An Actively Venting Serpentine Seamount on the Southeastern Mariana Forearc : "Shinkai 6500" Dives 280 and 281

Patricia FRYER*[1]

A serpentine seamount at 13°47'N, 146°03'E on the southeastern Mariana forearc has an active fluid seep at its summit. The active seep area is characterized by a small knoll on the northeast side of the summit of the seamount. Blocks of unconsolidated to partially cemented fine-grained serpentine muds at the summit of the knoll are encrusted with carbonates. These carbonates are similar to chimney materials sampled from other seep sites on similar serpentine seamounts on the Mariana forearc. Isotopic compositions of carbonates collected previously from this site indicate a slab-origin for the fluids responsible for the precipitation of the carbonates. The presence of fluid seeps in association with serpentine seamounts of the Mariana forearc provide a opportunity to study the spatial variability of slab-related fluids at a major convergent plate margin. Such studies are critical to the understanding of global geochemical mass balance related to plate tectonic activity.

Key words : Fluids, Serpentine, Seamount, Mariana, Forearc

* 1 School of Ocean and Earth Sciences and Technology, Hawaii Institute of Geophysics and Planetology, University of Hawaii

1. Introduction

The mariana system of the western Pacific (Fig. 1) is a nonaccretionary intraoceanic convergent margin. Almost no sediment from the Pacific plate is being accreted to the outer toe of the overriding plate where it contacts the down-going Pacific plate (Hussong and Fryer, 1981 ; Hussong and Uyeda, 1981). The Mariana forearc exposes numerous fault systems associated with both forearc extensional basins and with vertical tectonics related to seamount subduction (Mrosowski et al., 1981 ; Fryer and Fryer, 1987 ; Marlow et al., 1992 ; Fryer, 1993 ; Fryer,

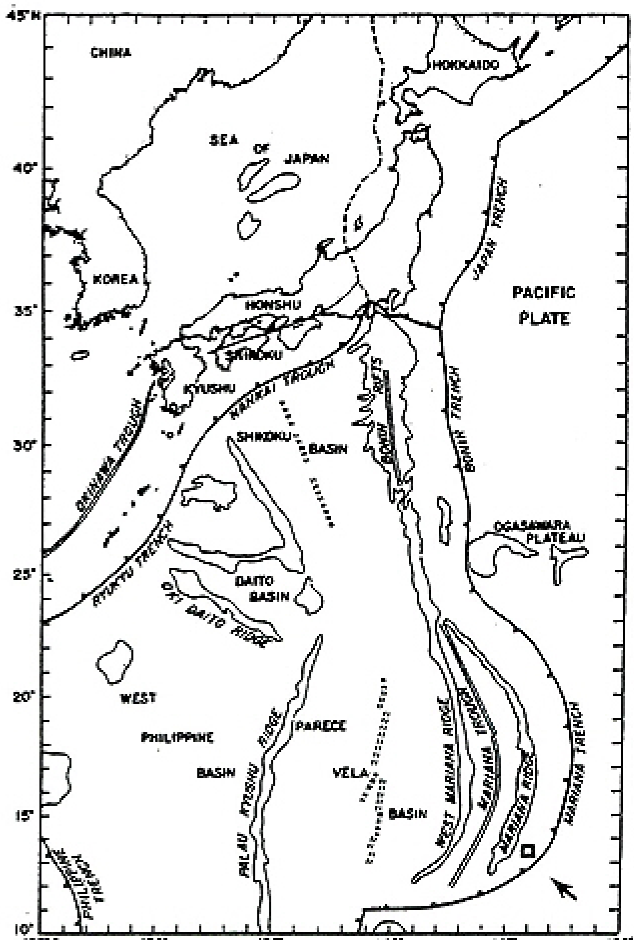

Fig. 1 Bathymetry and geologic features in the Philippines Sea region. Basins and ridges are outlined by the 4km bathymetric contour, except for the Izu-Bonin arc, West Mariana Ridge and Mariana arc, which are outlined by the 3km contour. Barbed lines locate axes of trenches ; medium double lines locate active spreading centers ; dashed lines locate relict spreading centers, single dashed line is a proposed new plate boudary. Locations of Figs. 2, 3 and Photos 1-10 are outlined.

