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Turbidites from giant Hawaiian landslides: Results from Ocean Drilling Program Site 842

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ABSTRACT

Pliocene to Pleistocene volcanic sand turbidites recovered 320 km west of the island of Hawaii at Ocean Drilling Program Site 842 contain fragments of fresh, weakly vesicular glass and tests of Pleistocene and Eocene radiolarians. This sand is probably related to turbidity currents generated from debris avalanches produced by giant landslides on the flanks of the Hawaiian Islands. On their way to Site 842, the currents flowed over the ~500-m-high Hawaiian Arch, indicating that the turbidity currents were at least 325 m thick. Similar sand has been reported 930 km south of the islands. Thus, Hawaiian giant landslides play a significant role in central Pacific deep-sea sedimentary processes.

INTRODUCTION

Recent studies have shown that turbidity currents from continental margins are capable of transporting sand over substantial topographic barriers (>1500 m high) and for great distances (>1000 km; e.g., Dolan et al., 1989). Giant landslides have been recently recognized on the flanks of the Hawaiian Islands (Moore et al., 1989) and provide a potential mechanism for generating massive and powerful turbidity currents in the interior of ocean basins. Ocean Drilling Program (ODP) Site 842 was drilled on the outer flank of the Hawaiian Arch. This project created an opportunity to evaluate whether the Hawaiian Islands have produced turbidity currents with adequate size and momentum to flow over the crest of the arch, which stands ~500 m above the deep to the east of the site. Our results show that at least three such currents have deposited sandy layers at Site 842. These turbidites are probably related to landslides that formed on the flanks of Mauna Loa, Lanai, and Kauai volcanoes, which are >265 km from Site 842. These landslides and/or associated turbidity currents had sufficient energy to erode the sedimentary sections around the Hawaiian Islands and to entrain Eocene radiolarians.

DRILLING OBJECTIVES

Previous studies (Edsall, 1975; Rehm and Halbach, 1982) had proposed that ash from the Hawaiian Islands is a significant contributor to sediment around the islands (e.g., layers up to 30 cm thick 928 km south of the islands). Site 842 is located west of the Hawaiian Islands on the outer flank of the arch that surrounds the southern end of the Hawaiian chain (Fig. 1). It was assumed prior to drilling that the only products from Hawaiian volcanoes to reach the site would be airborne ash carried by strong northeast trade winds (typically 25 to 50 km/h with gusts to 65 km/h) that blow over the islands. Thus, it was envisioned that the sediment cores from this site would allow us to evaluate the contribution of Hawaiian explosive volcanism to deep-sea sediment downwind from the main Hawaiian Islands.

Ash is not generally considered a common product of Hawaiian shield volcanoes. Typical Hawaiian eruptions are effusive with low lava fountains (<50 m) that produce lit-

