

マリアナ収束プレート縁辺南東部に おけるテクトニック変形, 火山活動 及び流体噴出の関係

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調査母船「よこすか」の航海Y9204 (1992年11月)において, マリアナ収束プレート縁辺南部で採集したデータは, 火山活動と流体噴出が全プレート縁辺を横断する主要断層帯に関係しているという仮説を支持している。潜水調査船「しんかい6500」の潜航調査により, 主要前弧断層の基部および背弧海盆拡大系における流体噴出が観察できた。また, 主要前弧断層の側面で露出している比較的新鮮な玄武岩質溶岩が観察されたが, これは最近の前弧火山活動を示唆している。

大規模な断層帯が, マリアナ前弧の南東部を横切り, さらにマリアナ海溝軸及び最南端のマリアナ背弧海盆拡大中心の両方と交差している。これらの断層帯によって流体噴出孔ができ, 弧マグマが前弧域の方へ移動する際の通路になっている可能性がある。また, 前弧南東部における断層活動は, マリアナ島弧のすぐ西の活発な拡大中心であるマリアナ舟状海盆の最南部における背弧拡大系域における大きな火山の原因となっているようである。採集した水深測量データおよび潜水観察結果は, この収束性縁辺環境における流体噴出, 変成作用の程度, 前弧火山活動および前弧構造の分布の間の構造的相互関係についての研究に役立つものである。

The Relationship between Tectonic Deformation, Volcanism, and Fluid Venting in the Southeastern Mariana Convergent Plate Margin

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Data collected during cruise Y9204 of the R/V "Yokosuka" (November 1992) in the southern Mariana convergent plate margin are consistent with the hypothesis that volcanism and fluid venting are related to major fault zones cross-cutting the entire plate margin. "Shinkai 6500" submersible dives permitted observation of fluid venting at the base of a major forearc fault and within the backarc basin spreading system during "Shinkai 6500"

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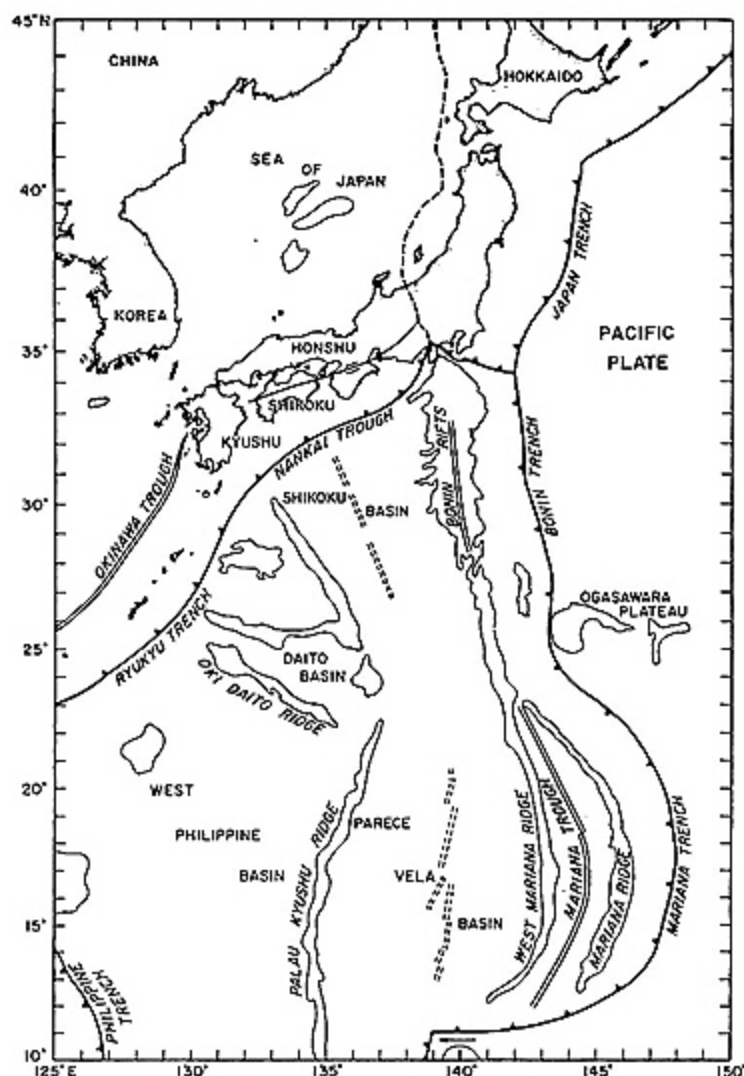


Fig. 1 Bathymetry and geologic features in the Philippine Sea region. Basins and ridges are outlined by the 4-km bathymetric contour, except for the Izu-Bonin arc, West Mariana Ridge, and Mariana arc, which are outlined by the 3-km contour. Barbed lines locate axes of trenches; medium double lines locate active spreading centers; dashed double lines locate relict spreading centers; single dashed line is a proposed new plate boundary.

Mottl, 1992). Venting of slab related fluids from one of these seamounts has been described in detail recently (Mottl, 1992). Recent volcanism (Pleistocene, 1.68 ± 0.37 Ma) associated with forearc faulting was discovered at a distance of about 80 km from the trench axis during deep ocean drilling at Ocean Drilling Program (ODP) Leg 125 Site 781 (Marlow et al., 1992).

The interrelationship between structure and fluid flux, metamorphism and volcanism in forearc regimes present some of the outstanding concerns facing the marine geological community. Most of the recent effort toward addressing these concerns have been through studies of accretionary forearc regimes (e.g. COSOD II 1987 ; Kulm and Suess, 1990; Langseth and Moore, 1990 ; Kastner et al., 1991;

submersible dives. Also observed were relatively fresh basaltic lavas outcropping on the side of a major forearc fault, suggesting recent forearc volcanism.

Large fault zones cross-cut the southeastern Mariana forearc and intersect both the Mariana Trench axis and the southernmost Mariana backarc basin spreading center. These fault zones may provide zones of egress of fluids and provide routes for migration of arc magmas into the forearc region. Faulting in the southeastern forearc is also likely the cause of concentrations of large volcanoes in the backarc spreading region in the southernmost Mariana Trough, the actively opening spreading center immediately west of the Mariana island arc. The bathymetry data collected and dive observations augment studies of the structural interrelationships between the egress of fluids, degree of metamorphism, forearc volcanism, and distribution of forearc structures in this convergent margin setting.

