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Near shore submarine hydrothermal activity in Bahia Banderas, western Mexico

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RESUMEN

Recientemente se descubrió la existencia de actividad hidrotermal en la zona de Bahía de Banderas. Las implicaciones de esta actividad en el esquema tectónico de la parte central de México apoya la hipótesis de que está ocurriendo actividad tectónica reciente en esta área. Se detectaron tremores en estaciones sismológicas portátiles que fueron instaladas en los alrededores. Se analizaron muestras de las chimeneas formadas por la actividad hidrotermal y se encontró una secuencia de depositación dominada por carbonatos en la primera etapa (calcita y dolomita), seguida por apatita y vetas tardías de barita. También se presentan capas de depositación secuencial de sulfuros y fosfatos que pueden interpretarse como resultado de las variaciones en la fugacidad del azufre.

PALABRAS CLAVE: actividad hidrotermal somera, México, depositación de sulfuros.

ABSTRACT

Shallow submarine hydrothermal activity was detected in the Bahía de Banderas area, Mexico. Volcanic-type tremors were recorded by portable seismological stations onshore. Vent samples suggest a depositional sequence dominated by carbonates in the first stage (calcite and dolomite), followed by apatite and late barite veins. Layers of sequential deposition of sulfides were also observed, and are interpreted as cyclic variations of sulphur fugacity.

KEY WORDS: underwater hydrothermal vents, Mexico, sulfide deposition.

INTRODUCTION

Hydrothermal vents in the ocean are known from deep-sea studies (Scott, 1997); however, few vents have been described at shallow depth (Pichler *et al*., 1999).

A few years ago local fishermen reported hydrothermal activity close to Punta Mita, in the Bay of Banderas, Mexico. Preliminary exploration identified a 400 m long area of intense hydrothermal activity. The hydrothermal fluids in the discharge centers reach temperatures of up to 87°C and produce hydrothermal deposition of some minerals. However, hydrothermal vents are not well developed, probably due to destruction by recurrent explosive events or by storm erosion.

The occurrence of hydrothermal vents in this area must be related to the tectonic evolution of western Mexico, which has not been clearly explained by seismicity and other parameters like heat flow (Eissler *et al*., 1984; Luhr *et al*., 1985; Prol-Ledesma and Juárez, 1986; Ferrari *et al*., 1994; Ferrari *et al*., 1997; Kostoglodov and Bandy, 1995; Dañobeitia *et al*., 1997). Regional tectonics is characterized by the presence of a triple point, where three rift zones have been identified: Tepic-Zacoalco, Chapala and Colima (Allan *et al*., 1991). The continental part defined by these features is known as the Jalisco Block (Figure 1), which has been interpreted as a distinct geological unit presently being rifted away from the North American plate (Luhr *et al*., 1985; Allan *et al*., 1991; Garduño and Tibaldi, 1991; Kostoglodov and Bandy, 1995). The Rivera-Cocos Plate boundary is not well defined, and it has been suggested that it is not a transform boundary but a divergent boundary (Bandy, 1992). Also, the connection between the northwest border of the Jalisco Block and the continent (the Tamayo Fault System) is not well defined. The Bahía de Banderas area may be experiencing strong crustal stresses as a result of the convergence direction of the Rivera Plate (Kostoglodov and Bandy, 1995).

The Punta Mita area, at the northwestern end of the Bay of Banderas, contains three main geologic units: granite, basalt and recent sandstone and conglomerates. Granitic rocks predominate in the area surrounding Bahía de Banderas. The age of some granites has been estimated to be between 90 and 100 Ma (Ferrari *et al*., 1997). Basaltic rocks in the area of Fisura Las Coronas have not been dated; however, radiometric ages of basalts located north and northeast of the bay range from 0.48 to 3.4 Ma (Lange and Carmichel,

