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The Ongoing Volcanic Eruption of El Hierro, Canary Islands

PAGES 89–90

El Hierro, the youngest of the Canary Islands (Spain), is no stranger to hazards associated with volcanic activity or to efforts to minimize the effects of these hazards on local communities. As early as 1793, administrative records of El Hierro indicate that a swarm of earthquakes was felt by locals; fearing a greater volcanic catastrophe, the first evacuation plan of an entire island in the history of the Canaries was prepared.

The 1793 eruption was probably submarine with no appreciable consequences other than that the earthquakes were felt [*Carracedo,* 2008]; over the next roughly 215 years the island was seismically quiet. Yet seismic and volcanic activity are expected on this youngest Canary Island due to its being directly above the presumed location of the Canary Island hot spot, a mantle plume that feeds upwelling magma just under the surface, similar to the Hawaiian Islands. Because of this known geologic activity, the Spanish Instituto Geográfico Nacional (IGN) has managed geophysical monitoring of the island since the beginning of the 1990s.

In summer 2011, El Hierro began a new episode of seismic and volcanic activity, prompting IGN to install more seismic stations and GPS receivers to monitor the nascent event. Through new data collected from these instruments, scientists are gaining a clearer picture of the evolving nature of El Hierro's eruptive behavior and the risks faced by the roughly 10,000 people living on the island.

Geologic Setting

El Hierro, 1.12 million years old [*Guillou et al.,* 1996], is the youngest of the Canary Islands and rests on a nearly 3500-meter-deep ocean bed (Figure 1). According to stratigraphic data, two eruptions are known to have occurred on El Hierro, one about 4000 years ago at Tanganasoga volcano complex and one 2500 ± 70 years ago at Montaña Chamuscada cinder cone (Figure 1b). The latter is the most recent El Hierro eruption prior to the current activity [*Guillou et al.,* 1996].

The principal configuration of El Hierro is controlled by a three-armed rift zone system in a characteristic "Mercedes star" geometry (Figure 1a). Two main shields (Tiñor and El Golfo) grew to reach levels of instability that led to giant gravitational landslides. The last stage of growth of El Hierro started some 158,000 years ago [*Guillou et al.,* 1996; *Carracedo et al.,* 2001], characterized by volcanism that concentrated mainly at the crests of the three-armed rift system. This emphasizes the crucial role played by rift zones in the construction of oceanic islands, exemplified by the Hawaiian and Canarian archipelagos.

Activity in 2011

In July 2011 a pattern of earthquakes (with an event every few minutes, with an average short-period body wave magnitude (m_{bLg}) of about 1–2) was detected by IGN's permanent seismic network. Though the greater part of these were insignificant from a seismic hazard point of view, the data reveal that they initially focused north of the island (Figure 1). Hypocenters