1 Introduction

Convergence of the Pacific Plate with the eastern margin of the Philippine Sea region (Fig.1) began in the early-middle Eocene and to have been followed by subduction of the Pacific Plate towards the Philippines and a series of arc rifting and backarc basin forming events (Karig, 1971, 1975; Natland and Tarney, 1981; Kobayashi and Nakada, 1979). During the last 6-8 m.y. spreading in the Mariana Trough, the currently active backarc basin south of 23°N, isolated the active Mariana arc from a remnant arc, the West Mariana Ridge (Karig et al., 1978; Hussong and Uyeda, 1981). Deformation in the platelet bounded by the Mariana Trench on the east and the Mariana Trough spreading center on the west resulted from an increase in the curvature of the platelet with respect to the West Mariana Ridge. Subduction of seamounts on the Pacific Ocean plate (Fryer and Smoot, 1985) also caused widespread vertical tectonic deformation of the region within 200 km west of the Mariana Trench (the Mariana forearc) (Fryer and Pearce, 1992; Mahoney and Fryer, 1988, 1989; Wessel, 1991; Wessel et al., submitted). Subduction of Pacific oceanic lithosphere occurs at absolute velocities between 8 and 10 cm per year to the northwest.

The subduction angle is about 12° at shallow depths, steepening in some places to nearly vertical below about 80 km (Eguchi, 1984).

Accretion of pieces of oceanic plate material onto the outermost 50 km of the forearc between 17 and 20°N has added to the complexity of that part of the forearc region (Johnson and Fryer, 1990; Johnson, 1992; Johnson et al., 1992; Johnson and Fryer, submitted). The majority of the Mariana forearc, however, is considered to be nonaccretionary (Hussong and Uyeda, 1981) and no large wedge of Pacific plate sediments has formed adjacent to the toe of the overriding plate. Serpentine seamounts formed on the outer half of the forearc, predominantly between 17–20°N, in response to tensional stress and vertical tectonic deformation (Fryer and Fryer, 1987; Fryer et al., 1990; Saboda et al., 1992). A few serpentine seamounts have also been identified in the southern portion of the forearc (13–14°N) (Fryer, 1992b). The serpentine seamounts are emplaced either by diapirism or by mud volcanism and some are currently sites of active venting of subduction-related fluids (Fryer et al., 1985; Fryer and Fryer, 1987; Haggerty, 1987; Fryer, Pearce and Stokking et al., 1991; Fryer, 1992a, 1992b; Fryer and Mottl, 1992;

Martin et al., 1991), but no nonaccretionary forearc has yet been investigated in detail with the objective of fluid studies. There are three fundamental geologic questions that such studies can address; (1) the problem of fluid-related mass-balance in convergent margins; (2) the metamorphism of the overriding mantle and crustal regions at convergent margins; and (3) the relationship between forearc volcanism and structure as it applies to the development of ophiolite sequences. The results of the "Shinkai 6500" dive observations and the bathymetry data collected on cruise Y9204 of the R/V "Yokosuka" described here present some of the first direct evidence to apply toward answering these important questions.

2 Previous Work

Global mass-balance and chemical transport within subduction zones depends in part on tectonic-induced circulation of fluids at convergent margins. Fluid transport affects metamorphism and diagenetic processes in the overriding plate, the formation of voluminous serpentine terranes, the thermal regime of the convergent margin, and composition of suprasubduction zone magmas. Recent studies highlight the importance of the role of fluids in the tectonic, thermal, and geochemical processes of these dynamic systems (e.g. COSOD II 1987; Haggerty, 1987; Peacock, 1987, 1990; Kulm and Suess, 1990; Langseth and Moore, 1990; Kastner et al., 1991; Martin et al., 1991; Mottl, 1992). Understanding the origin of these fluids and their circulation requires knowledge of both the structural evolution and the history of fluid flux within convergent margins.

Diffuse flow accounts for the bulk of fluid flux in sediment wedges at accretionary convergent margins; however, channelized flow does occur along faults and fractures. The rate of flux of channelized fluids has been shown to

be up to two orders of magnitude faster than that of diffuse flux (Moore et al., 1990). A rapid flux of fluid reduces the potential for fluid interaction with the medium through which the fluid flows and thus, presumably, results in vent fluids that more accurately represent the original composition of the source. The outer half of the Mariana forearc, where faulting is prevalent, and where the possibility of interaction with large sediment wedges is minimal, is an ideal locality in which to study the composition of slab-derived fluids if vent sites associated with faulting can be located.

The entire forearc region between the active volcanic arcs and the trench axes of the Mariana and Izu-Bonin convergent margins consists mainly of igneous and metamorphic rocks of suprasubduction zone composition. Thus "forearc" volcanism has played the major role in information of this 200 km wide, 2,500 km long region. The development of convergent margin ophiolite suites and interpretation of these suites in exposures on land depends critically on our understanding of their formation in situ. The only site in an active interoceanic convergent margin where young (Pleistocene, 1.68 ± 0.37 Ma) lavas have been recovered is at ODP Leg 125 Site 781, on the Mariana forearc immediately northwest of Conical Seamount (Fryer, Pearce and Stokking et al., 1991; Marlow et al., 1992). The lavas recovered there are of island arc tholeiite composition and were thus thought to have originated from the magmatic source for the currently active volcanic arc or to represent a forearc magma source with pressure, temperature, and source composition similar to those of the arc magma source (Marlow et al., 1992). For lavas from an arc source to have been erupted at ODP Site 781, some 120 km east of the volcanic front, either a conduit crosscut the forearc structure, or magma was injected

as a sill.

Several cross-arc structural trends are present in the southern portion of the Mariana convergent plate margin system. Structures south of 13° N (see Fig. 2), oriented east-west are probably strike-slip fault zones (Karig and Ranken, 1983). Karig and Ranken (1983) also showed several north-south striking features, probably also fault zones, south and southwest of Guam (Fig. 2). Bloomer and Hawkins (1983) reported the lithology of dredge samples taken from the north slope of the southern Mariana trench, along one of these major fault zones. Two of their dredge hauls (D 27 and D 28) from the break in slope of the inner trench slope east (D 28) and west (D 27) of the fault at approximately $144^{\circ} 10'$ E showed a wide range in composition of arc related material on the east (depth 4,000–5,000 m) and an almost monolithic recovery of serpentinized

peridotite from the west wall of the fault (depth of 5,000–6,000 m) with only very minor basalt, gabbro, and siltstone and a small amount of breccia. Dredges from further west along the inner wall of the trench (Bloomer and Hawkins, 1983) also recovered dominantly ultramafic rocks (D 26, D 21, D 20) at least as far west as $142^{\circ} 45'$ E, although a dredge at 4,500 m at $143^{\circ} 15'$ E (D 20) retrieved almost as much gabbro as ultramafics. "Shinkai 6500" dive 157 recovered serpentinized harzburgite rocks from the north slope of the trench at $143^{\circ} 26'$ E at depths below 5,800 m (T. Ishii, "Shinkai 6500" Dive 157 report). At a depth of 5,789 a pyroxenite cumulate rock was recovered on this dive. Thus, it appears that the north slope of the trench at depths in excess of about 5,000 m exposes predominantly ultramafic rocks. The paucity of mafic or other rock types from the inner trench slope dredge sites

