Introduction: Recent volcanism and associated hydrothermal activity of the Aeolian Arc (SE Tyrrhenian Sea, Italy) have been studied for the past 30 years [1,2]. The discovery of metalliferous hot spring deposits in the Pacific in the 1960’s stimulated exploration for this type of deposit in the Tyrrhenian Sea [3,4] because there they occur at much shallower depths. Hydrothermal systems in the Tyrrhenian Sea have produced a wide range of iron oxyhydroxide and iron sulfide deposits. These deposits are almost purely hydrothermal in origin, with negligible contribution from diagenetic processes. In addition, the Tyrrhenian submarine hot spring systems are a habitat for thermophilic chemosynthetic microbial communities. As such they are an excellent analog model-system for microbial communities associated with iron cycling in young geological formations, as well as for ancient geological formations, such as banded-iron formations (BIF). BIF formation is still a subject of debate, and new evidence suggests a polygenetic origin with possible microbial involvement [5]. Based on iron isotope fractionation, involvement of phototrophic iron oxidizers and possibly iron reducers has been proposed. Nonetheless, similar isotope values could be obtained through abiotic reactions as well [6]. Biogenic iron oxides represent a potential tool in the search for past and present life signatures on Earth and other planetary systems. This is of particular significance for Mars, because iron cycling may have been an important aspect of the planet’s geochemistry. Although the role of microbes in iron cycling and the formation of iron deposits has been the focus of a number of studies over the past two decades, it is still not fully understood whether they were simply beneficiaries of iron depositing processes, or whether they were actively “driving” iron deposition. More research is needed in order to fully assess the significance of microorganisms for iron depositing processes. The objective of our study is the integration of morphological evidence of microbial features with geochemical data in order to establish that microorganisms played a critical role in the formation of the described iron accumulations.

Site description and materials: The samples used in this study were retrieved from a depth of 100-215m in an area affected by hydrothermal activity, during a CNR (Consiglio Nazionale delle Ricerche) cruise in 1995. The samples consist mainly of iron oxyhydroxide deposits. The latter are of the fragmental-brecciated type, as well as of the encrusting type, and are intimately associated with vulcanoclastic sands and tuffaceous material. All samples are related to volcanic activity that started 0.2-0.1 Ma ago. Typical temperature ranges of hydrothermal active locations in the study area are around 100°C and somewhat above, with slightly acidic to circum-neutral pH (around 5.5 and 6) [7]. Unlike other hydrothermal iron-crusts from the study area that have been described as Manganese (Mn) enriched [7], our samples contain little or no Mn.

Methodology: Light microscopy and Scanning Electron Microscopy (SEM) with EDS (x-ray spectra) were utilized for characterization of mineral assemblages and detection of biomorphic structures. Luminescence microscopy was utilized to visualize distribution of organic matter within crust-samples. Samples analyzed for Total Organic Carbon (TOC) and δ13C of organic matter were homogenized and acidified to remove inorganic carbon prior to analysis, with necessary precautions to prevent contamination. To determine TOC and δ13C we used a Costech Elemental Analyzer with zero-blank autosampler that was in-line with Finnigan Delta Plus XP mass-spectrometer.

Figure 1. Scanning electron micrographs of potential bacterial colonies attached to chimney structure. The red framed image shows coccoidal forms between two layers of chimney wall, the blue framed image is their close-up. The yellow framed image shows rod forms attached to the outside wall. Note surface texture of singular cell (green frame). Amorphous Fe precipitates are common on bacterial cells as a way of cell protection and a means of cell attachment.
Observations: Using petrographic microscope and SEM/EDS microscopy we have detected a number of biomorphic structures, and confirmed the presence of very high iron contents in these samples. Through multi-hour EDS scans of three different types of iron crusts we found that our samples are not Mn enriched. Fe hydroxides and Fe oxides in form walls of small (mm scale) hydrothermal chimneys, and micro-layers with variable Fe contents, as well as Fe oxide coatings on the surfaces of silicate minerals and barite grains. All above mentioned Fe minerals are plausible products of hydrothermal activity, where Fe was delivered to the surface by hydrothermal fluids and precipitated in form of oxides/hydroxides once these fluids mixed with cold marine water. We distinguished two types of Fe-mineralization. The first type formed contemporaneously with the observed crusts (syngenetic) and constitutes their internal laminae; and a second type that formed subsequently and constitutes cements, cavity fills and grain coatings.

Light microscopy and SEM observations show potentially biogenic morphologies incorporated into subrecent silica sinter. These bacteriomorph features are clearly syngenetic with the surrounding mineral matrix and the encrusting nature of iron minerals suggests rapid growth in a zone of chemical disequilibrium. Figure 1 shows cocci-shaped forms that occur between layers of a fragmented small chimney. This suggests that the microbes colonized the zone where hydrothermal fluids mixed with marine water and were entombed in the wall structure due to rapid precipitation of iron oxyhydroxides. Rod-shaped bacteriomorphs occur in large numbers attached to the outer walls of chimneys and may be related to a later stage of hydrothermal activity. In addition, small micro-stromatolitic structures (mm scale) are also suggestive of microbial involvement (Fig. 2). In Figure 2 precipitated laminae, dominated by iron-oxides and hydroxides, are encrusting cocci-shaped features that are the basis of micro-stromatolitic features. EDS spectra showed different composition of encrusting laminae due to different levels of minor elements such as: Al, Ba, K, Si etc. All of the above bacteriomorph features may be fossilized remains of chemosynthetic microbial communities that colonized the periphery of submarine vent sites. At such locations, now marked by surficial crusts and chimneys, significant geochemical disequilibrium would have existed in the past due to the mixing of geothermal fluids with marine water, providing unstable electron domains as a source of energy that could be utilized for bacterial existence.

TOC levels are very low (0.07-0.14%) and fluorescence microscopy did not reveal notable point concentrations of organic matter within these samples. This suggests that most original organic matter was probably lost due to early diagenetic oxidation. The δ13C values range from -14.32 to -17.78‰, consistent with a marine microbial origin of the organic matter.

Conclusions: Iron crusts from submarine hot springs near Panarea contain a wide range of morphological features that resemble fossilized microbial life forms that were adapted to a harsh hydrothermal environment. These microbes were probably thermophilic (hyperthermophilic?), autolithotrophic and chemosynthetic organisms [8]. Characterizing these deposits and their associated microbial fossils should give us new insights about the level of involvement of microbial communities in this type of submarine hot spring deposits.

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