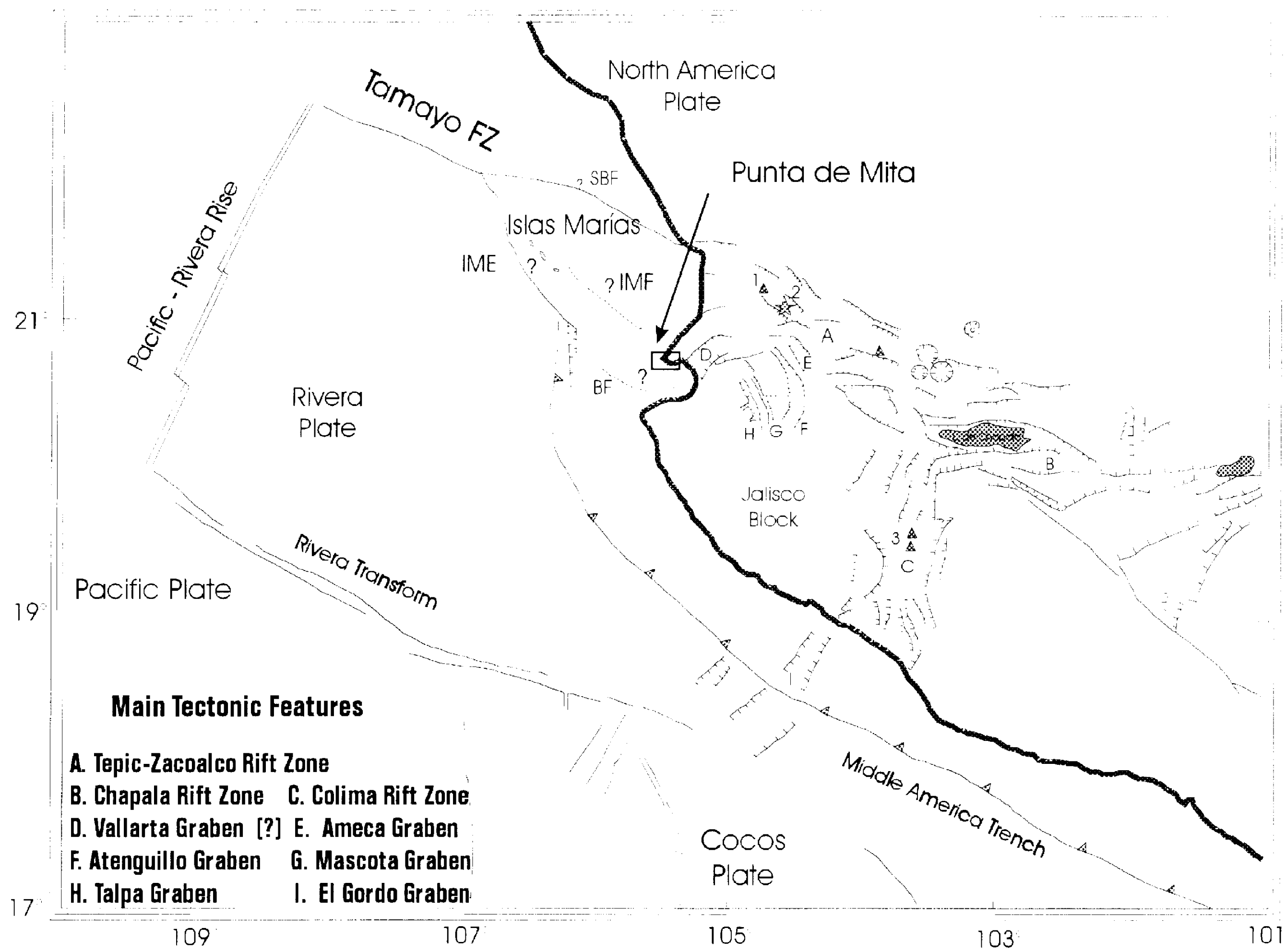


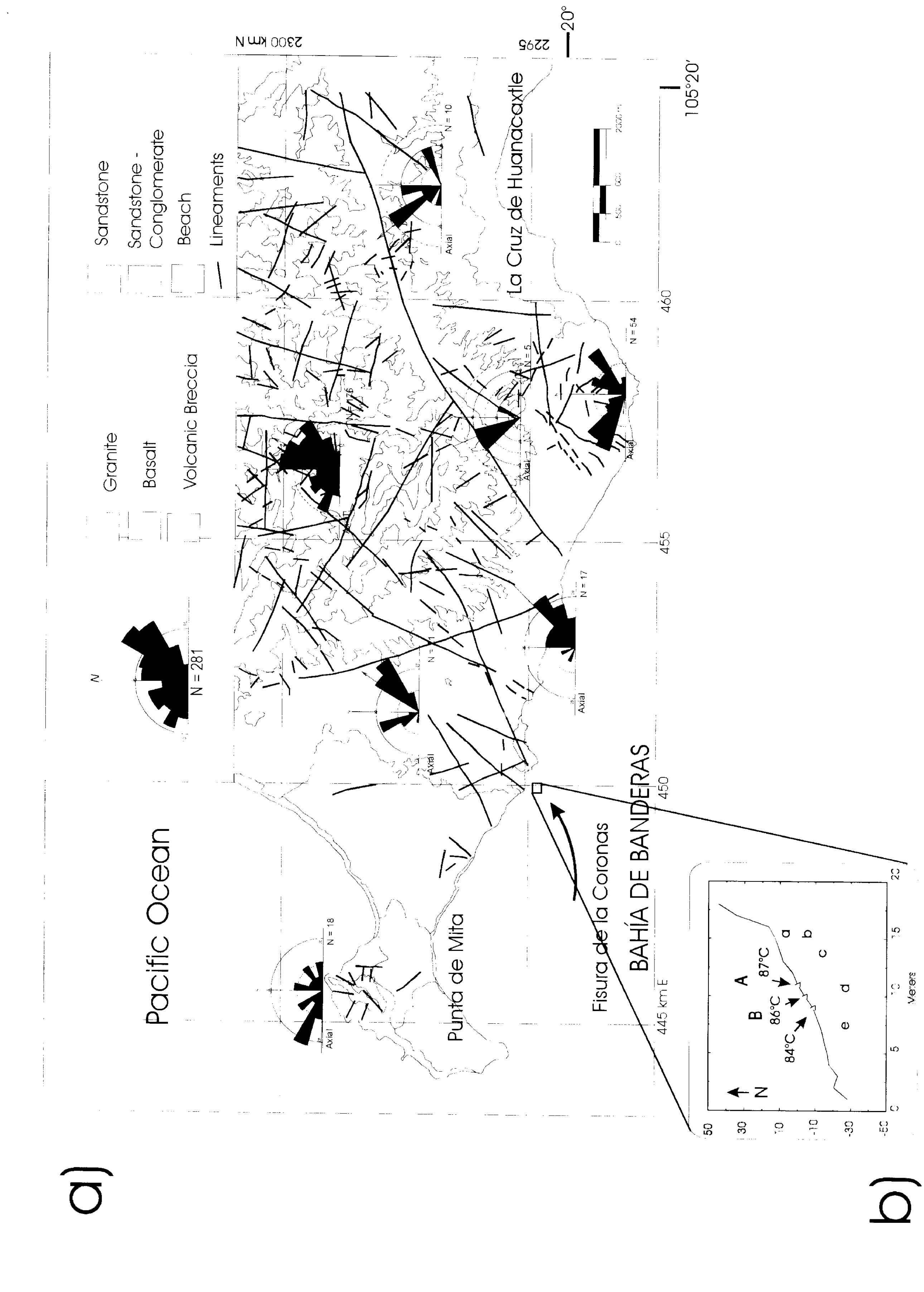
Fig. 1. Tectonic setting: 1. Sanganguey volcano, 2. Ceboruco volcano, 3. Colima volcano.

1991; Righter and Carmichel, 1992; Righter *et al.*, 1995). The age of a basalt outcrop at Punta Mita is reported by Gastil *et al.* (1979) as 10.2 Ma.

Photogeologic analysis was carried out on aerial photographs and the seven lineament groups identified in the photographs were correlated with the 1:50 000 geologic map, the results of this analysis are shown in Figure 2a. A basaltic flow in the SW section of the study area is affected by lineaments with directions N42°E, N20°E and N68°E; the latter coincides with the direction of "Fisura de Las Coronas" (N70°E) which is located 800 m offshore. These directions are similar to those reported for grabens and volcanic fields in the Jalisco block, related to NW-SE stretching (Maillol *et al.*, 1997). Therefore, the direction of Fisura Las Coronas coincides with the lineament group, which is also related to recent tectonic and volcanic activity in the Jalisco block.

Dañobeitia *et al.* (1997) recorded seismic signals at Punta de Mita in the northern part of Bahía de Banderas that looked similar to volcanic or hydrothermal events (Figure 3). These types of signals were also recorded by Núñez-Cornú *et al.* (1997).

