Discovery of ferromanganese hydrocarbon-related nodules associated with the Meknes mud volcano
(Western Moroccan margin)

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REGIONAL SETTING, STUDY AREA AND SAMPLE SUITE

The Gulf of Cadiz is located at the westernmost part of the Betic-Rift Arc, in the easternmost sector of the Azores-Gibraltar segment of the Africa/Eurasia collisional plate boundary (Fig. 1). It has a complex geological history and has undergone several episodes of rifting, compression, and strike-slip motion since the Triassic. The African-Eurasian convergence has promoted fault reactivation in widespread listric faults and hydrocarbon-rich fluid venting structures ( mud volcanoes, diapiric ridges, carbonate mud mounds, olistostromes and hydrocarbon-derived authigenic carbonates (HDACs)) (Medialdea et al., 2009).

Figure 1. Geological setting and bathymetry of the Gulf of Cadiz with the location of sampling sites in Meknes mud volcano (A) and Ferromanganese nodules field in the Bierian margin (B). Partially modified from León et al. (2012).

Figure 2. Multi-beam bathymetric image (Simrad EM31202S) and 3-D Peacemaker visualization of the Meknes mud volcano. Below, ultra-high resolution seismic profile through the Meknes mud volcano with the position of sampling stations and, below side-scan sonar image (MAY-1M at 100 kHz, TTR-15), Meknes MV has a flat summit, an elongated crater in the N-S trend and high steep slopes in the flanks. The profiles show low penetration, probably due to the presence of authigenic precipitates, and transparent to chaotic facies in the mud volcanic and carbonate mounds. There are also evidences of bottom current activity and erosion as the presence of contourites deposits and outcrops of carbonate mounds and HDACs.

Figure 3. A suite of ferromanganese nodules, HDACs and cold water corals were sampled by dredging in the discovered field after detailed bathymetric surveys. Mud-torresina was sampled by gravity coring at top of Meknes MV. Selected nodules were analyzed by different methods in order to define their physical, mineralogical and geochemical characteristics.

INTERNAL FEATURES AND MINERALOGY

The nodules have tabular-to-irregular morphologies and sizes ranging from 1 to 30 cm. Surface and internal colour varies between orange and black and reflects the fundamental mineralogical composition of the samples: iron-manganese oxy-hydroxides. The nodules show tabular-to-irregular morphologies and consist of a complex arrangement of laminae.

Figure 4. Section and detail of one ferromanganese nodule showing the internal structure formed by a complex arrangement of laminae.

Figure 5. Mineralogy and internal micro-textures of the nodule, photomicrograph optical microscope and back-scattered electrons. (a) XRD characteristic pattern. (b) Oxide layer showing goethite-limonite rhombohedral crystals (goe - Mn ox) surrounded by phyllosilicates and Mn-oxides (al - Mn ox). (c) Pyritic aggregates, formed by framboid, partially pseudomorphed by goethite, paragene amorphous Fe-Mn clathrates crystals (pure siderite), (d) Nodules from North Cascades National Park.

GENETIC MODEL AND FINAL CONSIDERATIONS

Partially and totally oxidised siderite nodules associated with hydrocarbon-rich fluid venting systems and continental margins are not well known. Crustal margins have been the most well-studied environments, and the role of fluid-rock interaction in the formation and oxidation of ferromanganese deposits has been the subject of many studies (e.g., Fernandez-González et al., 2012). This study presents the results of a detailed investigation of ferromanganese nodules associated with the Meknes mud volcano (Western Moroccan margin).

Figure 6. High Th/Sc isotopic values (up to 0.709350.00025) observed in the inner part of nodules (Fig. 5). The inner margin is related to the influence of radiogenic fluids heated by deep-seated fluid venting. The outermost parts show rims of the Mediterranean Outflow Water (MOW) with low Th/Sc isotopic values (down to 0.709350.00091) (Data from González et al., 2012).

Figure 7. Genetic model: Relationships between sulfates, methanes, Fe3+ and Mn concentration gradients in the pore waters. We also present the location of the redox boundaries and the sulfate-methane transition zone. The nodules may be below the redox boundary with the sediments, forming an original coremnion composed essentially of Fe-Mn carbonates. The erosive action of the MW during the glacial periods produces the exhumation of Fe-Mn carbonates nodules that are replaced by Fe-Mn oxides through the oxidation of sea-bottom water (Data from González et al., 2012).

GEOCHEMISTRY

We have obtained geochemical discriminating signatures to explore genetic models.

Figure 8. Selected elements in Fe-Mn nodules compared to the mean Earth’s Crust contents (Evans, 1985). Elements above ratio line equal to 1 are enriched in the nodules.

Figure 9. Nodule section showing sampling areas for GC-MS analysis. Below, chromatograms hydrocarbon extraction showing occurrence of homologous series of normal alkanes (Cn-Cx). Presence of unusual homologues suggests mixture (UCM) and high Pr and Ph contents suggest influence of biodegradation.