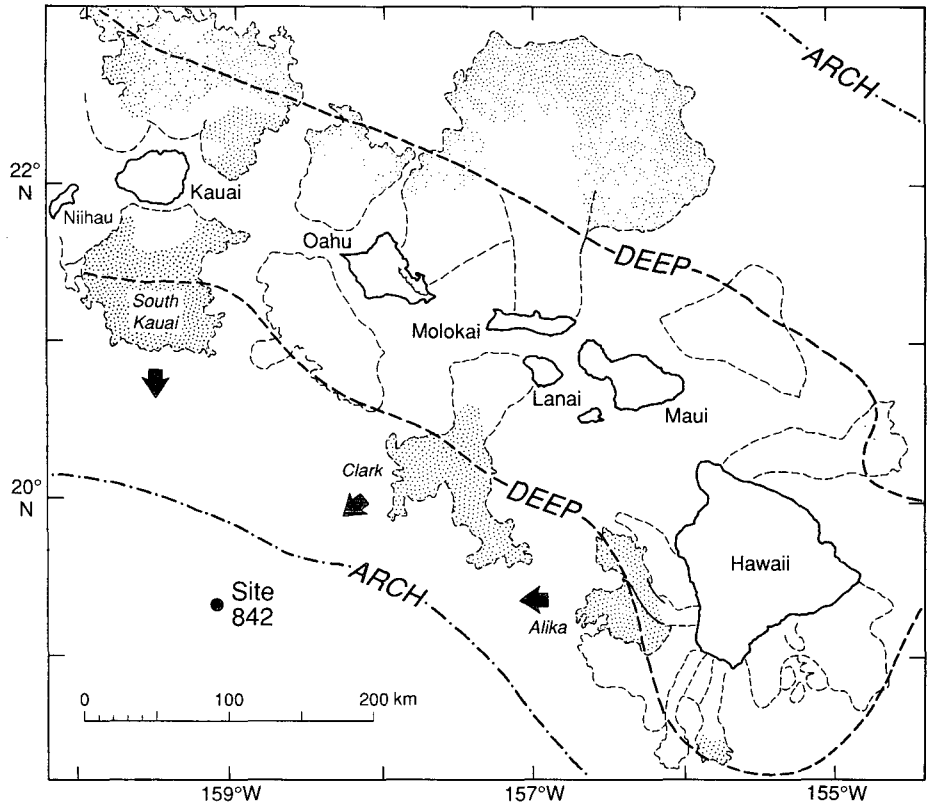

Figure 1. Map of Hawaiian Islands showing major landslides (bounded by light dashed lines; after Moore et al., 1989). Dot pattern shows areas covered by deposits from debris avalanches associated with these slides. Avalanches that traveled toward ODP Site 842 (solid circle) are Alika slide from Mauna Loa Volcano, Clark slide from Lanai Volcano, and South Kauai slide from Kauai. Heavy dashed line indicates axis of Hawaiian deep; heavy dash-dot line indicates Hawaiian Arch axis.

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tle ash (Walker, 1990). However, Kilauea Volcano exploded violently in 1790 and produced ash clouds that rose many tens of kilometres and deposited up to 12 m of ash at the crater rim (McPhie et al., 1990). The greatest potential source of airborne ash from Hawaiian shield volcanoes probably occurs when they emerge above sea level. During this stage, copious quantities of ash can be produced (perhaps 0.1 km^3/yr based on the average magma supply for Hawaiian shield volcanoes; e.g., Dzurisin et al., 1984) as magma and seawater react violently (see Kokelaar, 1986). The ash produced during these eruptions would be characterized by high vesicularity (40 to 50 vol%; Moore, 1985) and limited compositional variation within individual ash horizons (e.g., Batiza et al., 1984).