1996). Fluids derived from the subducted slab find their way to the sea floor along the faults and debouch there causing precipitation of carbonate chimmey structures or encrustations on fault surfaces (Fryer et al., 1990 ; Fryer et al., 1995). These fluids differ in composition depending on locality (Haggerty, 1987 ; Haggerty, 1992 ; Mottl, 1992). The lack of an accretionary sediment burden and the presence of numerous faults to channelize flow makes such a region an excellent natural laboratory in which to study the composition of slab-derived fluids. The complexities of fluid-sediment interaction that is so common in accretionary convergent margin settings are not such a problem in an environment like the Mariana forearc (Fryer, 1996). Furthermore, the presence of fluid vents in association with the nearly monolithic serpentine seamounts of the outer half of the Mariana forearc (Fryer and Fryer, 1987) assure a simplified history of water-rock interaction enroute to the sea floor.

In September of 1995 two dives were conducted on a serpentine seamount, at 13°47′N, 146°03′E (Fig. 2), informally named Chomorro Seamount. It is one of three serpentine seamounts located in a small cluster at the southwestern edge of a forearc gaben (Fryer, 1996). The objectives of the dives on the serpentine seamount were to determine whether the seamount is a site of active fluid seeps, to observe seeps, if present, and to collect samples representative of both the body of the seamount and any secondary precipitates associated with fluid seeps. This paper summarizes the results of these dives and suggests the significance of the fluid seeps at the seamount.

2. Previous Studies

A dredge site at about 3,800-3,750m taken in 1981 on the eastern mid-flank region of the seamount (Figs. 3 and 4) yielded serpentinized harzburgite and carbonate chimney samples (Fryer, 1996). These chimney structures are identical in mineral composition to carbonate chimneys discovered on Conical Seamount at 19°30′N (Fryer et al., 1990 ; Fryer, 1996) although the carbon and oxygen isotope compositions of these samples are different (Haggerty, 1987).

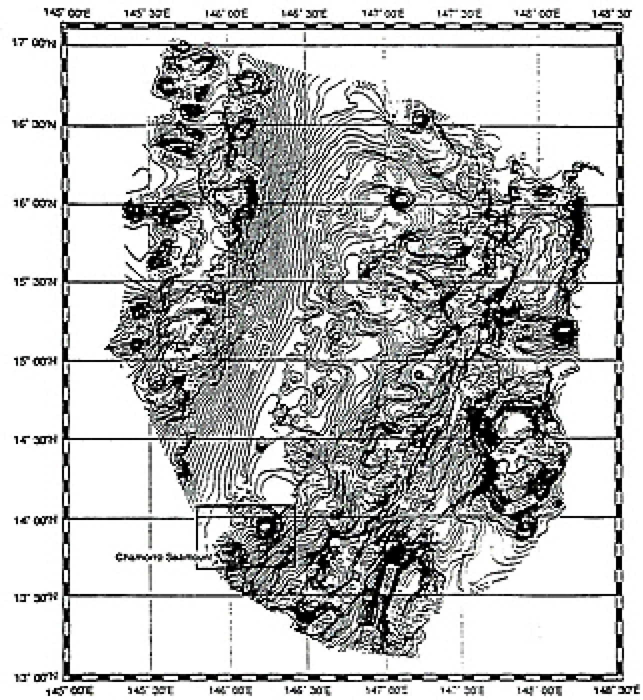

Fig. 2 Bathymetry of the southeastern Mariana forearc, contoured at 200m intervals, based on US Navy SASS data. The box shows the location of Fig. 4. This figure is modified after Fryer (1996).