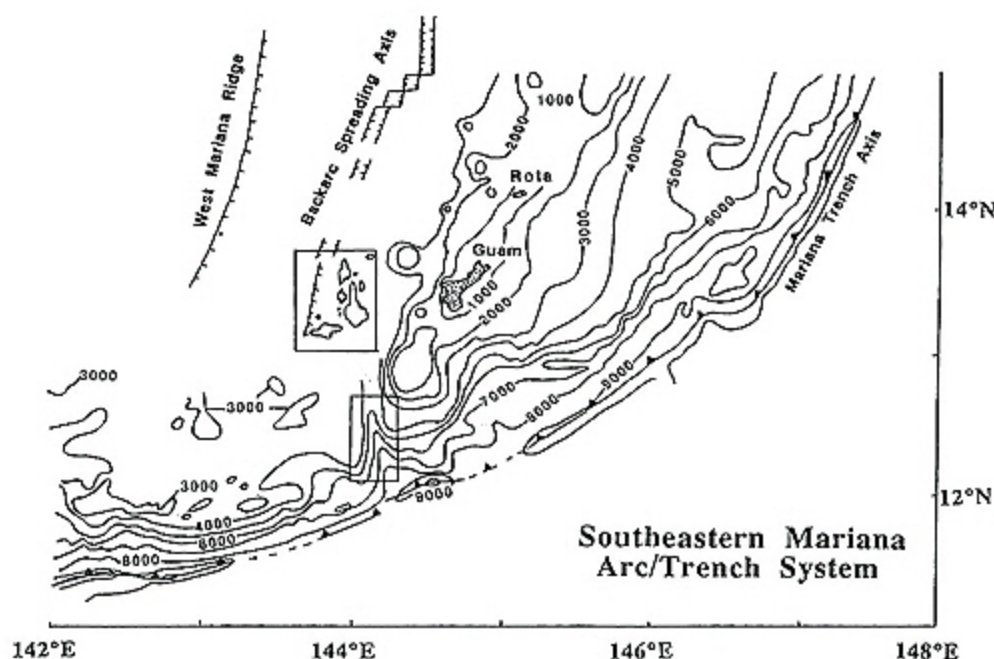


Fig. 2 Bathymetry of the southeastern Mariana convergent margin contoured at 1,000 m intervals. The location of the Mariana Trench is designated by a solid line with triangular barbs. The location of the spreading center of the backarc basin is designated by parallel solid lines with inward facing hatchures. The boxes outline areas from which more detailed bathymetry data were recently collected as shown in Fig. 3 (A) and 5 (B).

suggests that arc mantle predominates the exposures and that this mantle material for the most part lacks the intrusives or layered cumulates indicative of suprasubduction zone magma chamber structures. The major exception to this observation is the material recovered from "Shinkai 6500" dives 158 and 159 on the fault scarp at $144^{\circ} 10' \text{ E}$.

3 Bathymetry Data and Diving Results

3.1 Bathymetry Data

Southern Mariana forearc: Recently acquired

multi-narrow beam bathymetry data (Fig. 3) from near $144^{\circ} 10' \text{ E}$ between $12^{\circ} 10' \text{ N}$ and $12^{\circ} 37' \text{ N}$ during cruise Y9204 of the R/V "Yokosuka" are consistent with Karig and Ranken's (1983) regional structural interpretations. An eastward-facing fault with a throw of nearly 2,500 m strikes approximately north-south at about $144^{\circ} 10' \text{ E}$. Observations of nearly unsedimented talus slopes and lava outbreaks during submersible diving on the western wall of the fault (Dives 158 and 159) suggest recent movement on the fault (see

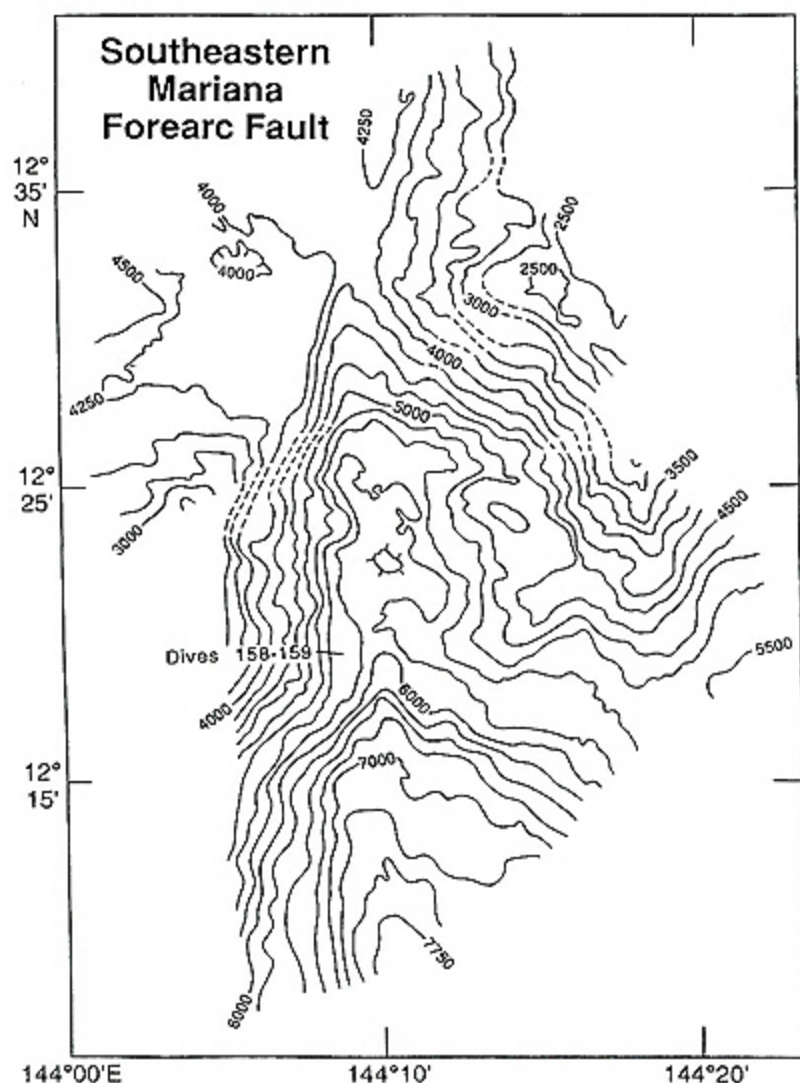


Fig. 3 Bathymetry data collected in a R/V "Yokosuka" multi-narrow beam survey southwest of Guam (refer to Fig. 2 for location of survey) in November of 1992. The 250m contour interval has been hand smoothed.

below).

The dives recovered 7 basalts and 3 microgabbros from depths of 5,180-5,730 m. The latitude of the dive is 12° 20' N, that of the Bloomer and Hawkins (1983) dredge (D 27) was 12° 15' N. The fact that basalts and gabbros were recovered from almost the same depth and from nearly the same geographic position (only 8 km to the north of the dredge) requires that either a fault contact exists between the two localities or that volcanism and intrusions have occurred along the fault scarp mantling and intruding what would otherwise be exposures of serpentinized ultramafics.

