# MINERALOGY OF A SHALLOW HYDROTHERMAL SUBMARINE CENTER NEAR PUNTA MITA (WESTERN MEXICO)

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**ABSTRACT**

The "Fisura de Las Coronas" hydrothermal system is located in the Western coast of Mexico. Submarine hot springs were discovered southeast of Punta de Mita at depths from 9 to 11 m. The surveys included mapping 70 m of "Fisura de Las Coronas" which has a 70 NW direction. Photographic, video and spring temperature profiling was carried out in the vent area. A large vent growing from the sandy bottom, a large vent in basaltic rock, and numerous small springs aligned on the sand-gravel bottom were observed. In addition to the mapped sea floor manifestations at the "Fisura de Las Coronas", bubbles have been observed on the ocean surface along a lineament of at least 400 m length. The occurrence of recently reported hydrothermal manifestations on the sea bottom at 11 m depth in western Mexico provides a unique opportunity to study metals deposition and the reactions between the geothermal fluid and the host rock at conditions prevailing at shallow depth in the ocean. The hydrothermal manifestations are located in basaltic rocks on the sea bottom, and result in the replacement of the original rock forming minerals by hydrothermal minerals, as well as direct deposition of carbonates (calcite, aragonite), sulfates (barite), sulfides (Fe-sulfide, pyrite, and only minor galena) and native elements (copper). The observed hydrothermal alteration sequence is similar to the alteration processes already described in deep active and fossil submarine hydrothermal systems, which occur under more reducing conditions. Sulfides are always restricted to the inner sections of the vents, where conditions may remain more reducing, before interaction with the oxidizing shallow seawater. In the outer parts of the vents carbonates predominate. The absence of anhydrite and the abundance of calcite indicate that the saturation of anhydrite is not achieved in this system, and calcite is deposited as the seawater is heated by the geothermal fluid.

## 1. INTRODUCTION

Many hydrothermal activity centers in the ocean are well known from deep-sea studies; however, only few deposits have been described which are located at shallow depth (Scott, 1997). The deep hydrothermal vents have provided important information about metal deposition prevailing at those depths (Graham et al., 1988; Rona, 1988; Humphris, et al., 1995; Parson et al., 1995; Scott, 1997). However, sulfide deposition has seldom been studied at shallow depth (Pichler and Dix, 1996; Pichler et al., 1999).

Few years ago the local fishermen reported hydrothermal activity close to Punta Mita (Mexico). Preliminary explorations allowed the identification of a 400 m long area where intense hydrothermal activity occurs (Fig. 1). The measured temperature of the hydrothermal fluid in the active centers reaches up to 87°C, and after mixing with the seawater it generates deposition of some minerals. Hydrothermal chimneys are not well developed; this is probably due to the immaturity of the deposit, as well as to the destruction of the early-formed hydrothermal chimneys by recurring explosive events or by erosive processes during storms.

The Fisura de Las Coronas hydrothermal area is located in the Western coast of Mexico. A submarine spring was located southeast of Punta de Mita (Fig. 1) at a depth of 11 m. The surveys included mapping 70 m of "Fisura de Las Coronas" which has a 70° NW direction. Photographic, video and spring temperature profiling was carried out along the vent area. In September 1997 we observed (Fig. 2) three main surface manifestations: one large vent growing from 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 manifestations at the "Fisura de Las Coronas", bubbles have been observed on the ocean surface along a lineament of at least 400 m length. Preliminary pH measurements show values from 4.5 to 6.7 for water collected at the vents, and 7 for surface seawater away from the manifestations area.

## 2. GEOLOGICAL SETTING

The Punta Mita area contains three main units, 1) granite, 2) basalt and 3) recent sandstone and conglomerates. The eastern part of the area is dominated by a granitic intrusive 500 m thick. The area is characterized by extensional tectonics that generates a graben system (Allan et al., 1991; Ferrari et al., 1994). The main structural features (Fig. 1) were defined from the lineaments identified on aerial photographs and from the 1:50,000 geologic map. Seven lineament groups were distinguished on the basis of this analysis. 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 11 m deep and at approximately 500 m from the coast.

