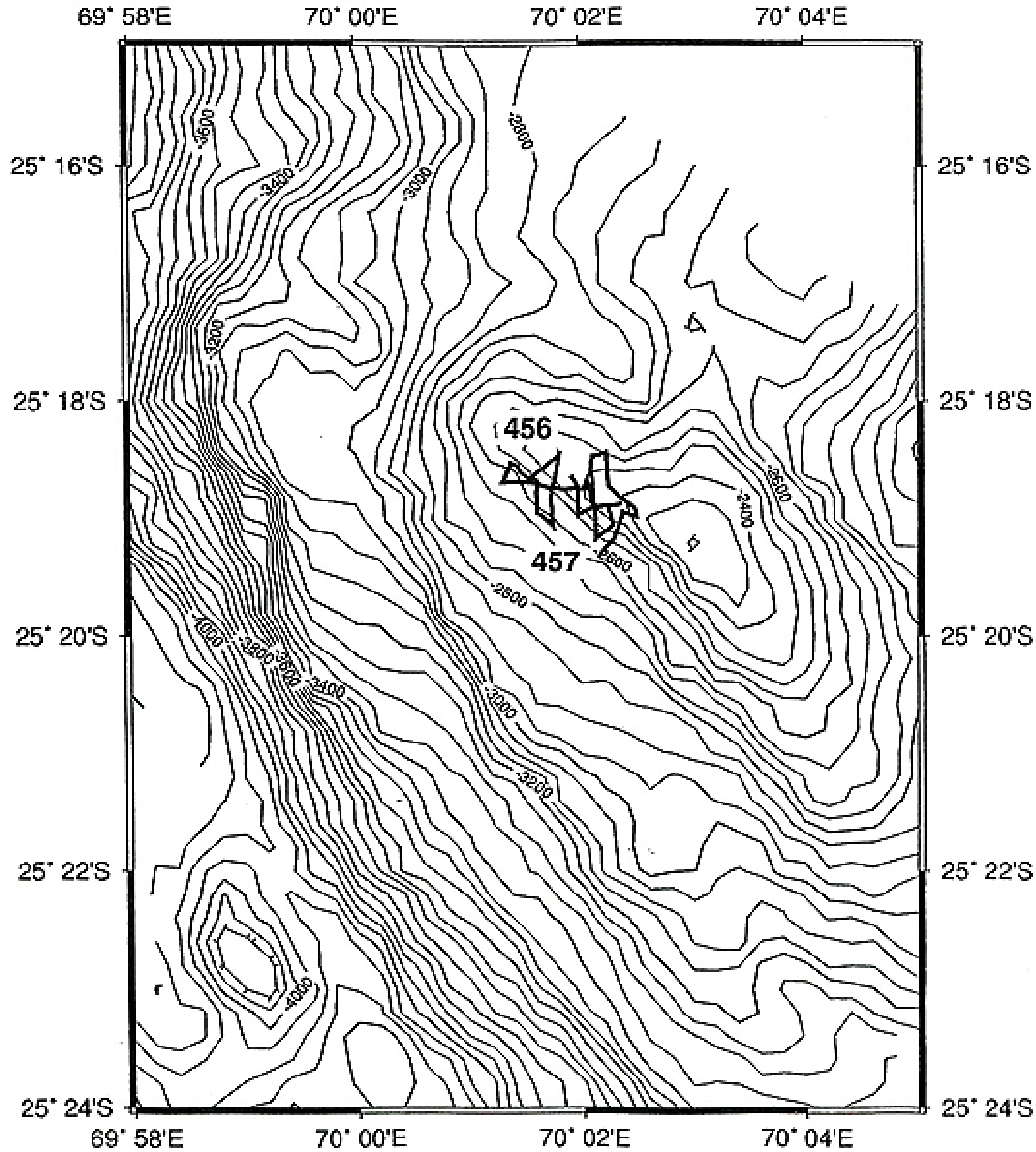

Fig. 4. Dive tracks of the *Shinkai 6500* on the first segment of the CIR north of the Rodriguez Triple Junction.

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