Possible venting of fluid from the base of the fault scarp was observed on "Shinkai 6500" dive 158. The feature was observed on approach to the bottom at the beginning of the dive. A roughly circular hole approximately 75 cm in diameter was observed on a sediment-covered surface. The edges of the hole were vertical and exposed several well-defined sediment layers. The edges of the hole were slightly built up from the surrounding seafloor with a rim about 20 cm high. A dark fluid apparently denser than ambient sea water was seen undulating and bubbling gently within the hole about 30 to 40 cm from the rim (Photo 1). In two places the rim was breached and dark streaks of the fluid could be seen trailing off across the seafloor in the down-current direction. These observations were made and captured on video tape as the submersible was stabilizing prior to the start of the dive traverse. As the pilots set the submersible down on the seafloor, the skids landed on the edge of the hole and caved in most of the sides of the hole. Water samples were taken in the hole (Photo 2), but the fluid compositions are not yet available. Analysis of the samples is underway by M. Mottl and T. Gamo. The hole is located at the base of the fault scarp

on the west side of a slight mound that is elongate along strike of the fault. The seafloor in the vicinity of the hole is heavily bioturbated and we observed numerous small benthic animals (Photo 3). We also observed small cones and holes filled with fecal pellets, however none of these holes were larger than 10 cm in diameter. The sharp sides of the large hole, suggests that if it is not artificial it was being actively excavated by upwelling fluids. The hole is not a biological excavation. The water column contains fish, small planktonic forms and a few jelly-fish-like animals of approximately 15-30 cm diameter. The fault scarp above the site of the vent is covered by several unsedimented talus chutes, intermittent outcrops of massive mafic rocks, and two localities where lava outbreaks mantle the outcrops. The petrology of the rocks is described in detail below.

Volcanism has apparently occurred along the fault scarp, at least between the depths of 5,400 and 5,275. There is a suggestion that volcanism may also have occurred further north along the scarp. A bathymetric bulge (Fig. 2) along the fault trace at 12° 23' N, 144° 09' E rises over 500 m above the local terrane and may represent a small volcanic edifice built as a consequence of volcanism along the base of the fault scarp. The small proportion of mafic rock in the dredge (D 27) described by Bloomer and Hawkins (1983) suggests that voluminous volcanism and intrusive activity may not extend much further south, or if it does that it may be confined to the lowermost portion of the fault scarp.

Trench axis: Bathymetry data collected between longitude 143° 35' E and 144° 10' E at about 11° 50' N (Fig. 4) show the region of intersection between the trench axis and the major north-south trending fault at 144° 10' N. The trench axis shows a shoaling of 2,250 m where the fault trace intersects the trench axis.

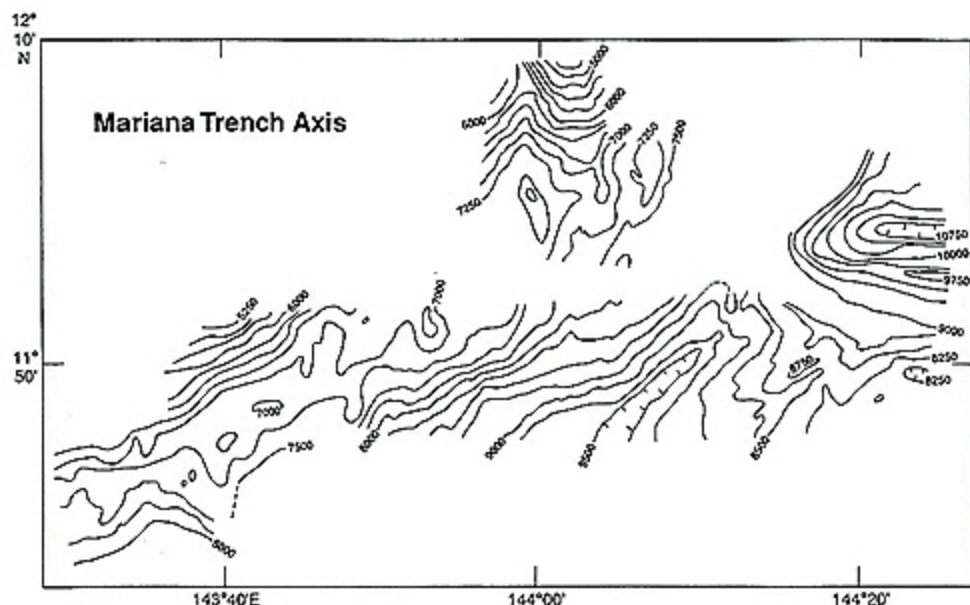


Fig. 4 Bathymetry data collected in a R/V "Yokosuka" multi-narrow beam survey of the Mariana Trench axis southwest of Guam in November of 1992. The 250 m contour interval has been hand smoothed.

The trend of the trench axis changes from northeast-southwesterly to the west of the intersection shoal to east-westerly to the east of the shoal. The trench axis is also 1,250 m deeper east of the intersection shoal. The morphology of the intersection suggests that the movement on the fault is likely left-lateral strike-slip with a component of dip-slip down-dipping to the east. This would account for the deepening of the trench axis east of the intersection and would facilitate the local change in the strike. This fault is unique. It is the only known fault that is continuous across the entire forearc region and has been documented as a site of forearc volcanism.

The regional morphology of the north slope of the trench suggests that it is also being deformed by strike-slip faulting parallel to the trench axis. A line of small northeast-southwest trending highs parallels the trench axis at a distance of about 20-25 km up-slope. These may represent the edge of a fault zone trending along strike of the inner slope of the

trench. On a regional scale (Fig. 2), a large reentrant in the upper edge of the north slope of the trench also suggests east-west trending faulting. The details of the interactions of these faults must await further surveying, but it is likely that the north-south trending fault is dominant in this region, and may represent a profound boundary between strain regimes in the southern Mariana forearc.