The hydrothermal system host rock is basalt, although breccia fragments can be recognized in the altered samples collected at the vents. Basaltic flows were observed on the beach, in the closest area to the submarine vents. The fresh basaltic flow is overlaid by a pyroclastic breccia that contains variable size basalt fragments, and is similar to some fragments recovered near the vents. The mineralogy of the basalt is simple and consists of euhedral clinopyroxene and plagioclase phenocrysts, included in a groundmass composed of plagioclase as microlite crystals and volcanic glass. They are densely vesicular. The vesicles are rounded and less than 1 cm in diameter.

Some sea bottom manifestations occur in detrital sediments. The detrital sediments on the sea bottom are a mixture of grains of different provenance, but biogenic fragments of skeletons of different marine organisms (corals, algae, briozoa, foraminifers, echinoderms, molluscs) predominate, with small amounts of pellets and rock fragments or grains from diverse sources: acid volcanic rocks, basic volcanic rocks and, rarely, granitic rocks. The microcline and quartz grains are not rounded and microcline is fresh, indicating a very proximal source area. Some fragments of hydrothermally altered and sulfide covered volcanic rocks can also be distinguished among these fragments. This texture can be a consequence of the observed brecciation of the deposit related to hydrothermal explosive processes.

## 3. HYDROTHERMAL MINERALS

Although mineralization is not well developed, a wide variety of minerals can be differentiated. The mineral composition is strongly influenced by the interaction of the host rock and the geothermal fluid in the replacement products, and also by the location of the secondary minerals relative to the outflow channels in the vents.

Three main types of textures can be considered: replacement products of basalt, cement of sands, and vug filling.

### 3.1 Replacement

Replacement takes place in the hydrothermally altered basalt: the plagioclase crystals are pseudomorphically replaced by zeolites (heulandite, analcime) and the pyroxene crystals and the groundmass are replaced by an assemblage consisting of celadonite and pyrite (Fig. 3).

The pyrite grains are generally rounded, have only a few microns in diameter and are randomly distributed inside the celadonite groundmass. In some cases framboidal aggregates occur (Fig. 4), as well as some small cubes. The framboids are often recrystallized, or are rimmed by euhedral pyrite. In other cases, pyrite is found as a replacement product of ilmenite or magnetite crystals.

### 3.2 Direct deposition from the fluid

Hydrothermal minerals are also formed by direct deposition from the fluid, they occur filling vugs and veins, and typically sulfide deposition is found within the vents and carbonates in the external part the vents. The inner part of the vents and the surface located immediately on the outflow are covered by sulfide layers with botroidal texture and variable chemical composition (Fig. 5 and Table 1). The outer part of the vents is generally covered by carbonate layers. The vugs in the basalt are filled by a rim of a celadonite-pyrite association, and then heulandite and lastly analcime (Fig. 6). In other cases, aragonite appears as a late product. The aragonite crystals are euhedral, and show the typical cyclical twinning on {110}. The size of these crystals is less than 50 microns. In some cases, the zeolite minerals are euhedral and the crystals often display concentric zoning. They are microcrystalline and can achieve up to 500 microns in size; frequently, the growth of zeolites fills all the porosity.

Hydrothermal precipitates act as cement of the sands. Calcite crystals are by far the most important products, followed by barite and barium-calcite. Calcite starts to develop as euhedral rhombohedral crystals (up to a few tens of microns in size) that grow on calcic skeletons of different organisms or on detrital particles. Subsequent complete filling of porosity produces sparitic cement. Barite is rather abundant. It is developed as tabular, euhedral crystals having up to 50 microns in length. They are usually arranged in radial or bow tie groups. These groups can nucleate along all the stages of the hydrothermal growth of calcite in the vugs or in veins. Apatite radial groups are also covering the early-formed carbonate cement.