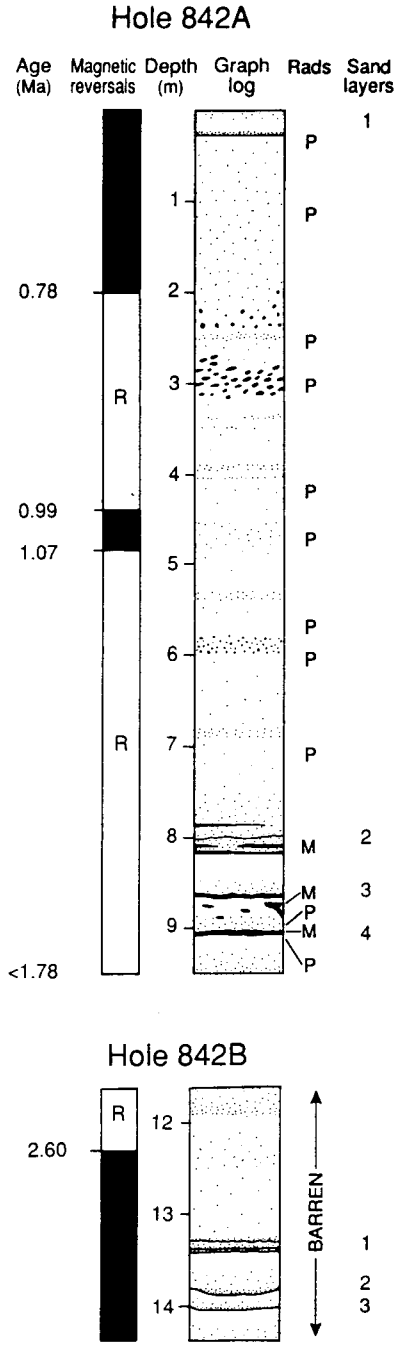

Figure 2. Summary logs of sand distribution (dark areas) in and magnetic polarity of Pliocene to Pleistocene sediment from Hole 842A and bottom part of Core 2H from Hole 842B. Magnetic polarity determinations are from Shipboard Scientific Party (1992); polarity ages are from McDougall et al. (1992). Rads column indicates locations where samples were taken for paleontological examination; P indicates samples with only Pleistocene radiolarians; M indicates samples with mixed Pleistocene and Eocene radiolarians.

STRATIGRAPHY

Two holes were drilled at Site 842. Volcanic sand is common throughout the 9.5 m of core recovered from Hole 842A (Fig. 2) and the upper 14 m of core from Hole 842B. The sand is found as grains disseminated within pelagic sediment and in distinct layers. The basal contact of these layers is sharp; the glass grain size becomes finer progressing upward into the overlying brown clay. Hole A has four distinct sand-rich layers; Hole B has three layers near the base of core 2H (Fig. 2). There are many remnants of sand-rich horizons in the cores that are now disrupted, probably by bioturbation, into round to elongate globules 2–4 mm wide.

The age of the volcanic sand layers can be constrained by paleomagnetic data and biostratigraphy. The youngest layer (~25 cm below the sea floor [bsf]) is from a normally polarized, 200-cm-thick section of sediment (Fig. 2). It may be ~100 ±20 ka, assuming a constant sedimentation rate at the site and no erosion associated with deposition of the sand. This age is consistent with the absence of the radiolarian species *Axoprunum angelium* in a sample taken from 3 cm below the sand layer. This species last lived ~0.42 ±0.02 Ma (Morley and Shackleton, 1978) and is present in the core 1 m below this interval (Hull, 1994).

The lower three sandy layers from Hole 842A are from near the bottom of a reversely magnetized section (Matuyama; 1.07 to 1.78 Ma) and date from ~1.4 to 1.6 Ma on the basis of estimates of sedimentation rates from paleomagnetic data (Shipboard Scientific Party, 1992). This estimate is consistent with the presence of nannofossils assignable to the lower part of Quaternary Zone NN19 in a sample taken between the bottom two sandy layers in this hole (Shipboard Scientific Party, 1992; J. Firth, 1993, personal commun.). These three sandy layers also contain a reworked assemblage of poorly to moderately preserved, early to middle Eocene radiolarians with well-preserved Pleistocene radiolarians. Eocene radiolarians are not present in fine-grained sediment above or below these sandy layers (Fig. 2).

The three volcanic glass sand layers in Hole 842B at 13 to 14 m bsf are in a reversely magnetized section (Fig. 2), which is inferred to have been deposited between 2.75 and 3.0 Ma (Garcia, 1994). Unfortunately, this section of the core is barren of microfossils, so we have no independent verification of this age estimate.

PETROGRAPHY AND GEOCHEMISTRY

Volcanic sand layers at Site 843 are lithologically heterogeneous. Their main components are volcanic glass (75–85 vol%), clay (<1–20 vol%), siliceous biogenic material (common radiolarian tests and sponge spicules and rare diatoms and silicoflagellate tests; <1–5 vol%), olivine (<1–3 vol%), plagioclase (<1–3 vol%), and clinopyroxene (<1 vol%). Glass and mineral fragments range from 0.01 to 0.42 mm in length. Virtually all (>99%) of the glass fragments are blocky or platy. Some are strongly elongate (aspect ratios up to 1:8). Bubble-wall forms are uncommon (<5%). The glass fragments range from fresh to completely altered. The fresh glass is transparent and tan to light brown. The glass fragments are cloudy to opaque and dark gray in equal proportion in thin section. Altered glass, which is yellowish to reddish and, in the extreme cases completely altered to clay, is rare (<1 vol%) in the upper part of the cores (<10 m bsf) but predominates in samples from deeper in Hole 842B.