Backarc basin: The north-south trending fault at 144° 10' E probably extends north across the volcanic arc into the backarc basin (Fig. 5). Prior to the R/V "Yokosuka" cruise the southernmost bathymetry data from the backarc basin were from SeaBeam swaths and a single SeaMARC II line at about 13° 40' N (Hagen et al., 1992). From these data Hagen et al., 1992) suggested that the Mariana backarc basin spreading center at 13° 40' N is a narrow, relatively low-relief feature in contrast to portions of the backarc spreading center further north (e.g. Fryer and Hussong, 1981; Hawkins et al., 1990; Smoot, 1990). Bathymetry

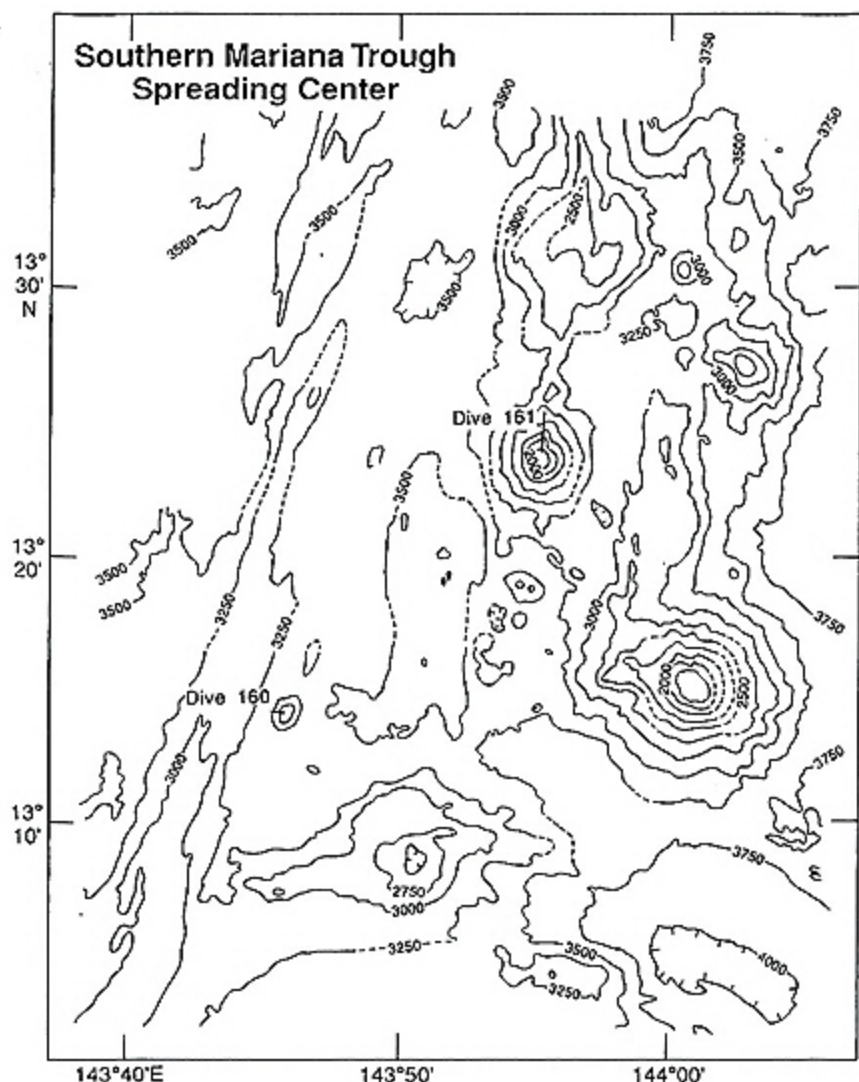


Fig. 5 Bathymetry data collected in a R/V "Yokosuka" multi-narrow beam survey west of Guam in the Mariana backarc basin (refer to Fig. 2 for location of survey) in November of 1992. The 250m contour interval has been smoothed. The positions of the two "Shinkai 6500" dives completed in November 1992 (described in text) are shown on the map. Note in particular the southern most edifice in the survey region. It has suffered deformation along a right-lateral strike-slip fault zone. Such a fault lies colinear with forearc faults (same sense of motion) at 13° N. Note also that the southeastern portion of the survey region indicates a perturbation of the structural trend. The north-south striking fault shown in Fig. 3 lies along longitude 144° 10' E and may influence the development of the backarc basin structures.

data collected on the R/V "Yokosuka" cruise show that, far from being a narrow, relatively inactive spreading center, the southern extension of the spreading center broadens southward over 40' of latitude from 5 km at 13° 40' N to over 40 km at 13° 10' N.

The volcanic edifices are large and active both tectonically and volcanically (Fig.5). Dives 160 and 161 of the "Shinkai 6500" were located on volcanoes at 143° 35' E, 13° 14' N (160) and 143° 55' E, 13° 22' N (161). On dive 160 on the smaller volcano, the lavas were covered

with volcanoclastics and sediments to a depth of several centimeters over nearly the entire edifice. At the bottom of the slope, near the western bounding fault of the spreading center, knife-edge tensional fissures in the sediment and exposed lavas, indicate recent faulting and continued tectonic activity on the westernmost margin of the rift valley. Very fresh glassy pillow fragments of basalt and basaltic andesite were recovered from the volcano. The larger volcano examined on dive 161 was virtually devoid of sediment. At the summit large active hydrothermal chimneys (composed predominantly of marcasite) shed hydrothermal sediments in mounds at the base of the chimneys. Maximum vent water temperature at the summit was 202°C at a depth of 1,420m. Communities consisting of bacterial mats, snails, shrimp, and crabs, similar to those observed at 18° N in the Mariana backarc basin were observed within the hydrothermal fields. The chimney structures were as much as 10m high in places at the summit of the volcano. Extremely fresh basalt and basaltic andesite rocks were recovered from the volcano, along with the chimney from which the water temperature was taken. Detailed description of these dives are given by L. Johnson (Dive Report for "Shinkai 6500" Dive 161, this volume) and by H. Maekawa (Dive Report for "Shinkai 6500" dive 160).

The distribution and morphology of the volcanoes in this part of the back arc basin may be attributed to several phenomena. The extension of the active volcanic line of the Mariana arc passes very near the survey area (Fig. 2). It is possible that the large volcanoes on the east side of the spreading axis are actually arc volcanoes superimposed on the spreading center region. It may be that within this region both backarc basin lavas and arc lavas are generated and form a complex

interrelated plumbing system, as has been suggested for the northernmost Mariana backarc basin active rifting region (Baker et al., submitted). Additional bathymetry data from the southeastern portion of the backarc basin would help to trace the distribution of volcanism and thus to establish the connection between the arc volcanic line and the backarc spreading center if such a connection exists. The north-south trending volcanic ridges that form at the eastern boundary of the spreading center give clear evidence that magma from the major volcanic centers is leaking along the fault zones at least at the edge of the spreading center. If the forearc fault trend intersects the backarc spreading center there may be two effects: (1) magma egress is likely to be greatest at the intersection of these structural elements, thus contributing to enhanced volcanism in this part of the basin, and (2) fissure eruptions may follow the north-south trending fault at 144° 10' E southward into the forearc region. At the southeast corner of the backarc basin bathymetry map (Fig. 5) the topography of the seafloor curves around from an east-west orientation to a more southerly trend suggesting influence by the north-south trending fault of the forearc at 144° 10' E. A continuation of the bathymetry survey would be required in order to determine the possible structural interrelationships between the previously surveyed areas. The seamount furthest south in the spreading center region surveyed is offset in a right-lateral sense by strike-slip faulting along a zone oriented east-west across the backarc basin. The latitude of the offset is nearly the same as that of the east-west striking fault zone(s) identified in the forearc east of Guam at 13° N (Karig and Ranken, 1983) (Fig. 3 and 5). The extent of the east-west fault zone is less well delineated by existing data, but structures exposed on Guam (e.g. Emery, 1962) suggest

that east-west striking strike-slip faulting in a right-lateral sense has contributed to the current structure and morphology of the island. If east-west trending faults extend into the backarc basin they may also facilitate magma egress at the spreading center. Most likely the answer is that all three phenomena play a role in the development of the volcanoes of the backarc spreading center at 13° N. The east-west fault zone may also permit leakage of arc magma into the forearc.

