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Petrological and geochemical Highlights in the floating fragments of the October 2011 submarine eruption offshore El Hierro (Canary Islands): Relevance of submarine hydrothermal processes

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This paper describes the main physical, petrological and geochemical features of the floating fragments that were emitted in the initial stages of the 2011–2012 submarine eruption off the coast of the Canarian island of El Hierro, located 380 km from the Northwest African Coast. It attempts to assess the potential of radiometric analyses to discern the intriguing origin of the floating fragments and the differences between their constituent parts. In this regard, the material that conforms the core of the fragments contains the largest concentration of uranium (U) ever found in volcanic rocks of the Canary Islands. This enrichment in U is not found in the content of thorium (Th), hence the floating fragments have an unusual U/Th ratio, namely equal to or larger than 3. Although the origin of this material is under discussion, it is proposed that the enrichment in U is the result of hydrothermal processes.

1. Introduction

In early October 2011, a submarine eruption started offshore the island of El Hierro (Canary Islands, Spain), 380 km WNW from the closest point of the Northwestern African Coast. This submarine eruption shows similar features to the one occurred between 1998 and 2001 in the Serreta Submarine Eruption, west of Terceira Island, in the Azores Archipelago (Gaspar et al., 2013).

The El Hierro eruption followed the migration to the south of the island of a seismic swarm (roughly 12,000 earthquakes of Richter Magnitude equal to or greater than 2.0, detected by the Spanish National Geographic Institute, IGN) that began on 17 July 2011, approximately 30 km northwards. On October 10, the signal of volcanic tremors appeared in the seismic records, indicating the likely onset of an eruption. Some authors point that the eruption started on October 10 (e.g. Marti et al., 2013a,b). However, the first visible evidences of the eruption, specifically greenish and brownish colored spots, appeared on the ocean surface was on October 12 with the emergence of the first plumes reaching the surface (Troll et al., 2012; Meletlidis et al., 2012). The emission center was located at approximately 360 m below sea level and 3 km SSW from the most southerly point of the coast of the island. The evidences of the submarine eruption, namely the tremor signal and the emission of volcanic materials on the ocean surface, disappeared by March 2012 and on 5 March 2012, the eruption was officially declared stopped. Nevertheless, visual evidences point to the persistence, until today, of continued emissions of gas bubbles from the seafloor in the eruptive area. This eruptive process caused a significant impact on the marine ecosystem resulting in relevant changes among them, thermal increase of the seawater, acidification, deoxygenation and metal-enrichment (Fraile-Nuez et al., 2012).

Following the onset of the submarine eruption, abundant dark fragments resembling volcanic bombs appeared floating on the ocean surface. Previous works have already established the dual nature of such bombs (Troll et al., 2012; Carracedo et al., 2012;

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Rodriguez-Losada et al., 2012a, 2012b, 2012c). These fragments, popularly known as "restingolitas" after being named by the amateur association "Actualidad Volcanica de Canarias (AVCAN)", were first seen at approximately 3 km SSW of the coastal village of La Restinga, located in the southern tip of the island. The fragments (Fig. 1) are 10–20 cm long in its major axis, having a low bulk density (roughly 0.6 MG/m^3), and being composed of two different materials: a grayish-white to white glass, hereafter referred to as White Foamy Core (WFC) and a thin (1 cm or less) glassy Dark Crust (hereafter DC) that covers WFC. Mingling between both materials, with very net limits, can be observed. Ductile deformations are clearly seen in WFC with strong convolutions, engulfing part of DC in ductile conditions (Fig. 1). Regarding the WFC, there is an antecedent in the previous subaerial volcanic eruption of Teneguía volcano (La Palma Island) in October 1971. In that eruption, fragments of rhyolite–trachyte pumice were found among the basaltic pyroclastics thrown out during the explosive phases of the Teneguia volcano. It was proposed that these pumices were produced by remelting of an acid phase in a subvolcanic complex extended underneath the La Palma Island (Araña and Ibarrola, 1973).

In the case described in this paper and after approximately three weeks of eruptive activity, the floating fragments did not longer contain the WFC, being entirely basanitic "lava balloons", some exceeding 1 m in size. Studies on the volatile content of the mafic magmas emitted in this eruption have revealed that in this submarine eruption the volatile concentrations were among the highest ever measured in magmas of oceanic islands (Longpré et al., 2013).

