Impact of Volcanic Eruptions on the Seafloor Around Montserrat, West Indies

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Volcanic activity in the Lesser Antilles island arc (West Indies) produces large quantities of ash, pumice, and rock that are delivered to the shallow and deep marine environments of the western Caribbean Sea and eastern Atlantic Ocean. On the island of Montserrat, in the northern part of the Lesser Antilles, Soufrière Hills volcano has erupted frequently since 1995 (Figure 1). About 1.1 km^3 of andesitic magma (Wadge et al., 2010) has erupted, and much of this material has been transported into the ocean as pyroclastic flows—hot avalanches of rocks, ash, and gas that travel at speeds in excess of 160 km per hour (Wadge et al., in press). In addition, mud flows (lahars) carrying volcanic debris wash into the ocean during periods of intense rain.

High-resolution bathymetric mapping around Montserrat revealed the importance of volcanic collapses that generate large landslides, known as debris avalanches, as a critical mechanism for transporting large amounts of volcanic material into the marine environment (Deplus et al., 2001; Lebas et al., 2011). Debris avalanches can trigger significant tsunamis, and contribute to the geological hazards associated with this dynamic boundary.

Figure 1. Map of the northern Lesser Antilles island arc showing the location of Montserrat island. Inset photo is an explosive eruption of Soufrière Hills volcano, located in the southern part of Montserrat.

The current volcanic episode includes an eruption on December 26, 1997, that devastated the southwest flanks of Soufrière Hills volcano and razed two villages, sweeping the houses and their contents into the sea. E/V *Nautilus* investigated the effects of both the recent influx of volcanic material into the sea from the eruption and larger debris avalanche events that took place in the recent geologic past. Effects from discharge of volcanic flows into the sea were found to be localized and related to the flows' intensity/concentration. A major dome collapse (the largest of any historical dome collapse worldwide) in July 2003 initiated a submarine pyroclastic flow (Trofimovs et al., 2006). Observations of carbonate shelf blocks on the surface of these deposits indicate that the shelf was also destabilized by this event.

In the area offshore of St. Patrick's village, which was destroyed by the 1997 eruption, few effects could be seen in shallow water (100–200 m). Dense colonies of whip corals (*Stichopathes* sp.) occupy the marine slopes, indicating that volcanic flows had little impact just offshore of the village despite the devastating effect on land (Figure 2a). It is likely that the energetic flows were too dilute to form high-concentration flows that continued downslope into the marine environment. In contrast, only a few hundred meters along the coast toward the capital city of Plymouth, the shallow seafloor has been swept clean of most marine organisms. They have been replaced by coarse deposits of volcanic ash and boulders (Figure 2b), and repeated lahar deposits over the last 18 years have formed a significant shallow-water deltaic fan. These observations may offer insight into rates of recovery of marine ecosystems as deep as 1,000 m following extreme geological disturbances.

Previous work identified at least five major debris avalanches around Montserrat, although the ages and sources are poorly constrained (Le Friant et al., 2004). ROV dives focused on sampling and observing individual blocks in the deposits to facilitate correlations with land-based sequences and estimation of the units' ages. East of

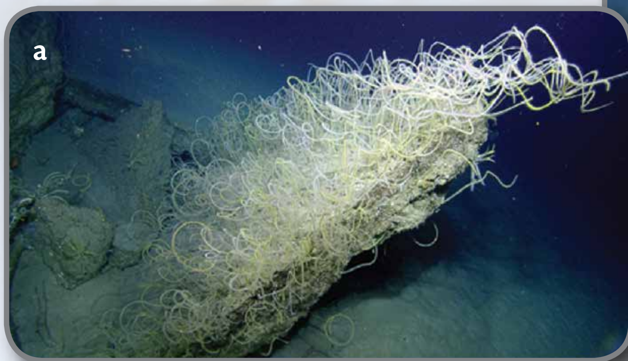

Figure 2. (a) Abundant whip corals (*Stichopathes* sp.) on volcanic blocks offshore of St. Patrick's village, Montserrat. (b) Blocks and volcanic ash offshore of Plymouth, Montserrat. Note the lack of sessile bottom organisms in the area off of Plymouth.

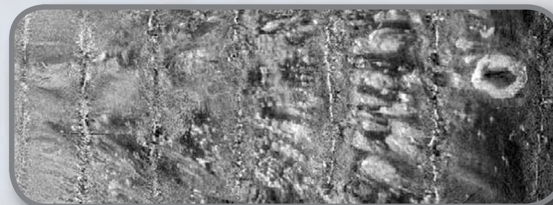

Figure 3. Backscatter image of debris avalanche Deposit 1 east of Montserrat (see Figure 1 for location) revealing radial flow alignment of megablocks. Large megablock at the right side of the image is the size of Wembley Stadium in London.

Montserrat, a major debris avalanche (Deposit 1) off the Tar River valley contains some of the largest blocks found on the seafloor (Figure 3). Samples collected from blocks in this area consisted of hornblende-bearing andesite lava typical of the Soufrière Hills volcanic center, hydrothermally altered volcanic rocks, and moderate numbers of carbonate blocks (Figure 4). Exposures on the steep megablock faces show characteristics typical of debris avalanches, with a chaotic mixture of different rock types and domains of intact stratigraphic sequences from the original volcano. The diversity of rock types in Deposit 1 blocks suggest that the collapse originated from a dominantly subaerial volcanic source, but also included parts of the shallow carbonate platform surrounding the island. A possible origin site of this deposit is English's Crater, a large collapse scar in the Soufrière Hills.

In contrast, exploration of blocks in debris avalanche Deposit 5, located to the southwest of Montserrat, revealed sources mainly on the shallow submarine shelf of the island. These blocks contain abundant indurated carbonate rocks displaying karst solution features typical of subaerial weathering and bedded units with highly rounded volcanic boulders and cobbles typical of deposits emplaced in the high-wave-energy coastal zone or derived from discharge of lahars into the sea. These observations support the interpretation of Deposit 5 by Cassidy et al. (2013) as related to large-scale collapse of the southwestern submarine flank of Montserrat 8,000 to 12,000 years ago. A significant discovery of the exploration was the pervasive development of carbonate hard grounds on the western flanks of the volcano at 150–400 m water depth (Figure 5).

Figure 4. Exposed face of a megablock from debris avalanche Deposit 1 off the east coast of Montserrat. The outcrop consists of coarsely bedded volcanic debris (base) interbedded with hydrothermally altered tuffs (yellow and red bands). Width of the field of view is about 2 m.

Figure 5. Indurated carbonate crust off the south coast of Montserrat. The crusts are typically several to tens of centimeters thick and consist of cemented biogenic and volcaniclastic material. Red laser dots to the right of center in the image are 10 cm apart.