Major element and S analyses were made of glass fragments in the sand layers (see Garcia [1994] for analyses and methods used). The totals for most of the major element analyses are 99.5% ±0.5%, indicating that the glasses are fresh and volatile contents are relatively low. All of these glasses have low S contents (<0.06 wt%, most <0.02 wt%; Fig. 3A). Typical Hawaiian submarine tholeiitic glasses have S contents of >0.04 wt%; subaerially erupted tholeiitic glasses have S contents of <0.015 wt% (Fig. 3). Thus, the volcanic sand glasses were probably erupted under shallow-marine to subaerial conditions that allowed partial degassing of the lava before solidification.

The glasses are all tholeiitic and are similar in composition to Hawaiian tholeiites (Fig. 3B). The compositional variation among the Site 842 glasses spans the entire range of the current data base for Hawaiian tholeiitic glasses (excluding the preshield tholeiites from Loihi, which are not shown in Figure 3B). The compositional variability of the Site 842 glasses may indicate that the sands are from a larger portion of Hawaiian volcanoes than has been sampled subaerially or from dredging the submarine flanks.

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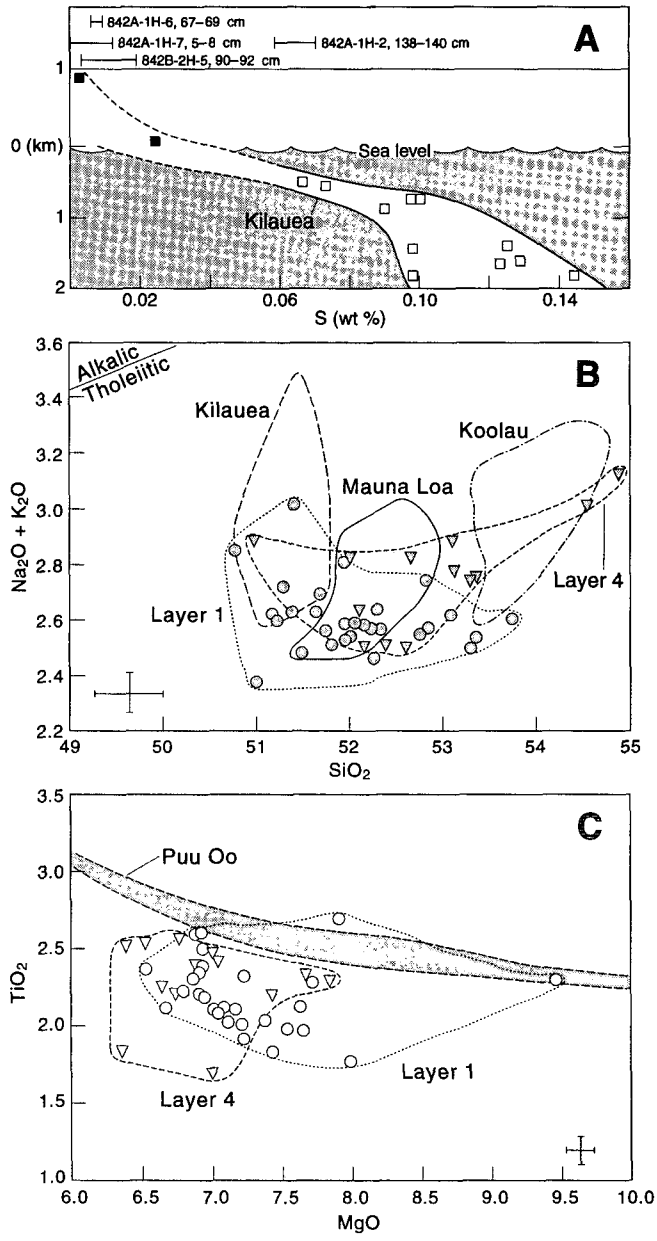