3.2 Petrology Data

Rock samples were collected from the talus slope at the base of the scarp and at outcrops further up slope (Fig. 6). A modal description of the samples is given in Table 1. The outcrops observed on dive 159 between 5,700 and 5,400 m are primarily massive mafic rocks with variable sediment cover (Fig. 7). The outcrops have occasional small (1–3 m high), near

vertical scarps. At a depth of about 5,400 m and at about 5,300 m there are two outbreaks of lavas. At 5,400 m the lava outbreak constitutes a small ridge about 2 m high that extends at an azimuth of approximately 150° from the fault slope. The ridge exposes lavas intermittently through a sediment cover, thus does not appear extremely young. The lavas at 5,300 m mantle exposures of large blocks of massive mafic rock. The lavas from these two locations appear to be in situ. The lavas are vesicular, containing from 18–23% vesicles by volume, with the exception of one rock that contains only 5% vesicles.

The two samples collected on dive 158 are both very sparsely porphyritic basalts. Sample 158-4 is coarser than 158-5 and has olivine crystals (altered to iddingsite) intergrown with plagioclase laths and clinopyroxene. Both lavas contain interstitial glass. The glass in

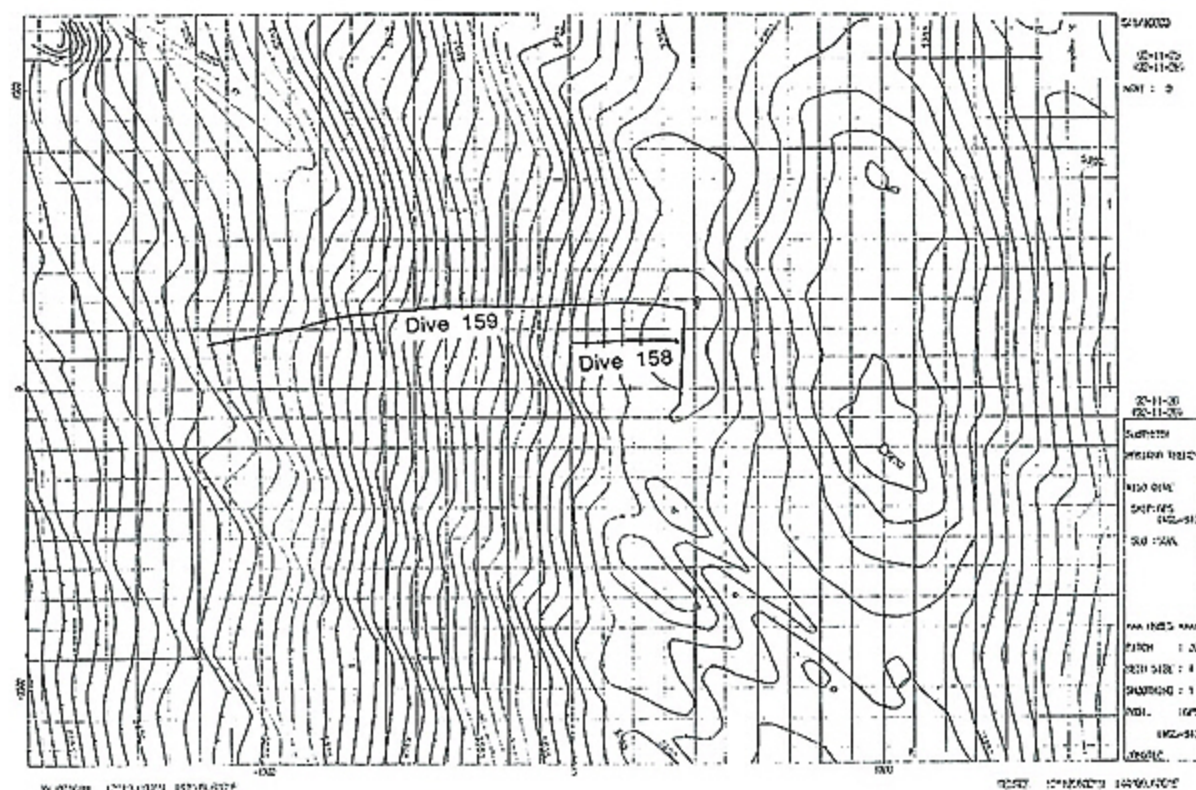


Fig. 6 Detailed dive map.

Table 1 Modal Analysis of "Shinkai 6500" Dives 158 and 159 Rock Samples.

Sample	Rock Type	plag	cpx	ol	mt	glass	ves	other
158-4	basalt	55	19	tr	5	15	5	tr
158-5	basalt	27	13		13	29	16	
159-1-1	basalt	29	21	1	1	28	19	tr
159-1-2	basalt	17	36		5	24	18	
159-1-3	basalt	identical to 159-1-2						
159-3-2	basalt	identical to 159-1-2						
159-4	basalt	7	4		3	63	23	
159-2	microgabbro	17	36			29	18	
159-3-1	microgabbro	50	16		1	20	13	
159-5	microgabbro	49	26	1	1	23		

plag = plagioclase, cpx = clinopyroxene, ol = olivine, mt = magnetite,
glass = glass in interstices or as groundmass, ves = vesicles,
other = clays or iron oxides.

Lithology and Sample Locations for Dive 159

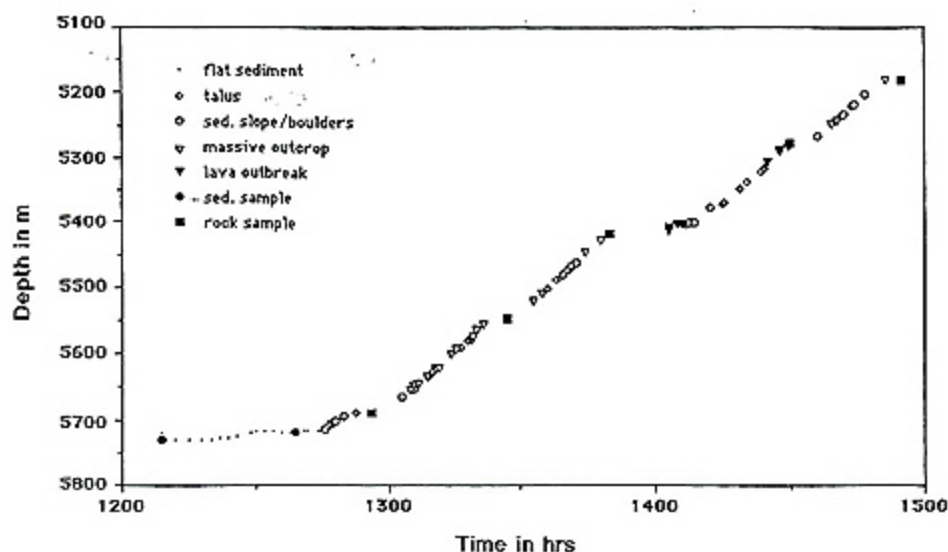


Fig. 7 Profile of dive 159 showing distribution of lithology and sample location along the dive track. Prominent breaks in slope represent sampling stations, not steps in the slope.