In this work, we attempt to evaluate the intriguing differences between WFC and DC, both constituents of the floating fragments appeared in the early stages of the eruption and previous to the late appearance of the basanitic lava balloons not studied in this work. Additionally, we analyze the concentration of uranium (U) and thorium (Th) in the fragments relative to those obtained for a large set of Canarian volcanic rocks (Aparicio et al., 2003; Hernandez et al., 2011).

There are experimental, geochemical, and field evidences associating U and Th contents with the type of igneous rock. Both uranium and thorium are incompatible elements (low partition coefficients); hence they remain in the melt relative to exsolved magmatic fluids (Brenan et al., 1995; Keppler and Wyllie, 1990; Peiffert et al., 1996). The partition coefficient is typically lower in U than in Th and consequently, its degree of incompatibility greater (Ahrens, 1995; LaTourrette and Burnett, 1992; Feigenson et al., 1996, among others). Since U has more tendency than Th to remain in the melt, it may be expected a differential enrichment of U over Th in the glass resulting from the cooling of the melt (Zielinsky, 1981; Leroy and George-Aniel, 1992; Cuney and Kyser, 2009; Dostal and Capedri, 1975).

Studies of many volcanic systems (e.g. Castor and Henry, 2000) show that U and Th concentrations in volcanic rocks increase with differentiation to more felsic compositions. High U concentrations in felsic rocks exceed 9 ppm, with some exceeding 20 ppm; high Th concentrations are above 20 ppm, and some more than 40 ppm. In this regard, the felsic rocks constitute potential sources of uranium (Maithani and Srinivasan, 2011). Other studies (Cuney and Kyser, 2009) point to high U concentrations in peralkaline volcanic rocks, but high values are also found in alkali rhyolites, metaluminous rhyolites, and some calc-alkaline tuffs (Castor and Henry, 2000). On the contrary, midocean ridge basalts typically contain 0.2 ppm of U (Kelemen et al., 2004).

2. Geological setting

As the magma extruded on the seafloor, it is likely that this magma interacted with volcano-sedimentary layers beneath the volcano (Troll et al., 2012). This interaction might be responsible of the special characteristics of the "restingolitas", and hence it is important to understand the geological evolution of the island of El Hierro, but also the ocean floor underneath.

The island of El Hierro has a surface of 278 km^2 and a maximum altitude of 1501 amsl, being the youngest and situated most south-westerly of the Canary Islands. The Y-shaped configuration of El

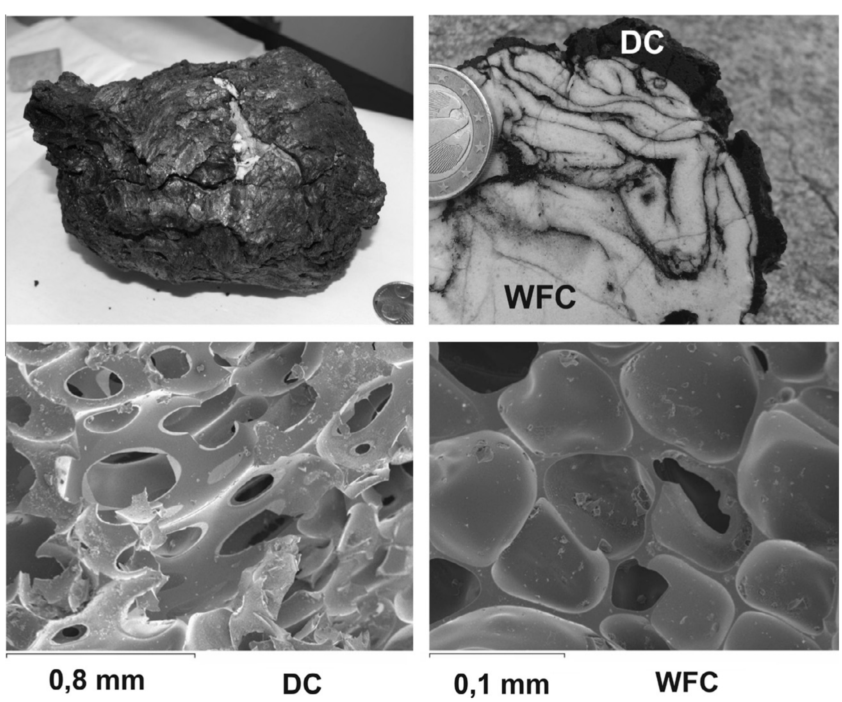

Fig. 1. Close up view of the entire floating fragment (upper left) and central section (upper right). Intense folding of the white core (WFC) engulfs part of the dark crust (DC). Lower left: Electron microscope image of DC and lower right: Electron microscope image of the WFC.