Fishermen reported the occurrence of bubbles in parts of the bay, and noticed that hydrothermal activity had increased in the last year. During our first expedition to study the hydrothermal activity at Fisura Las Coronas, a submarine spring was found southeast of Punta de Mita (Figure 2a) at a water depth of 11 m. No other points with similar activity have been identified elsewhere in the Bay of Banderas. Local sea floor mapping shows a major structural pattern where active vents occur, 70 m of Fisura de Las Coronas which trends N70°E (Figure 2b). Photographic, video and spring temperature profiling was carried out along the vent area in September 1997. We observed one large vent growing on the sandy bottom, one large vent in a basaltic rock, and numerous small springs aligned on the sand-gravel bottom. In addition to the mapped sea floor vents at Fisura de Las Coronas, bubbles have been observed on the ocean sur-


a)
b)
Pacific Ocean
Punta de Mita
Fisura de la Coronas
BAHÍA DE BANDERAS
La Cruz de Huanacaxtle
Granite
Basalt
Volcanic Breccia
Sandstone
Sandstone - Conglomerate
Beach
Lineaments
N = 281
2300 km N
2295
20°
105°20'
445 km E
450
455
460
87°C
86°C
84°C
A
B

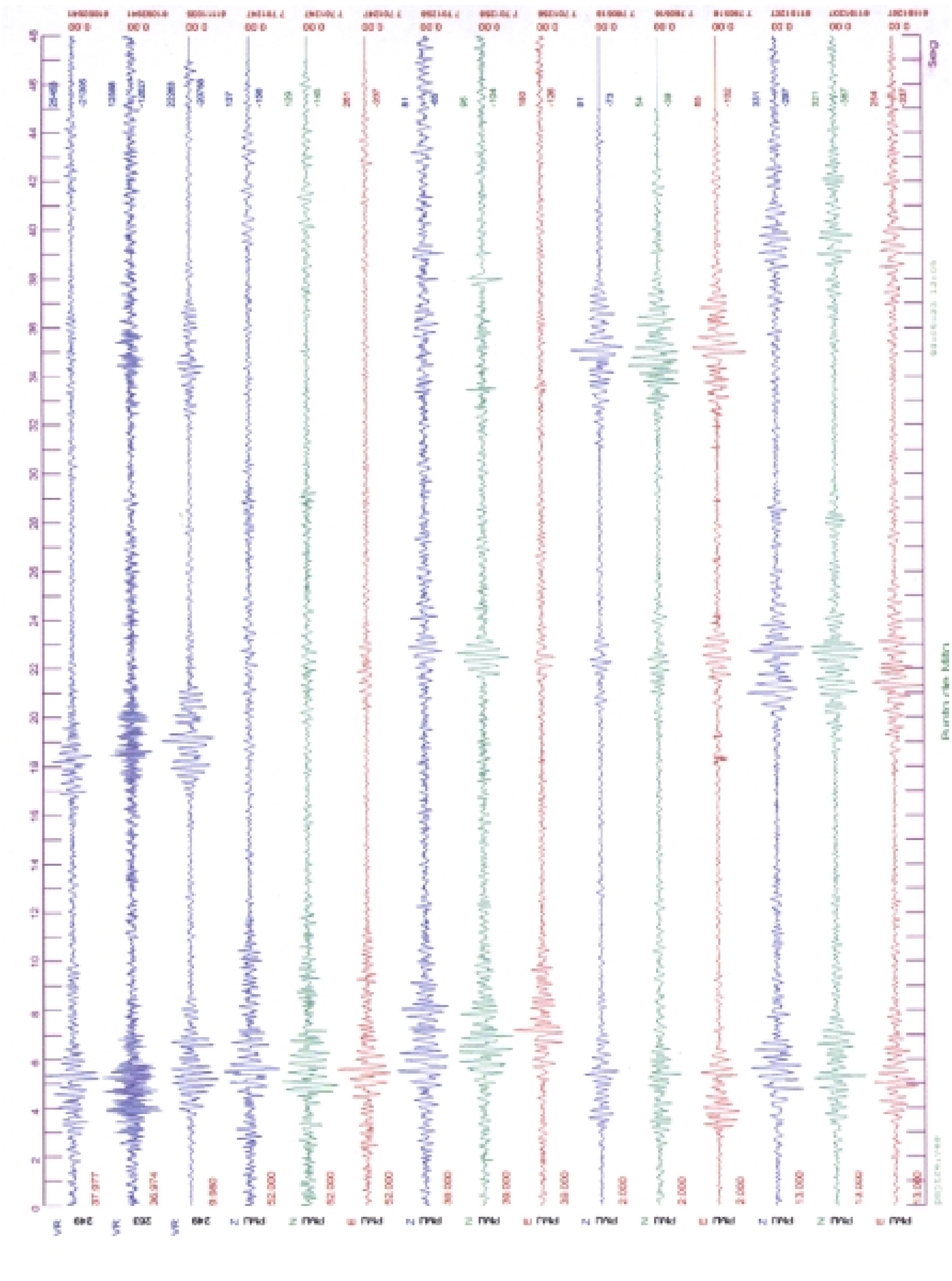


Fig. 3. Seismograms of volcanic tremors recorded in portable seismographs installed at station PMJ near "Fisura de Las Coronas" (2 to 6 km). Upper scale is time in seconds. The letter to the left designates the component: Z, N, E, and VR denotes the Z component. Numbers to the left under the seismogram indicate the initial time in seconds; the hour and minute are the last four numbers to the right of the seismogram; the first four numbers indicate the date (year and Julian day). The horizontal number to the right of the seismograms denotes the amplitude.

face for about 400 m on the same direction as Fisura Las Coronas. Vent **A** (Figures 2b and 4a) is on basaltic rock, where a hot spring discharges fluids with a temperature of 87ºC. It formed a chimney about 20 cm high with a 10 cm opening. Vent **B** (Figure 2b) is also on basaltic rock. The chimney is about 1 meter high with a 30 cm lateral opening; fluid is discharged at 86°C. Between **A** and **B**, strong bubbling was observed on the sea floor (Figure 4b). The temperature at the basaltic rock is 84°C.

In January 1998, a new survey was done after hurricanes Paulina and Olaf. Important changes were observed. The sand-gravel bottom was partly removed and a basaltic structure like a scar appeared, with many small bubble sources. An increase in the rate of bubbles and fluids was observed. Noise from bubbles was clearly audible while diving and was recorded by the video camera. Due to hydrothermal explosions vent **A** was completely destroyed (Figure 4c), and