Abundant Fe-sulfide is deposited within the vent conducts and also on the rims. This deposition occurs in the form of Fe-sulfide layers with variable composition (Table 1), the outer layers being enriched in iron with respect to the inner layers. The presence of different types of sulfides may be due to the replacement of the minerals deposited in a first stage, as observed in some deep submarine hydrothermal systems (Graham et al., 1988; Hannington et al., 1995). The replacement conditions in Las Coronas must be different, as they occur at shallow depth, therefore at higher amounts of dissolved oxygen. The experiments show that below 100°C pyrite is formed from FeS phases (Morse et al., 1987; Schoonen and Barnes, 1991) or from polysulfide phases (Murowchick and Barnes, 1986)

Small grains of native copper have been identified. They are up to 50 microns in length, and have dendritic shape. Some Cu-rich areas display a blue-violet-shade in hand specimen.

## 4. CONCLUSIONS

The observed hydrothermal alteration sequence is similar to that described in deep submarine hydrothermal systems, except for the lack of anhydrite. The absence of anhydrite in the vent deposits is intriguing, as it should be deposited by seawater super saturation.

The mineral paragenesis that occurs in the altered volcanic rock consists of sulfides, celadonite and zeolites. Sulfides, calcite, barite and native copper are deposited directly from the fluid.

The development of pyrite may be related mainly with the hydrothermal alteration processes occurring in the basalt. Leaching of iron from the basalt and a $H_2S$ supply by the geothermal fluid control its formation. The formation of pyrite from the Fe-sulfides deposited may follow the results of the experiments; however, the source of sulfur and the effects of the high concentration of oxygen present on the mineralization must be carefully studied.


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Table 1. SEM-EDS semi quantitative analyses of the Fe-sulfide layers in sample shown in Fig. 5. First analyses correspond to the inner layers and the last two to the outer layers.

| Fe (%) | S (%) |
|---|---|
| 57.36 | 42.64 |
| 56.25 | 43.35 |
| 55.36 | 44.63 |
| 53.19 | 46.81 |
| 53.22 | 46.78 |
| 55.25 | 44.75 |
| 37.24 | 62.06 |
| 25.59 | 74.40 |