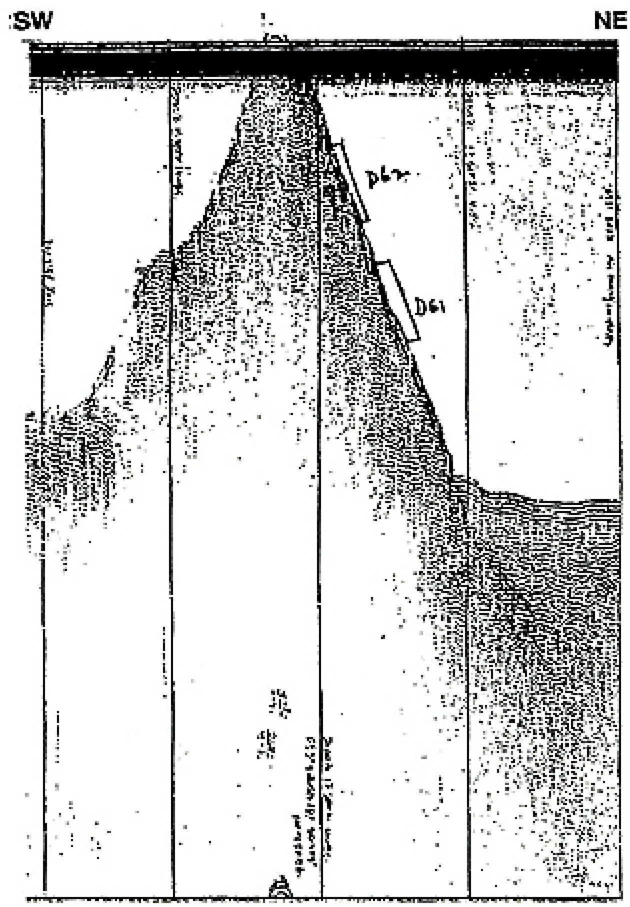

Fig. 3 Seismic Reflection Profile of Chamorro Seamount from southwest to northeast (see Fig. 4 for track location) showing approximate relative locations of 1981 dredge sites. Carbonate chimney fragments were recovered at the deeper site (D61). The actual dredge site lies along the track of dive 280 (Figs. 4 and 5) slightly southeast of the profile.

Haggerty (1987) noted that compared with aragonite from fracture-zone carbonates, thought to have a dominantly sea water origin, aragonite in chimmey samples dredged from this seamount is depleted in Sr (Mariana samples=7,000-9,400ppm ; fractue zone aragonite=9,500-11,600ppm), is enriched in Mg (Mariana=750-6,300ppm ; fracture zone <300ppm), and has a significantly lighter carbon isotopic signature (Mariana= −1.2 to −21.2‰ ; fracture zone= +0.03 to +1.12‰) and a heavier oxygen isotopic signature (Mariana= +5.1 to +7.6‰, fracture zone= +3.16 to +4.87‰). At least two origins are consistent with these values : sea water interactions with ultramafics and dewatering of subducted oceanic lithosphere and/or from the mantle underlying the forearc.

Reflection profiles collected in 1981 across the seamount shows local steepening, suggesting deformation of the flanks (Fig. 3). The persence of the chimney structures on the flank of the seamount could imply that as deformation of the flank took place, pathways were initiated that provided escape routes for slab-related fluids. Based on the dredge and geophysical evidence, this seamount could be either a mud volcano or a horst in which faulting has opened fluid venting paths. Detailed mapping of the seamounts with the R/V "Yokosuka", (cruise Y 9506) multi-narrow-beam sonar system on Sept. 6-8, 1995 shows a much flatter summit on the seamount to the northeast than on Chamorro Seamount (Fig. 4). The more flattened summit may suggest that the seamount to the northeast is not currently active, although detailed imagery or bottom photography would be required in order to determine the nature of the second seamount.