Figure 3. A: S content of some Site 842 glasses. Brackets show range of S content for 8–10 glass fragments for each layer. Low S content of most of Site 842 glasses indicates that they were degassed at time of quenching. Variation of S content in Kilauea volcanic glasses vs. depth (above and below sea level) is shown for comparison. Solid squares indicate subaerially erupted samples; open squares indicate submarine-erupted samples. Data for Kilauea samples from Byers et al. (1985), Dixon et al. (1991), and D. Muenow (unpublished data). B: SiO_2 (in wt%) vs. total alkalis ($Na_2O + K_2O$ in wt%) diagram for glasses from two Hole 842A sandy layers and several Hawaiian shield volcanoes (MgO, >6.35 wt%). Note large range in glass composition for sandy layers compared to glasses from some well-studied Hawaiian volcanoes (circles—glasses from layer 1, Hole 842A; triangles—glasses from layer 4, Hole 842A). Fields for tholeiitic and alkalic lavas are from Macdonald and Katsura (1964). Data for Hawaiian glasses are from Garcia et al. (1989) for Kilauea and Mauna Loa and unpublished data (Garcia) for Koolau. Two-sigma error bars for these analyzes are in lower left corner. C: MgO vs. TiO_2 variation diagram for Site 842 glasses. Shaded area represents lava compositions for 9.5 yr of Puu Oo eruption of Kilauea Volcano (data from Garcia et al., 1992). Data for ODP samples are from Garcia (1994). Note wide range in TiO_2 content at a given MgO content for Site 842 glasses compared to Puu Oo lavas, which have undergone both magma mixing and crystal fractionation (Garcia et al., 1992). Two-sigma error bars are in lower right corner.

Wide ranges in TiO_2 at a given MgO content are observed within individual sand layers (Fig. 3C). These ranges are well beyond those that could be caused by crystal fractionation of the observed minerals (olivine, clinopyroxene, and plagioclase) from compositionally similar parental magmas. This is especially true for the more mafic glasses (>7.0 wt% MgO), which would have contained only olivine phenocrysts. For comparison, the field for lavas from the current, long-lived (10+ yr) Puu Oo eruption of Kilauea Volcano is relatively narrow despite these lavas' complex history of magma mixing and crystal fractionation of olivine, clinopyroxene, and plagioclase (Fig. 3C). Thus, the wide range in sand-glass compositions within individual sandy layers must reflect lavas that were derived from many different parental magmas. On the basis of the relative homogeneity of historical and prehistoric Mauna Loa lavas (Rhodes, 1983), many tens of thousands of years would be required to produce this variation for an individual volcano.

ORIGIN OF THE VOLCANIC SAND LAYERS

The Pleistocene sand layers from Site 842 have sharp basal contacts, graded bedding, and a mixed assemblage of Pleistocene and Eocene radiolarians. Glasses within the layers are heterogeneous in composition, are platy to blocky in shape, and have low vesicularity. These features are inconsistent with a pyroclastic origin and are better explained by erosion and sedimentation by turbidity currents.

What was the source for and nature of the turbidity currents? Although there are many Cretaceous seamounts near Site 842 (Shipboard Scientific Party, 1992), the fresh nature of most of the glass fragments and the similarity of the glass compositions to Hawaiian lavas (Fig. 3) indicate that the source of the sands was the Hawaiian Islands. Thus, the turbidites traveled at least 240 km from the nearest island (Oahu) and up and over the gently sloping (<1°) Hawaiian Arch, which has ~500 m of relief near the drill site. The presence of reworked Eocene radiolarians in the sandy layers indicates that the turbidites are related to major erosional events. Recently it has been recognized that giant landslides have formed on the submarine flanks of many Hawaiian volcanoes (Moore et al., 1989). These landslides generated avalanche flows that could have substantially eroded the unconsolidated deep-sea Tertiary sediment near the islands.