fragments were spread around the vent. This vent had become a strong source of fluids and bubbles. A new fluid source 20-cm wide had formed at a distance of one meter from vent **B** in the same rock, which seemed to be completely hollow. Strong currents make it difficult to perform accurate temperature measurements of the vent fluids, due to the rapid mixing of the ascending thermal fluid with the seawater. Preliminary pH measurements were performed on water samples taken at different depths; they show a decrease in pH values from 7.9 on the surface to 6.7 near the source. No changes in the ecosystem have been noticed.

PETROGRAPHY AND GEOCHEMISTRY

Several samples of vents were collected. The samples are mainly composed of alkaline basalt fragments, detrital crystals and shells cemented by calcite, phosphates, and clays. The detrital crystals are mostly quartz and feldspars. The basalt fragments contain abundant vesicles filled by clays, especially chlorite, and zeolites. The matrix is completely altered to clay; however, most phenocrysts remain unaltered. The samples are covered by fine white layers, and also by sulfide layers a few microns thick (Figure 5). Sulfides are also observed disseminated within the fragments and often fill the vesicles where chlorite occurs. No replacement textures were observed in the disseminated sulfide crystals; we infer that they were deposited directly from the fluid into the cavities. Hand specimens showed typical blue-violet copper sulfide colors on the surface; however, a petrographic examination of polished samples did not show any copper minerals. The most recently collected sample, a basalt fragment, had remained within the chimney and was totally covered by a white layer a few millimeters thick.

Two samples were analyzed for trace elements. One sample was composed only of white layers deposited on the sample surface, and the second sample was a single clean rock fragment without sulfides or white layers. Both samples had low concentrations of copper and zinc, between 0.001 and 0.004 %, and barium between 0.003 and 0.03%. Vanadium ranges from 11 to 52 ppm.

X-ray diffraction analyses were performed on three samples: the white layers and a rock fragment of the first samples collected from the vents, and the white cover of the lastly collected sample. All samples are mostly composed of calcite and minor dolomite; however, the most recent sample shows analcime as the second most abundant mineral. This mineral was not observed in the first samples. The white layer in the first sample was mostly composed of calcite and trace amounts of quartz. The rock fragment contained calcite, quartz, dolomite, feldspars and chlorite. These results agree with the petrographic examination.