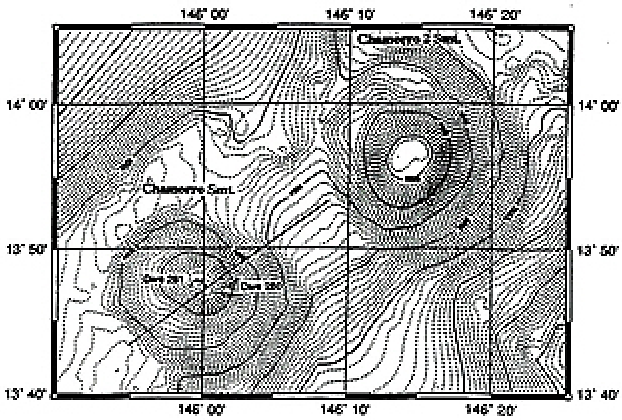

Fig. 4 "Yokusuka" bathymetry of serpentine seamounts on the southeastern Mariana forearc, 50m contours (Fryer, 1996). The two "Shinkai 6500" dive locations are shown on the southwestern seamount (informally called Chamorro Seamount). The straight line indicates the location of the seismic reflection profile shown in Fig. 3. A more detailed bathymetry map of Chamorro Seamount is given in Fig. 5.

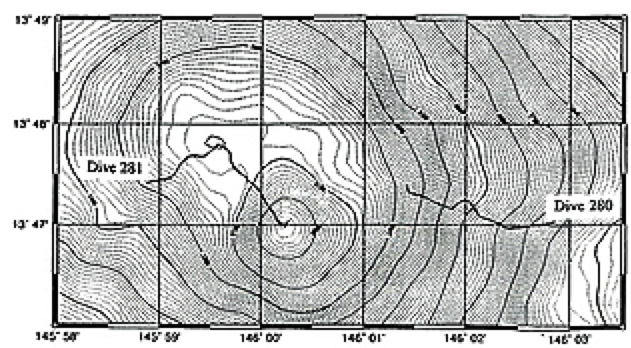

Fig. 5 ""Yokusuka" bathymetry of a serpentine seamount at~13°47'N, 146°E (informally called Chamorro Sea- mount), 10m contours. Track lines for "Shinkai 6500" dives 280 and 281 are shown on the map. A site of active fluid egress was discovered at the summit of the seamount on dive 281.

3. Dive Observations

Two dives with the "Shinkai 6500" submersible on the seamount (dives 280 on 9/7/95 and 281 on 9/8/95) (Fig. 5) both support the interpretation of flank deformation and confirm the origin of the seamount as similar to that of Conical Seamount, that is, by serpentine mud volcanism (Fryer, 1992). Dive 280, traversed from a depth of 3,840m to 3,380m on the eastern flank. In the region of the 1981 dredge site, we observed serpentine mud and debris flows lightly encrusted with manganese and dusted with a thin sediment cover (Photo 1). This material contains many clasts of ultramafic rocks. Seep slopes observed on dive 280 in the vicinity of the 1981 dredge haul suggest secondary mass movement on this flank, which may indicate recent tectonic deformation of the edifice. At a depth of about 3,550m scattered clasts of foraminiferal limestone lie among the ultramafic clasts and lightly sedimented serpentine matrix of the slope. The clasts of limestone are loosely lithified by carbonate cement and the forams are partially dissolved. Some of the limestone fragments are dissolving in place on the seafloor and thus appear to drape the surrounding surface pebbles (Photos 2 and 3) some of the fragments are partialy encased in serpentine mud (Photo 2 – foreground). In one of these areas the serpentine matrix is well-exposed and consists of a light green unconsolidated serpentine mud with numerous dark clasts (Photo 4). Several fragments of the foraminiferal limestone lie scattered on the seafloor near this exposure. Some of these fragments contain swirls of green serpenitine mud and contain small clasts of serpentinized ultramafic rock (Photo 5). The interpretation is that forminiferal sands that had been deposited at a higher elevation on the seamount were disrupted and engulfed by serpentine mud protrusions. These were subsequently reworked by mass wasting and deposited at deeper levels on the slopes of the seamount. Although most of the slope is covered with debris flows material consisting of numerous clasts of ultramafic rock, one region of well-exposed serpentine mud flow is located at a depth of about 3,500m (Photo 6). The serpentine mud at this locality contains few clasts (similar to the mud flows on Conical Seamount (Fryer et al., 1990 ; Fryer, 1992)). The abundance of clasts in debris flow deposits on the flanks suggests that during mass wasting events the finer, unconsolidated serpentine muds may be winnowed away by bottom currents. No carbonate chimney structures were observed on this dive. Thus, although we did not the 1981 chimney fragments dredged from this locality possibly originated farther up the slope and were reworked by subsequent mass wasting. Support for this interpretation came from the second dive (dive 281) at the summit of the seamount.

