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Recent storm and tsunami coarse-clast deposit characteristics, southeast Hawaiʻi

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ABSTRACT

Deposits formed by extreme waves can be useful in elucidating the type and characteristics of the depositional event. The study area on the southeast coast of the island of Hawaiʻi is characterized by the presence of geologically young basalts of known age that are mantled by recent wave-derived sedimentary deposits. The area has been impacted by large swells, storms and tsunamis over the last century, and in combination with known substrate ages makes this an ideal location to study recent deposits produced by such events.

Three distinct coarse-clast deposit assemblages can be recognized based on clast size, composition, angularity, orientation, packing, elevation and inland distance of the deposit. These deposits are characterized as one of three types. 1) Gravel fields of isolated clasts, primarily boulder-size material, and scattered pockets of concentrated sand and gravel in topographic lows. 2) Shore-parallel and cuspate ridges composed mostly of rounded basalt gravel and sand with small amounts of carbonate detritus. The ridges range in height from about 1 to 3 m and are 10s of m wide. 3) Cliff-top deposits of scattered angular and sub-angular clasts along sea cliffs that are generally greater than 5 m elevation. The gravel fields are primarily of tsunami origin from either the 1975 Kalapana event, or a combination of the 1975 tsunami, and 1868 tsunami or earlier events. The ridge deposits are presently active and sediment continues to be added during high wave events. The cliff-top deposits contain evidence of deposition by both tsunami and storm processes and require further investigation.

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1. Introduction

Sedimentary deposits produced by extreme-wave events, such as storms and tsunamis, have the potential to provide valuable information on the magnitude and frequency of marine inundation, wave characteristics, and hazard risk along vulnerable coasts. Because there are many coasts that can be impacted by both large storm waves and tsunamis, it is important to develop criteria to distinguish between the two types of events. Differences in the severity and frequency of impacts between the two phenomena necessitate an understanding of the potential hazard risks. There is a growing body of literature devoted to extreme wave deposits (e.g. Morton et al., 2007; Switzer and Jones, 2008; Goto et al., 2009), but in general there is little agreement as to what constitutes diagnostic criteria to distinguish storm from tsunami deposits, this is especially the case in coarse-clast sediments and boulders (e.g. Switzer and Burston, 2010). For example, on the island of Bonaire in the Netherlands Antilles, shore-parallel ridges of gravel-rich, reef-derived sediment have been ascribed to both predominantly tsunami origin (Scheffers, 2005; Scheffers et al., 2009) and predominantly storm-wave origin (Morton et al., 2008). In this case there is no historical record of tsunamis impacting Bonaire and several recent hurricanes that tracked near the island did not contribute significant sediment to ridge complex development which has lead to the conflicting interpretations of the deposits.

This paper examines primarily coarse-clast deposits that have formed recently from extreme waves of both tsunami and storm origin along the southeast coast of the island of Hawaiʻi. The study area offers a rare opportunity to observe coarse-clast deposits from recent storms and tsunamis on land surfaces of known age, which can aid in the interpretation of the origin of the deposit.

2. Regional setting

2.1. Geology and geomorphology of the study area

The island of Hawaiʻi is a young volcanic island formed by the coalescence of five subaerial volcanoes, three of which have been historically active. The study area on the southeast coast (Fig. 1) is underlain by volcanic deposits of the youngest Hawaiian volcano, Kilauea, currently in the shield forming stage. It began erupting about 300,000–600,000 years ago and has been erupting almost continuously ever since (Holcomb, 1987). Kilauea has erupted from three main areas,

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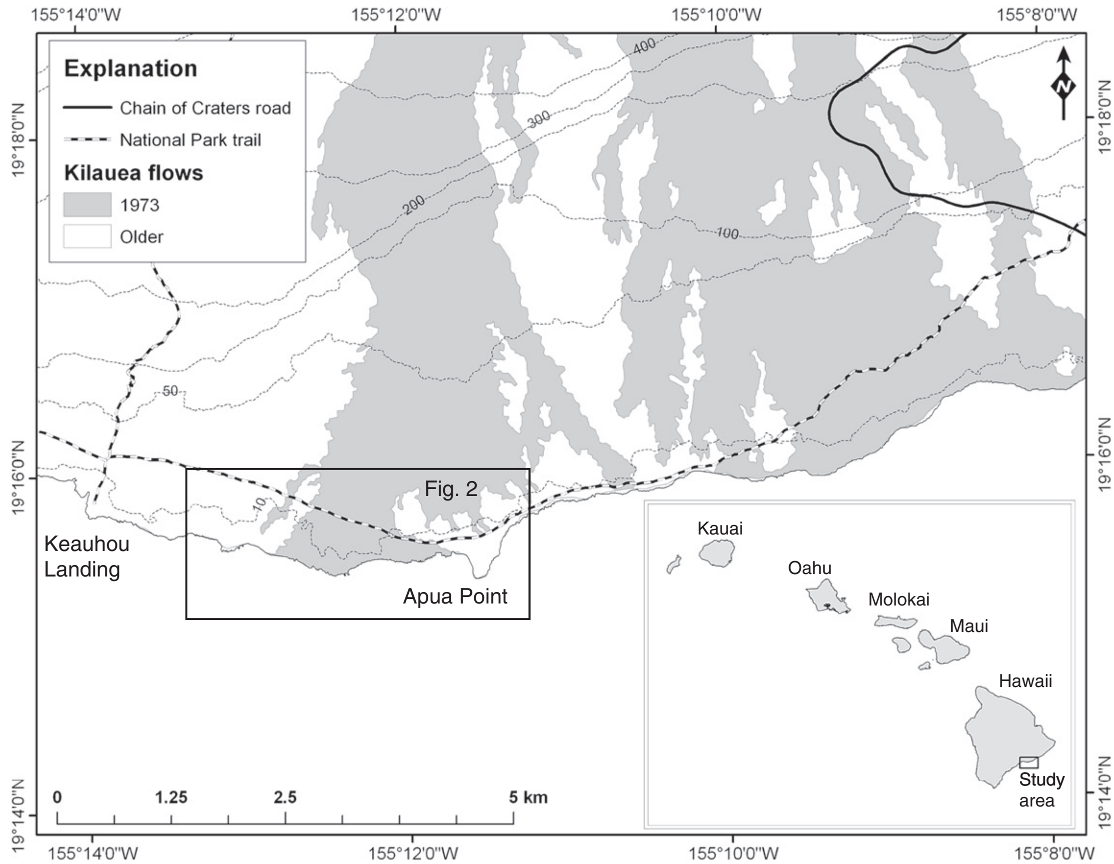