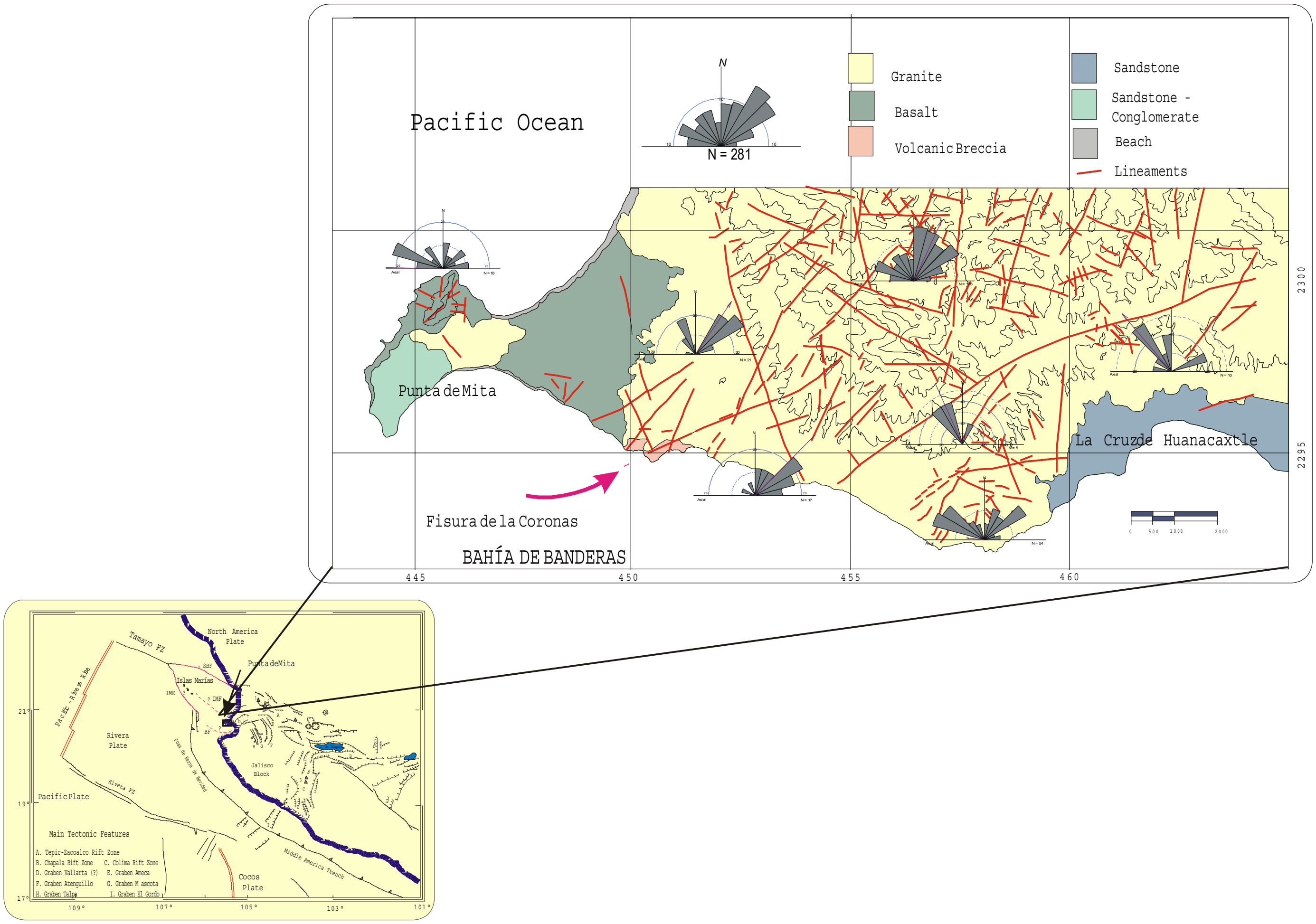


Fig. 1. Location and geology of the study area (after Ferrari et al., 1994)

Fig. 2. Vent growing on sandy bottom.

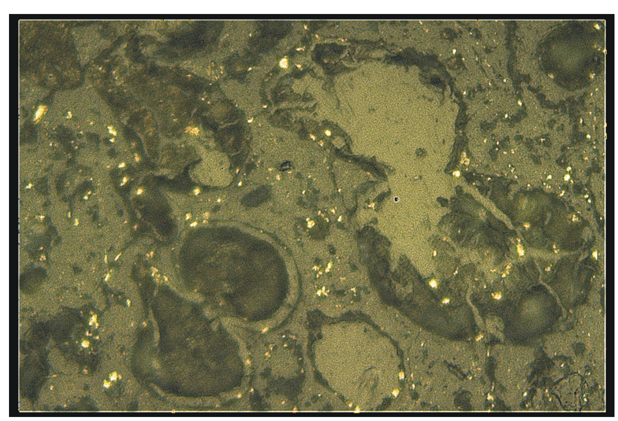

Fig. 3. Pyrite and celadonite as replacement products in basalt.