Dive 281, from depths of 3,176 to 2,982m, traversed the flat, west-central summit region (Fig. 5). This locality is bathymetrically similar to the site of the main venting region at the summit of Conical Seamount (Fryer et al., 1990). On Dibe 281, however, the flat part of the summit is sedimented with a light-colored foraminiferal sand and is partially covered with a thin veneer of small manganese nodules (Photo 6). The summit area on this seamount lacks the prervasive small tensional faults and outcroppings of serpentine muds characteristic of the summit venting area on Conical Seamount. The persence of scattered sponges and delicate corraline structures suggest this region has been stable for some time. The actively seeping portion of the summit region is confined to the prominent 160m high knoll on the southeast side the summit. This knoll has formed by protrusion of serpentine muds with entrained large clasts of ultramafics. It lacks sediment cover, and was probably formed recently. A patch about 50 meters in diameter of slabs of partially consolidated serpentine mud occurs at the top the knoll. The slabs contain small clasts of serpentinized peridotite. Many of the slab edges are partially coated with thick (up to 15cm) encrustations of carbonate (Photos 8 and 9). One of the larger ultramafic clasts at this locality contains a vein of carbonate (Photo 10) and several of the small clasts in the slabs of serpentine mud also are fractured and veined with carbonate. The fracturing of the clasts probably occurred during transport from depth where fluids permeated the rock and deposited the secondary vein minerals. There are no chimney structures, but rather this fluid venting region is forming concentrations of carbonate at numerous localities within the patch of serpentine mud slabs. At a depth of about 2,932m there is a disarticulated shell of a clam about 10-12cm long (at 15 : 33 : 44 on video of Camera #1 and at 15 : 33 : 46 on Camera #2). As we left the site the pilot observed 3 or 4 chams estimated to be about 20cm long and 7-10cm wide clustered near one of the cracks between slabs (Suzuki, pers. comm). The carbonate sample retrieved was coated with a greenish-yellow gelatinous substance (visible in the upper portion of Photo 9), identical in appearence to bacterial matting observed and collected with the *Alvin* submersible on an active Conical Seamount chimney (Fryer et al., 1990 ; Fryer, 1993). A small cluster of worm tubes (2-3mm diameter, tan colored) was discovered inside the carbonate sample when it was broken open aboard ship.

The seamount is actively venting fluids that cause precipitation of carbonate materials similar to those of Conical Seamount, however the locality supports a far richer biological commiunity than did that observed at the summit of Conical Seamount. Analysis of the carbonate material and investigation of the biological specimens is underway. The summit knoll possibly repersents a reactivation of this seamount with protrusion of serpentinite and the generation of serpentine mud flows.