Fig. 1. Location map showing the main Hawaiian Islands (inset) and the study area in Hawai'i Volcanoes National Park (HAVO). The age of the lava flows that form the bedrock surface are from Holcomb, 1987.

its summit and two rift zones. Most Kilauea eruptions are non-explosive, sending lava flows slowly down slope. The study site encompasses bedrock of both recent and historical basalts (Wolfe and Morris, 1996; Sherrod et al., 2007) that consist of the 1973 Mauna Ulu Flows, the Keauhou Flows (~500–350 years old) and the Kipuka Nene Flows (~1500–1000 years old; Holcomb, 1987). In addition to volcanic activity, Kilauea has undergone repeated inflation and deflation periods with subsidence of more than 200 cm near the summit while the adjacent south flank has risen more than 50 cm (Delaney et al., 1998). Kilauea has continued to spread along its rift system, accompanied by displacement and subsidence near the summit and south flank uplift and seaward slip (Owen et al., 2000).

Our area of detailed study in Hawai'i Volcanoes National Park (HAVO) extends from Apua Point to Keauhou Landing (Fig. 1), a segment of coast that forms the seaward margin of several broad, gently seaward-sloping, lava deltas that abruptly end at the coast with sea cliffs interspersed with small pocket beaches. The underlying basalt platform that forms the coastal plain rises in elevation from sea level to about 90–120 m where it intersects the base of a steep escarpment. Width of the platform in the study area ranges from about 1750 m at Keauhou Landing to 4150 m at Apua Point. There are both roughly shore-parallel and shore-normal low-relief ridges throughout the area. Some of these features approach 10 m in overall relief and appear to be related to lava flow and subsequent cooling processes.

Most of the area is underlain by relatively smooth pahoehoe lava flows, although there are some areas of rough a'a flows. The relatively smooth pahoehoe surface is often interrupted by elliptical, domed volcanic structures called tumuli. Tumuli are created in slow-moving lava and are commonly 10s of m in diameter and extend 2–6 m above the surrounding lava. Fractures and cracks are common within the tumuli dome and are a local source of coarse sediment. Coastal vegetation varies from very sparse on recent flows to thin and patchy on the older flows. Land islands with vegetation and weathered lava (kipukas) occur where younger flows have completely surrounded older lava. This irregular landscape creates topographic lows that serve as suitable sediment traps separated by elevated areas of low sediment deposition. Apart from local downslope runoff there is no network of surface streams that would influence the distribution of sediment clasts. Finer sediment could be reworked during heavy rain and high wind events. Sediment at the coast is derived either from the cliff face, immediate offshore zone, or more rarely from gravity-driven deposition from upslope.

2.2. Recent tsunami history

The coasts of the Hawaiian Islands are subject to the impacts of both storm waves and tsunamis. Because of its location in the central North Pacific, the Hawaiian Islands receive trans-oceanic tsunamis from locations around the Pacific Rim as well as locally generated tsunami. Using confirmed published sources Walker (1994) noted 22 Pacific basin tsunamis with runup elevations greater than 1 m in the islands of Hawai'i since 1812. The highest tsunami runup elevation reported by Lander and Lockridge (1989) was 16.4 m at Waikolu Valley, north Molokai as a result of the 1946 Aleutian Islands earthquake event. Tsunami runup on the island of Hawai'i from the 1946 tsunami ranged from 2 m at Honaunau on the west coast to nearly 17 m at Pololu Valley on the northeast coast (Lander and Lockridge, 1989; Dudley and Lee, 1998. The last large tsunami of distant origin to strongly affect the Hawaiian Islands was generated by a great (magnitude 9.5) earthquake in Chile in 1960 that caused extensive damage in the Hilo, Hawai'i area (Dudley and Lee, 1998). The recent February 27, 2010 magnitude 8.8 earthquake in Chile created a Pacific-wide tsunami, however the tsunami in Hawai'i was