The minimum height of the turbidity currents that deposited the sandy layers at Site 842 can be estimated by using the maximum run-up elevation that the flow encountered (Muck and Underwood, 1990). This height is ~500 m for the Hawaiian Arch near Site 842. Because the height of the turbidity current must be at least 65% of the bathymetric obstruction to be able to crest the feature (Muck and Underwood, 1990), the turbidity currents that deposited the sand layers at Site 842 must have been at least 325 m thick. Similar size or larger turbidity currents have been interpreted to have formed from landslides off the northeast flank of South America (Dolan et al., 1989). The turbidity current model for the origin of the Site 842 sand layers is illustrated in Figure 4.

IMPORTANCE OF TURBIDITY CURRENTS TO THE SEDIMENT BUDGET AROUND THE HAWAIIAN ISLANDS

Mixed radiolarian assemblages (typically Eocene and Pleistocene) have been reported in many cores taken from around the Hawaiian Islands (e.g., Deep Sea Drilling Project Site 67; Winterer, Riedel et al., 1971). Some early workers (e.g., Riedel and Funnell, 1964) attributed mixed assemblages to bottom currents from Antarctica. Schreiber (1969) noted that mixed assemblages are commonly associated with

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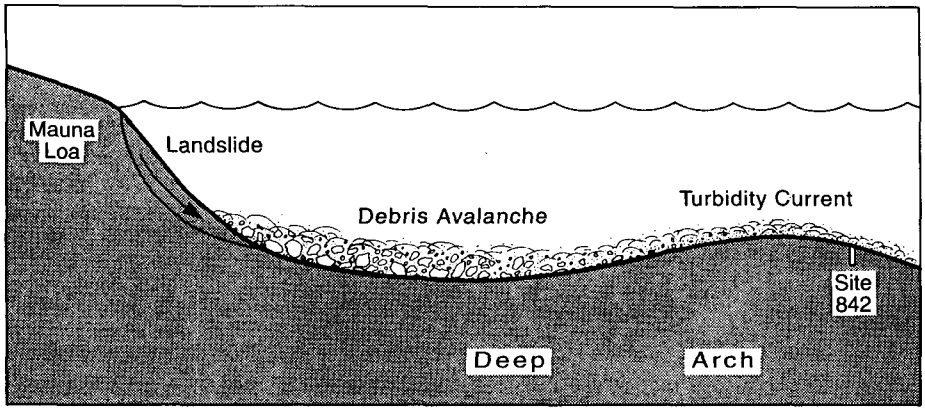

Figure 4. Sketch illustrating proposed relation of landslides on flanks of Hawaiian volcanoes to debris avalanches and their associated turbidity currents that might have deposited volcanic sand at Site 842.

volcanic sand layers, which she interpreted to be products of turbidity currents. Similar deposits of tholeiitic glasses up to 30 cm thick and dating from 1 to 2 Ma were found 930 km southeast of the Hawaiian Islands in cores taken near the Clarion Fracture Zone. Rehm and Halbach (1982) concluded that the sand layers originated from the island of Maui but could not have been deposited from turbidity currents because a 400-m-deep trough is located 20 km north of the coring sites. They preferred an eolian origin for the sand layers. However, the slightly vesicular to nonvesicular nature of the glass sand, the substantial thickness of individual layers, and the perpendicular angle of the Clarion site to the prevailing northeasterly trade winds over the Hawaiian Islands are features better explained as products of turbidity currents associated with the catastrophic slope failures on the flanks of the Hawaiian Islands. If they are, some Hawaiian turbidity currents may travel vast distances (1000+ km) over significant bathymetric highs and lows.

CONCLUSIONS

Hot-spot–produced oceanic islands are built rapidly, which causes them to be gravitationally unstable and to generate giant landslides on their flanks (Moore et al., 1989). Giant landslides from the Hawaiian Islands have produced turbidity currents that distribute sediment over large parts of the central Pacific basin. Thus, far-traveling turbidites are not restricted to continental margins and are a potentially important factor in deep-sea sedimentation processes.

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