4. Significance of Active Fluid Seeps

Discovery of an active seep at the summit of this seamount repersents the third documented site of fluid egress on the Mariana Forearc (Fryer, 1996). To-date all documented sites are associated with serpentine seamounts. These seamount are located in the outer half of the Mariana forearc within 100km of the trench axis and either lie at the intersection of several fault zones or are themselves heavily faulted (Fryer, 1996). The relationship between serpentine seamounts and fluid seeps is imoportant because it may provide a means to determine the variability of fluids with depth to the slab and to determine whether spacial variability in slab-derived fluids is significant in convergent margin settings. The fault zones with which most serpentine seamounts are associated provide a route by which slab-derived fluids may be channeled to the surface. The rates of channeled fluid flux are greater than that of diffuse flux. This is important bacause the faster fluids travel to the seafloor, the less chance there is for water-rock interaction. The uniformity of the rock types associated with the serpentine seamounts also reduces the potential for divergence of the fluids from their original compositions. Mottl (1992) has shown that the fluids escaping from Conical Seamount have compositions of trace elements that cannot be accounted for water-peridotite interactions alone. These fluids probably do represent a more pristine signal from the slab than has been seen in any other convergent margin setting (Fryer, 1996).

Fluid egress in association with major cross-forearc fracture zones (Fryer, 1996) provides another potential target for studies of slab-derived fluids. Several large fault zones that extend from the trench axis, through the volcanic arc and into the backarc basin have been indentified in the southern portion of the Mariana system (Fryer, 1993; Fryer, 1996; Fryer et al., in prep.). Although seeps at serpentine seamounts are proven sources for slab-derived fluids, they are only point locations for collection of slab-derived fluids. Studies of fluids along transects of the foreac, using only seamount sites as collection localities, are thus limited in terms of distance from trench and of depth to slab. Faults that crosscut the entire forearc region have the potential to provide a continuous sampling of slab-derived fluids with distance from the trench, and with depth to slab.

Side-scan sonar imaging surveys and detailed sampling using remotely operated deep submergence cehicles will be conducted in the near future in the central and southern Mariana forearc regions. These studies will further clarify the roles of both the serpentine seamounts and the forearc fracutre zones as sites for the study of slab-related fluid egress on the Mariana forearc.

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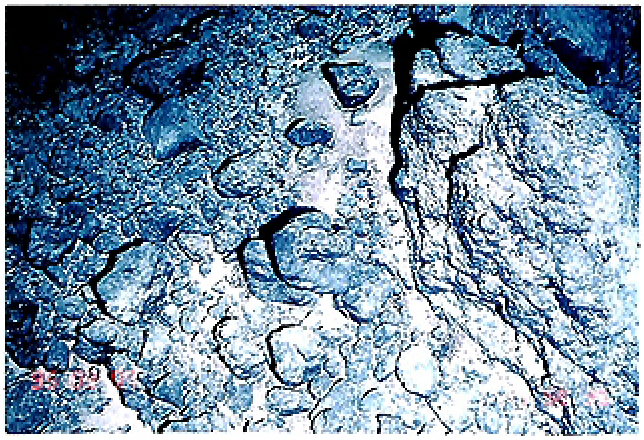

Photo 1 "Shinkai 6500" bottom photograph of the seafloor at about 3,700m on dive 280 in the vicinity of the 1981 dredge site. The photograph shows fragments of manganese encrusted ultramafic rock clasts lightly dusted with pelagic sediment.

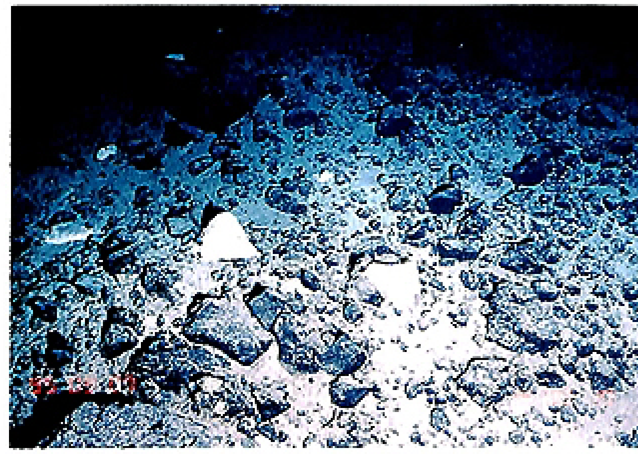

Photo 2 "Shinkai 6500" bottom photograph of fragments of foraminiferal limestone resting on the seafloor observed at a depth of about 3,550m on dive 280. The fragment in the foreground is partially encased in green serpentine mud.