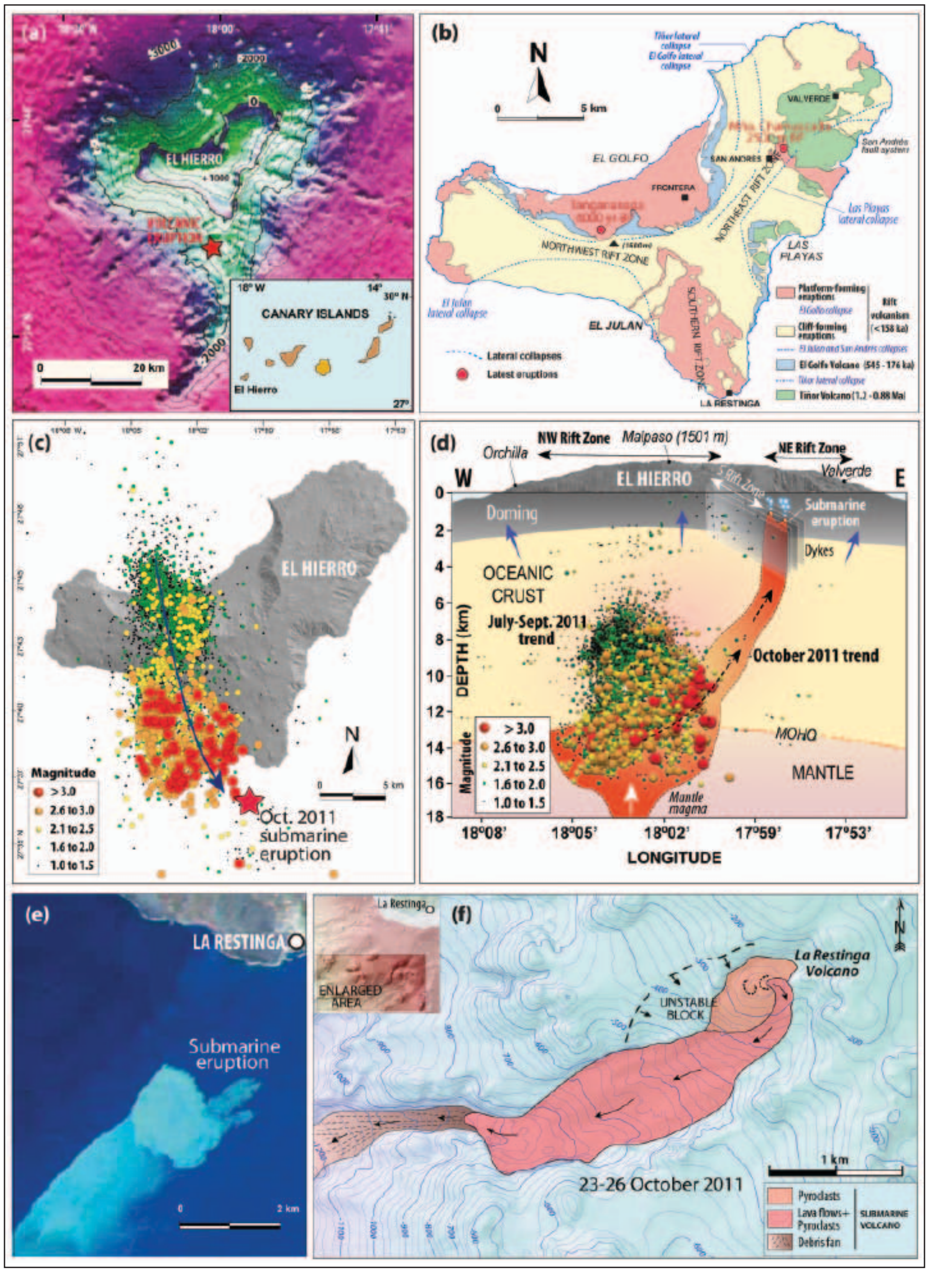

Fig. 1. The submarine eruption of El Hierro. (a) Location of the submarine vent (red star); image from Masson et al. *[2002]. Inset shows the island's location within the Canary Islands archipelago. (b) Simplified geological map of El Hierro, showcasing two recent eruptions. (c) Epicenter distribution migrating southward, 19 July to 8 October 2011 (data from Instituto Geográfico Nacional (IGN; www.ign.es). (d) Hypocenter depths increased from 3 August to 9 October 2011, when they became shallower (<3 kilometers). (e) Plume of dissolved magmatic gases and suspended matter from the 11 October 2011 underwater eruption (satellite image by RapidEye). (f) Map of the submarine eruption between 23 and 26 October 2011 (bathymetry from the Instituto Español de Oceanografía, Oceanographic Campaign BIMBACHE1011-1; see ship log at http://www.ieo.es/apartar/ieoprensa/hierro/hierro-leg1.pdf).*

initially were concentrated within the lower oceanic crust at depths of between 8 and 14 kilometers (see www.ign.es), in agreement with petrological evidence of previous eruptions [*Hansteen et al.,* 1998]. The seismic and petrological data are thus in line with a scenario of a magma batch becoming trapped as an intrusion horizon near the base or within the oceanic crust. Shifting seismic foci suggest that magma progressively accumulated and expanded laterally in a southward direction along the southern rift zone (see Figure 1), which caused a vertical surface deformation of about 40 millimeters (based on GPS measurements; see www.ign.es).