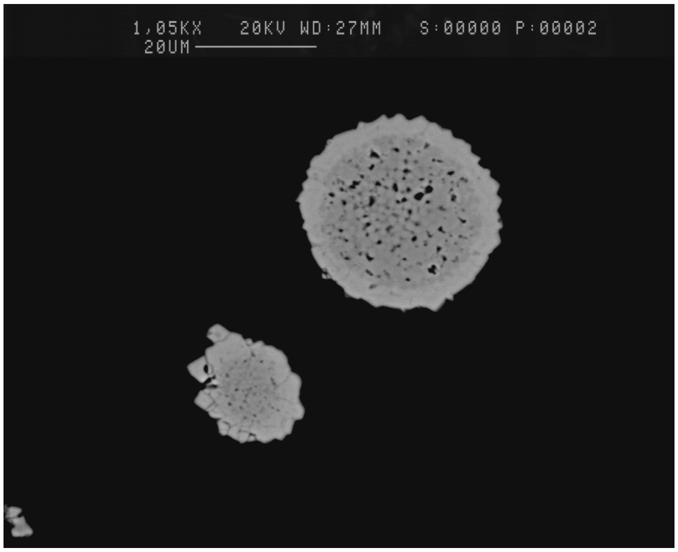


Fig. 4. SEM-EDS image that shows framboidal pyrite grains with an overgrown euhedral pyrite rim.

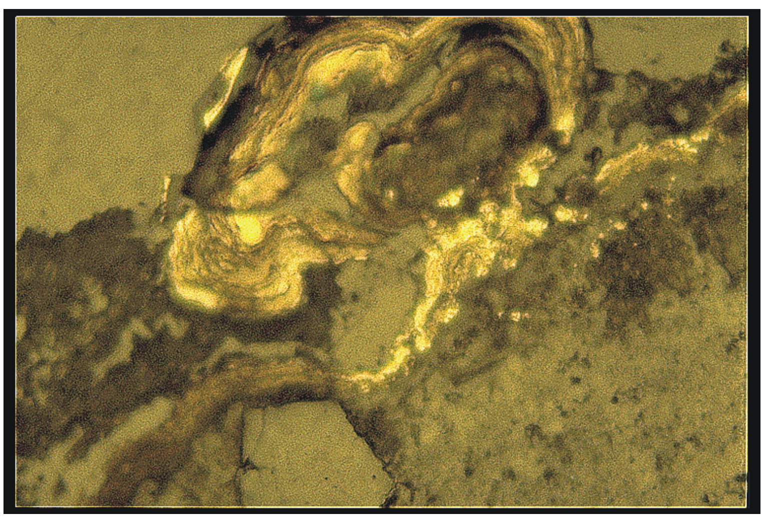

Fig. 5. Microphotograph that shows Fe sulfide layers with variable chemical composition.

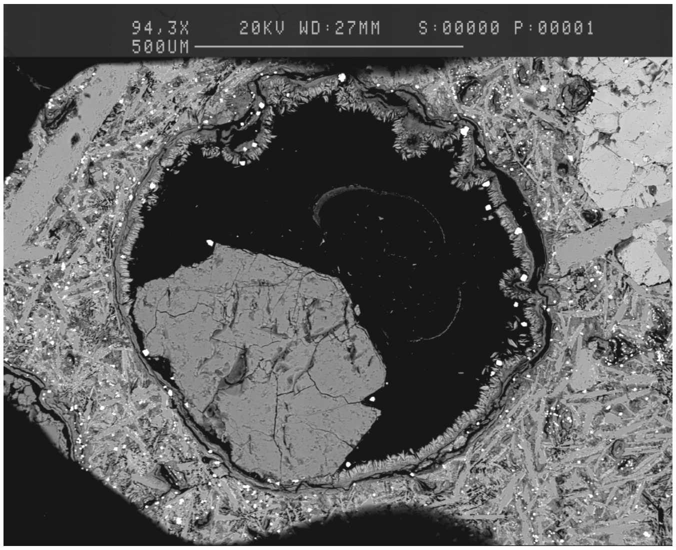


Fig. 6. SEM-EDS image that shows celadonite rims on vug walls in basaltic rocks. Analcime also occurs, as a late euhedral crystal. Pyrite grains are displayed as bright dots associated with celadonite in the altered volcanic rock and on the vug wall.