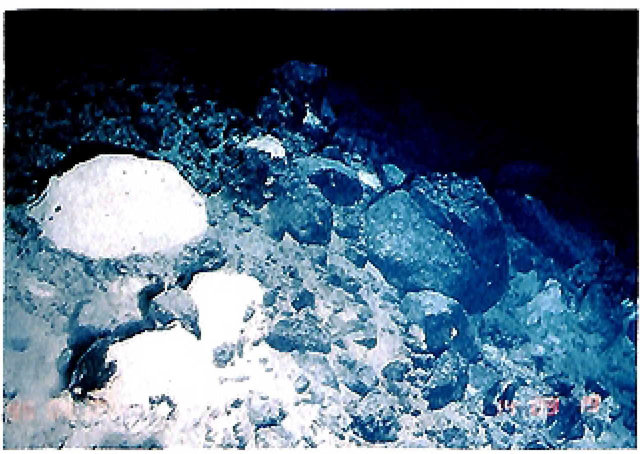

Photo 3 "Shinkai 6500" bottom photograph of fragments of foraminiferal limestone resting on the seafloor, observed at a depth of about 3,550m on dive 280. Noto the apparent draping of the seafloor caused by dissolution of the fragment in contact with seawater.

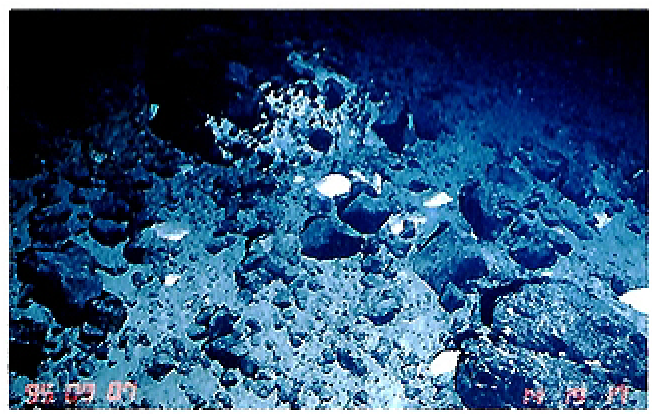

Photo 4 "Shinkai 6500" bottom photograph of the seafloor observed at a depth of about 3,550m on dive 280. Several fragments of light colored foraminiferal limestone are resting on the seafloor in the foreground. Visible in the background is a light-colored mound of serpentine mud encasing numerous dark clasts.

Photo 5 Photograph of a piece of foraminiferal limestone obtained on dive 280 containing swirls of green serpentine mud (right side of photo) and several small clasts of serpentinized ultramafic rocks (dark fragments). The scale bar at the bottom of the photograph is graduated in centimeter intervals.

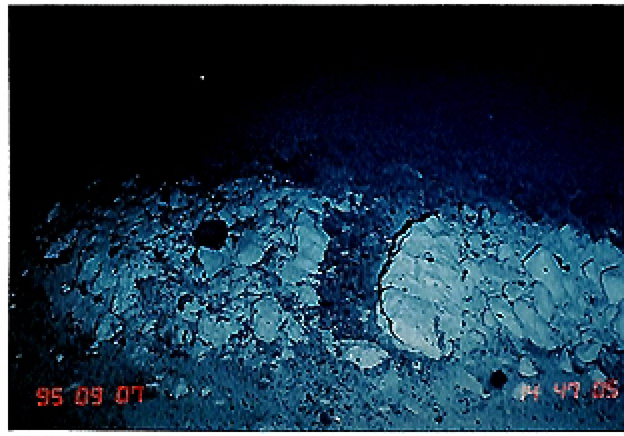

Photo 6 "Shinkai 6500" bottom photograph taken at a depth of about 3,500m showing an exposure of serpentine mud projecting slightly above the surrounding seafloor. Note the relative paucity of rock clasts in the serpentine mud by comparison with the large number of clasts seen in Photos 6-9.