SEM analyses were performed on three samples: a polished section of a rock fragment including the sulfide and calcite layers, and two small fragments with a strong blue-violet hue taken from the surface of the chimney fragment. The sulfide and calcite layers (Figure 5) were analyzed with a one-micron spacing; the results show a succession of iron sulfides, calcite, silica and phosphate layers. The fragments yielded up to 14% copper over all the surface; however, single crystals did not show noticeable copper content. Apparently, the copper has been coated recently on the sample; it is probably related to the recent increase in hydrothermal activity.

DISCUSSION

According to the results of the analysis of seismic data and magnetic anomalies, Kostoglodov and Bandy (1995) conclude that the greatest amount of extension within the Jalisco Block should be occurring in the Bahía de Banderas area. The occurrence of active hydrothermal vents near the coast in the Punta Mita area (Figure 2a) may be evidence of the recent tectonic activity in this area of the Jalisco Block.

There are several hypotheses about the mineralogical composition of the mounds in the earlier stages of activity of submarine hydrothermal systems; it has been proposed that either sulfides or sulfates and carbonates are the first minerals to be deposited. The early processes of deposition are documented in this area where no previous hydrothermal activity was reported that could have affected the sea water composition. The collected samples show that simultaneous deposition of carbonates, sulfides and phosphates takes place starting with the first stages of development of the chimneys.

Phosphate anomalies have been reported on low-temperature hydrothermal vents on the flanks of the Juan de Fuca Ridge (Wheat *et al.*, 1997). Copper sulfide deposition at shal-