158-4 is light brown and contains microlites of pyroxene (?). Skeletal magnetite crystals, about the same size as the average pyroxene grain are scattered throughout the rock, along with smaller euhedral magnetite crystals. In 158-5 the texture of the rock is similar, but there is no olivine and there is significantly more glass. The glass in 158-5 is dark brown, and choked with inclusions. Circular to co-

alesced vesicles are prevalent in the glass. Magnetite is also present in this rock, but only as minute euhedral grains in the groundmass. Phenocrysts of clinopyroxene and plagioclase are more common in this rock.

Five basalts and three microgabbros were recovered on Dive 159. The three samples (159-1-1, 159-1-2, and 159-1-3) recovered at the first sampling locality (Photo 4) represent two

different basalts (Table 1). The basalts are similar in texture, although 159-1-2 and 159-1-3 lack the olivine that is present in well-formed phenocrysts in 159-1-1. Sample 159-1-1 contains minute magnetite crystals scattered in the glass, while the other two show no magnetite or other opaque phases. The glass in samples 159-1-2 and 159-1-3 is choked with inclusions and may contain dusty magnetite too small to resolve in thin section. These two samples also contain vesicles of a different type than those present in 159-1-1. The latter contains small irregular vesicles scattered throughout the glass while the former two samples show two generations of vesicles. They contain a population of larger circular vesicles and a population of smaller circular to irregular-shaped vesicles. The smaller vesicles tend to concentrate in patches of glass. The vesicle distribution in the glassy patches is radial with elongate vesicles centered on the middle of the patch or of the individual coalesced patches. Sample 159-3-2, collected from outcrop at 5,400 m (Photo 5), is identical to 159-1-2 and 159-1-3. The lavas at 5,400 m were observed to overlie outcrops of massive mafic boulders of microgabbro (Photo 6). These lavas apparently were erupted to form a small ridge jutting out from the slope of the fault scarp. The depth of eruption of the lavas makes the formation of the vesicles of some interest. Similar types of vesicles were observed in lavas dredged from the northern Mariana backarc basin (Jackson, 1991; Fryer et al., submitted) and from the Sumisu rift (Fryer et al., 1990). The backarc basin lavas were dredged from a maximum depth of 3,500 m thus sample 159-3-2 represents the deepest (5,400 m) observed in situ lava from the convergent margin to show significant vesiculation. It is possible that samples 159-1-2 and 159-1-3 are talus fragments that have moved down-slope from the 159-3-2 locality. Sample 159-4, from 5,275 m, is similar to 159-1-

2, 159-1-3, and 159-3-2, however it has a much higher percentage of glass. Vesicles are more abundant in this sample (23%, see Table 1) than in any of the other lavas collected on this dive. The vesicles in this sample also show a tendency toward a patchy, localized radial distribution. The lavas have a rough surface and partially drape exposures of more massive mafic rock (Photo 7).

The three microgabbros collected on Dive 159 were taken from three localities where massive blocks of mafic rock were observed to form localized outcrops of nearly vertical slope (Photo 5, 6, 7, and 8). All three contain plagioclase intergrown with pyroxene and skeletal magnetite crystals. All three also contain interstitial glass with variable amounts of microlites of pyroxene and skeletal plagioclase. Sample 159-2, from the first locality at 5,544 m, contains the least interstitial glass of the three microgabbros. Sample 159-3-1 collected from the outcrop at 5,400 m that was partially draped with lava (Photo 6), contains the most highly altered interstitial glass with green clays replacing much of the glass and lining vesicles in the glass. This microgabbro sample contains the smallest crystals and the greater volume of vesicles of the three. Sample 159-5 from the last sampling locality (Photo 8) on the dive at 5,180 m, contains the greatest amount of glass. The plagioclase, pyroxene and magnetite crystals in this sample are larger than those in the other two. These microgabbros lack cumulate textures and may represent exposures of dikes.

4 Conclusions

The detailed bathymetry data, acquired during cruise Y9204 of the R/V "Yokosuka" in the southern Mariana forearc, and the observations during "Shinkai 6500" submersible dives 158 and 159 and have shown that volcanism and fluid venting are related to a

major north-south trending fault zone that cross-cuts the entire southern Mariana convergent margin. The morphology of the Mariana Trench axis is apparently affected by left-lateral strike-slip movement on the fault. Relatively fresh basaltic lavas and mafic microgabbros were observed outcropping on the side of the forearc fault and suggest recent volcanism. The high degree of vesiculation of the lavas even at depths in excess of 5,180 m suggests a fluid rich magma likely of supra-subduction zone origin. The possibility of fluid venting at the base the fault suggests that either hydrothermal activity or subduction-related fluid flux may occur along the fault.

Faults within the southernmost Mariana backarc basin spreading axis were also delineated on detailed bathymetry data from west of Guam. Predominant among these are north-south trending faults within the spreading region along which large volcanoes and north-south trending volcanic ridges have developed. "Shinkai 6500" submersible dives on one of the volcanoes of the eastern portion of the backarc basin spreading region recovered recent lava flows and active hydrothermal chimneys. A dive on a smaller volcano on the western side of the spreading region showed a greater sediment cover and no active hydrothermal fields, but did attest to the fact that recent tensional deformation affects the westernmost part of the spreading region. Tectonic activity is thus spread over a zone approximately 60 km wide at 13° N within the backarc basin. The greater size of the volcanoes on the eastern side of the spreading region may be caused by (1) a tendency for the rifting to remain on the arc side of the backarc basin (e.g. Baker et al., submitted), (2) the intersection of the spreading region with the active volcanic front (submarine in this part of the arc), (3) the intersection of the north-south trending and/

or an east-west trending fault zone with the spreading region, or (4) some combination of the above. Faulting of the southernmost of the volcanoes in the spreading region suggests that east-west trending fault zones may also cross-cut the Mariana convergent margin from the trench axis to the backarc basin and may provide avenues for egress of arc magmas across the entire Mariana platelet. Large fault zones cross-cut the southeastern Mariana forearc and intersect the Mariana Trench axis. The deflection of the east-west trend of this lineament toward the southeastern corner of the bathymetry survey suggests that there may be some influence from the major north-south trending fault at 144° 10' N in this part of the backarc basin. The interrelationships of the various regional fault trends cannot be determined without further detailed surveys.