Soon after the initial earthquake swarm was observed by the permanent seismometers associated with IGN, efforts were made to mobilize a more complete monitoring seismic and GPS array spaced roughly 2000 meters apart throughout the island. This expanded network, which was completely installed by September 2011, has allowed scientists to follow the progress of the recent activity at El Hierro.

The new instruments revealed that earthquakes and magma transport remained active but as of the beginning of October 2011 showed no sign of having breached the oceanic crust. Instead, magma continued to move south until, on 9 October, the magma apparently progressed rapidly toward the surface, as indicated by the first-time occurrence of shallow earthquakes (at depths of <3 kilometers). The scenario changed dramatically, however, at about 4:00 A.M. local time on 10 October 2011, when the increasingly frequent and stronger seismicity (up to M 4.4) ceased and was rather abruptly replaced by a continuous volcanic tremor (see www.ign.es).

These changes in seismicity indicated the opening of a vent on the flank of the submarine part of the southern rift zone at about 300 meters in depth. Afterward, patches of pale-colored water that smelled of sulfur and contained broken bits of corals were found floating 1 mile south of the coast. The eruption continued through October 15, with the appearance of submarine volcanic "bombs" with cores of white and porous pumice-like material encased in a fine coating of basaltic glass. These bombs are probably xenoliths from pre-island sedimentary rocks that were picked up and heated by the ascending magma, causing them to partially melt and vesiculate [*Troll et al.,* 2011].

Continuous Monitoring of an Ongoing Event

The 2011 El Hierro submarine eruption fits perfectly into the geological framework of the island and that of the Canaries as a whole. It took place at the youngest island, which is in an early stage of shield building, in the assumed present location of the Canarian hot spot, and is located within an active rift zone.

Bathymetric data (25 October 2011) obtained by the R/V *Ramón Margalef* of the Instituto Español de Oceanografía (IEO) indicate that a new submarine cinder cone, 700 meters in diameter with its summit at about 200 meters, is forming below sea level (Figure 1f) surrounding the vent. As of 16 February 2012, the eruption goes on unchanged, displaying volcanic tremor of low magnitude offshore of the town of La Restinga but with some deeper volcanotectonic earthquakes of magnitudes generally below 4 beneath the northern coast of the island.

In the first week of February the current peak of the submarine cone remained at a depth of 120 meters below sea level, with side vents around the main cone opening and closing (see ship log BIMBACHE1011-9 at http://www.ieo.es/apartar/ieoprensa/hierro/hierro-leg9.pdf). Deposition of hyaloclastitic material continued downslope, leading to a very slow net increase in edifice height. It thus appears likely that the El Hierro eruption is going to continue being submarine for an extended period of time and that Surtseyan activity is not foreseen any time soon. In any case, the authorities are prepared to evacuate people should the eruption get more serious.

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—Juan-Carlos Carracedo, Francisco-Jose Perez-Torrado, and Alejandro Rodriguez-Gonzalez, University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain; E-mail: jcarracedo@proyinves.ulpgc.es; Jose-Luis Fernandez-Turiel, Institute of Earth Sciences Jaume Almera, Consejo Superior de Investigaciones Científicas, Barcelona, Spain; Andreas Klügel, Universität Bremen, Bremen, Germany; Valentin R. Troll, Uppsala Universitet, Uppsala, Sweden; and Sebastian Wiesmaier, Earth and Environmental Sciences, Ludwig-Maximilians-Universität München, Munich, Germany