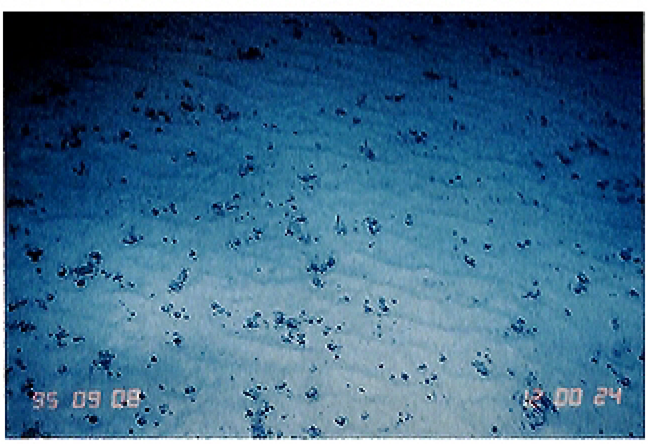

Photo 7 "Shinkai 6500" bottom photograph of the flat portion of the summit of Chamorro Seamount immediately west of the summit knoll, taken at a depth of about 3,100m. Foraminiferal sands comprise the bottom ripples and small manganese nodules make up the dark pebbles scattered on the surface.

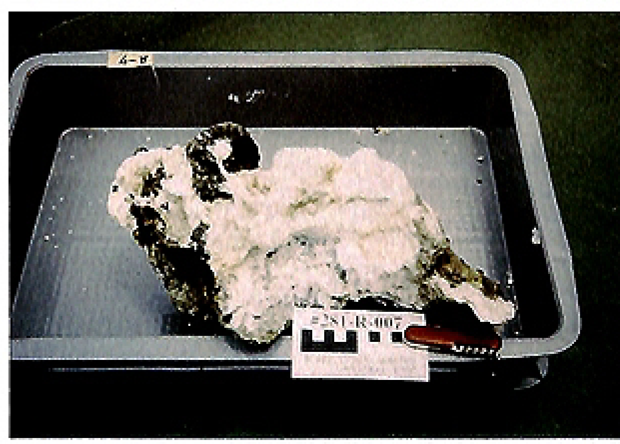

Photo 8 A large fragment of serpentine mud (dark material in the lower right of the fragment) encrusted with carbonate (white material), and encasing clasts of serpentinized ultramafic rock (large dark clast and other smaller ones). The scale bar at the bottom of the photograph is graduated in centimeter intervals.

Photo 9 Close-up of a fragment of serpentine mud (bottom half) with an encrustation of carbonate (upper half). The height of the photograph is about 17cm. Within the serpentine mud are orange-brown streaks of altered serpentine and small black flecks of maganese. The manganese flecks are also visible in the carbonate encrustation close to the contact with the serpentine mud. Pure white carbonate growth is present near the top of the photograph. At the upper surface of the fragment, near the top of the photograph, is a slightly greenish-to yellowish-brown gelatinous coating on the surface of the sample that is probably a bacterial mat.

Photo 10 Fragment of serpentinized harzburgite that has been fractured and veined with carbonate. The scale bar at the bottom of the photograph is graduated in centimeter intervals. Veins in the sample are pure carbonate. Bacause they lack serpentine mud, it is thought that the rock was fractured before or during transport and was infiltrated with fluids from depth that caused precipitation of carbonate.