The bathymetry data collected and dive observations augment studies of the structural interrelationships between the egress of fluids, degree of metamorphism, forearc volcanism, and distribution of forearc structures in this convergent margin setting. These fault zones provide zones of egress of fluids and may provide routes for migration of arc magmas into the forearc region. Faulting in the southeastern forearc is also likely the cause of concentrations of large volcanoes in the backarc spreading region in the southernmost Mariana Trough, the actively opening spreading center immediately west of the Mariana island arc.

Acknowledgments

The author expresses her thanks to the captain and crew of the R/V "Yokosuka" for their assistance and cooperation under extremely adverse weather conditions. Without the technical assistance, generosity, and cheerful dedication of the "Shinkai 6500" support crews (JAMSTEC), especially in making possible the second dive on the fault scarp, the discoveries

made on the dives would not have been possible. The author is indebted to them and very grateful. Drs. T. Gamo, L. Johnson, T. Ishii, and H. Masuda provided input into the interpretations presented here through stimulating discussions aboard ship. This work was supported in part by funds from NOAA NURP. This is SOEST contribution no. 3252 and PG contribution no. 732.

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(Manuscript received 22 July 1993)

(Notice) Photos are given on the following pages.



Photo. 1 Image captured from video tape from Dive 158 of a hole from which dark fluid was suspected to be seeping.

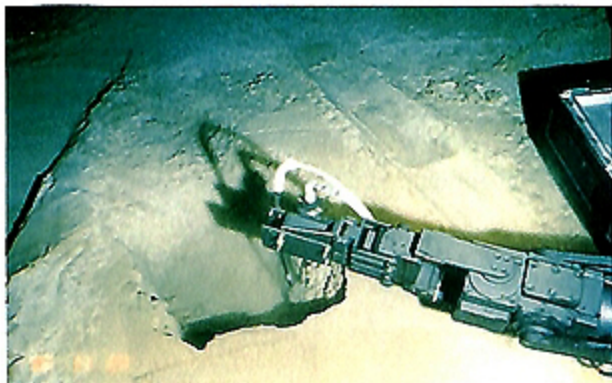


Photo. 2 "Shinkai 6500" external photo of the hole shown in Photo 1 after water sampling was attempted. Despite cave-in of the sides of the hole, the layered sediment is still visible in the right-hand wall of the hole.



Photo. 3 "Shinkai 6500" external photo of bioturbated sedimented sea floor at the base of the fault scarp.



Photo. 4 "Shinkai 6500" external photo of the locality from which samples 159-1-1, 159-1-2, and 159-1-3 were collected. This is a slightly sedimented talus deposit at the base of the fault, suggesting recent mass movement on the fault slope.

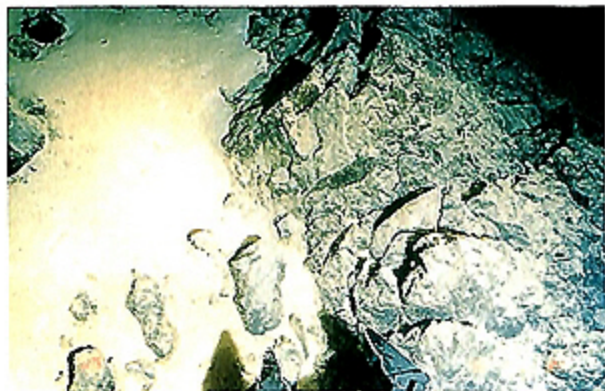


Photo. 5 "Shinkai 6500" external photo of the locality from which sample 159-3-2 was collected. The lavas are the blocky and outcrop through a patchy sediment cover.

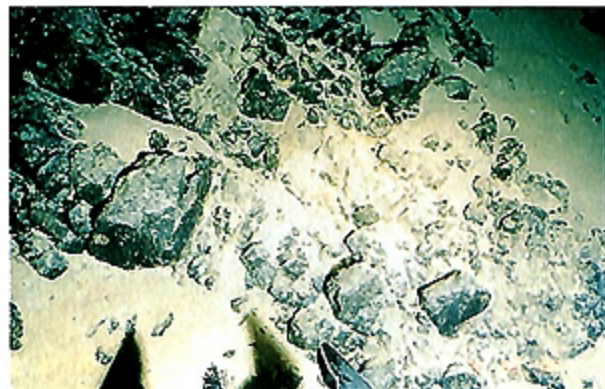


Photo. 6 "Shinkai 6500" external photo of the locality from which microgabbro sample 159-3-1 was recovered. The darker blocky rock outcropping at the left side of the photograph is the lava that constitutes sample 159-3-2 (see also Photo 5). The microgabbro is the more heavily sedimented outcrop immediately to the right of the lava.

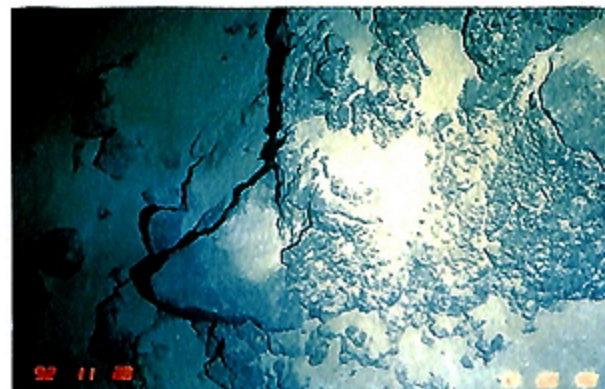


Photo. 7 "Shinkai 6500" external photo of the rough-surfaced lavas (159-4) at 5,280m (right) overlying outcrops of massive mafic boulders of microgabbro (left).

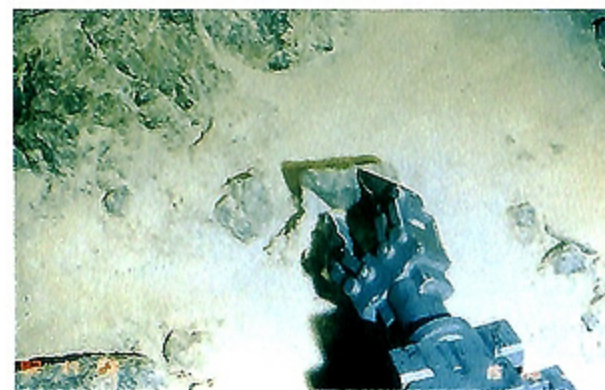


Photo. 8 "Shinkai 6500" external photo of outcrops of massive mafic boulders of microgabbro (159-5) at 5,180m.