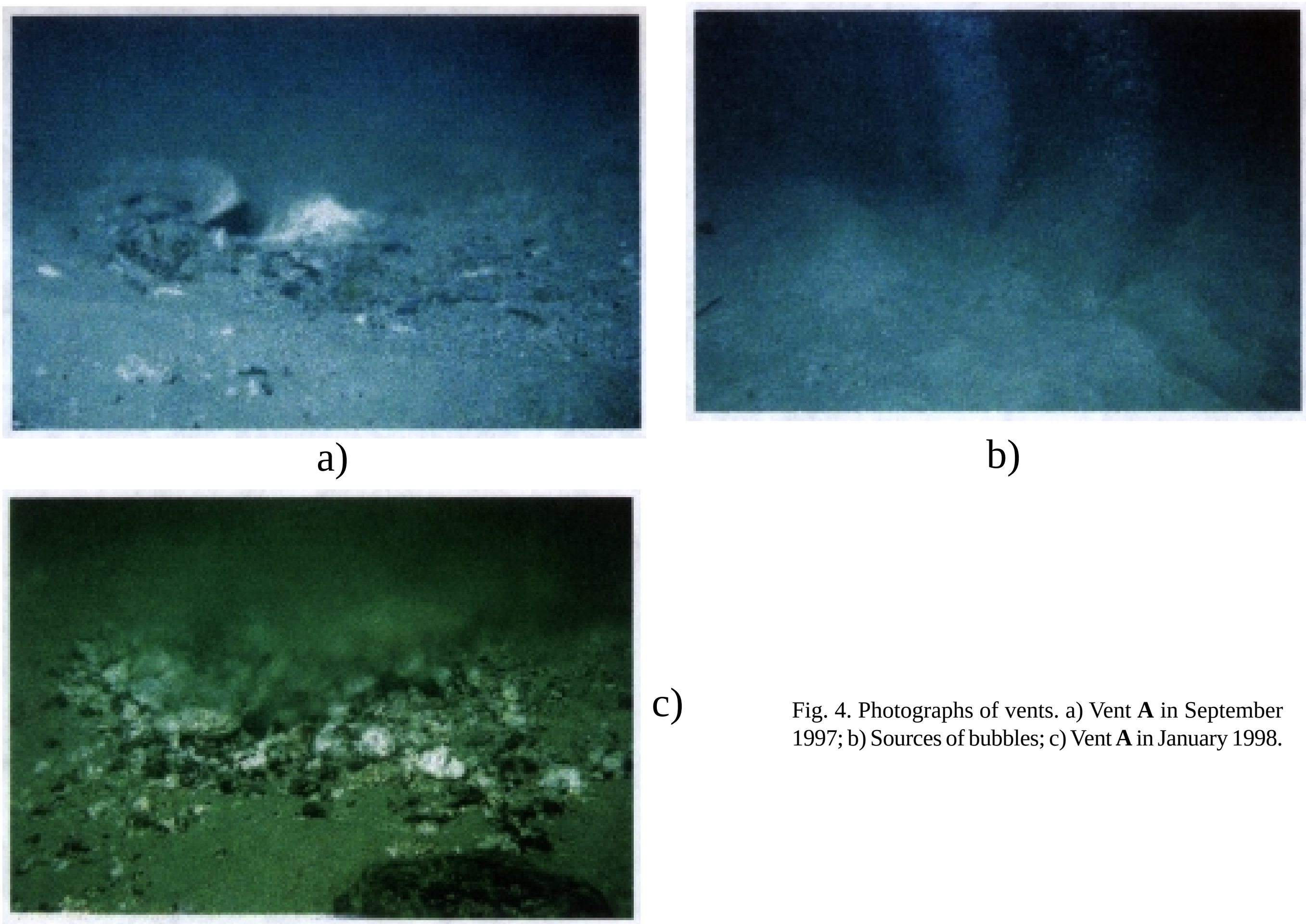


Fig. 4. Photographs of vents. a) Vent **A** in September 1997; b) Sources of bubbles; c) Vent **A** in January 1998.

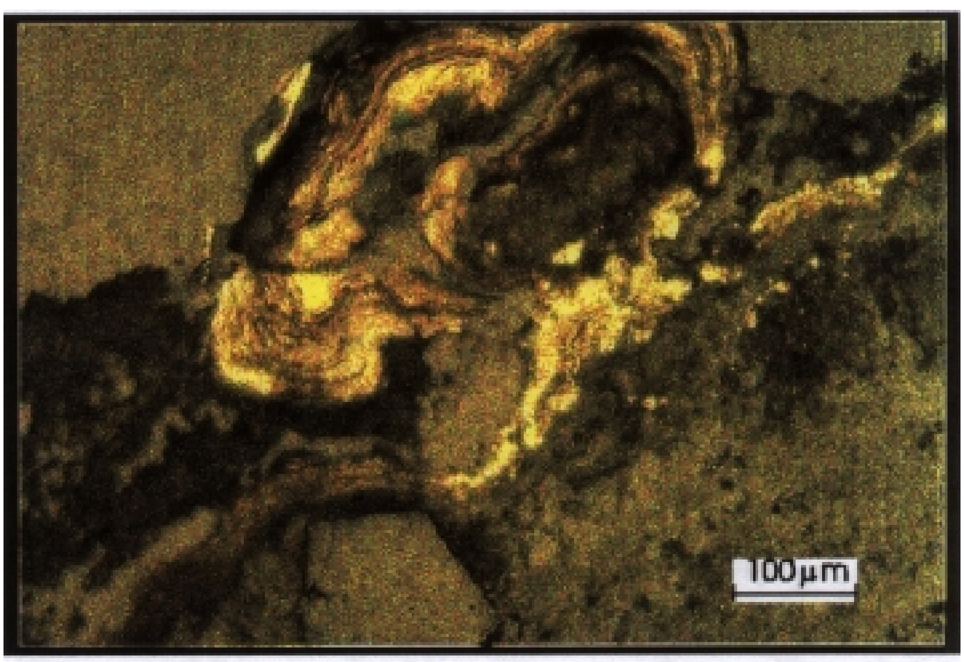


Fig. 5. Microphotograph of the sampled chimneys that shows layered sulfides.

low depths has been reported in Iceland related to active submarine volcanoes (Scott, 1977); however, in our case, there are no active volcanoes related to the vents. The discharged water and the nearby basaltic flows must be studied to determine whether they may be related to the hydrothermal activity, or whether they may be due to deep circulation of meteoric water. The presence of abundant sulfides in an oxidizing environment implies high sulfur fugacity, possibly related to a shallow magmatic source. Such a source is also suggested by the seismic signals that do not look like typical earthquakes due to faulting.

CONCLUSIONS

Field observations and geochemical studies indicate that the observed hydrothermal activity in the Bay of Banderas is recent. The occurrence of hydrothermal and seismic activity supports the assumption of active tectonics in the Bahía de Banderas area (Kostoglodov and Bandy, 1995). Sulfide and native copper deposition due to shallow hydrothermal activity in the ocean floor provides evidence about the possible formation of some type of exhalative deposits at shallow depths.

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