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Geological evidence and sediment transport modelling for the 1946 and 1960 tsunamis in Shinmachi, Hilo, Hawaii

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ABSTRACT

The Japanese community of Shinmachi, established on low-lying land between downtown Hilo and Waiakea, Hawaii, was obliterated by the 1946 Aleutian tsunami but was rebuilt, only to be destroyed again by the 1960 Chilean tsunami. The aim of this study was to find out if any geological evidence of these well documented events had been preserved in the sedimentary record in Wailoa River State Park, which replaced Shinmachi after the 1960 tsunami. This was achieved by collecting cores in the park and performing sedimentological, chronological and geochemical analyses, the latter also processed by principal component analysis. Sediment transport modelling was carried out for both tsunamis, to infer the source of the sediment and areas of deposition on land. The field survey revealed two distinct units within peat and soil, a thin lower unit composed of weathered basalt fragments within mud (Unit 1) and an upper unit dominated by fine volcanic sand within fine silt exhibiting subtle upward fining and coarsening (Unit 2, consisting of Unit 2A and Unit 2B), although these two anomalous units only occur on the western shore of Waiakea Mill Pond. Analysis with an ITRAX core scanner shows that Unit 1 is characterised by high Mn, Fe, Rb, La and Ce counts, combined with elevated magnetic susceptibility. Based on its chemical and sedimentological characteristics, Unit 1 is attributed to a flood event in Wailoa River that occurred around 1520–1660 CE, most probably as a result of a tropical storm. The sharp lower contact of Unit 2 coincides with the appearance of arsenic, contemporaneous with an increase in Ca, Sr, Si, Ti, K, Zr, Mn, Fe, La and Ce. In this study, As is used as a chronological and source material marker, as it is known to have been released into Wailoa River Estuary and Waiakea Mill Pond by the Canec factory between 1932 and 1963. Thus, not only the chemical and sedimentological evidence but also sediment transport modelling, corroborating the historical record, suggest that Unit 2A was deposited by the 1946 tsunami, and the sediment most likely originated from Wailoa River Estuary, beach and nearshore seafloor. The upper part of this unit, Unit 2B, is believed to have been deposited by the 1960 tsunami, as suggested by sediment transport modelling, although limited accommodation space is likely to have resulted in the thin deposit (3 cm thickness) present at that site. Limited accommodation space on the island of Hawaii has led to only rare locations where tsunami deposits are preserved, despite the repeated occurrence of tsunamis affecting the island.

1. Introduction and background

Hilo, on the east side of the island of Hawaii (Big Island), Hawaiian Islands (Fig. 1), is known to have been affected by numerous tsunamis in historical times, even before the devastating 1946 event (e.g., Macdonald et al., 1947). Indeed, because of their location in the middle of the Pacific, the Hawaiian Islands have often been impacted by tsunamis generated around the Pacific Ring of Fire (e.g., Lander and Lockridge, 1989). They also tend to trap tsunami energy, as their steep volcanic slopes lead to large-scale resonance oscillations (Munger and Cheung, 2008). Furthermore, tsunamis are amplified in Hilo Bay, due to the geometry of the Bay and insular shelf, resulting in a main oscillation period between 15 and 30 min, which is similar to the period of many tsunami waves, so that resonance is almost always triggered, independently of the direction of the wave approach (e.g., Cheung et al., 2013).

The first historical tsunami reported to have hit Hilo was generated by a severe earthquake around Copiapo, Chile at 11.00 pm on 11 April 1819. It struck the Hawaiian Islands around 4.00 am on 12 April and its effects were reported from both the west and east coasts of Hawaii (Big Island) and also Oahu (Lander and Lockridge, 1989; Fletcher et al., 2002). Hilo may have been affected by an earlier event on 12 December 1812, believed to have been generated off the

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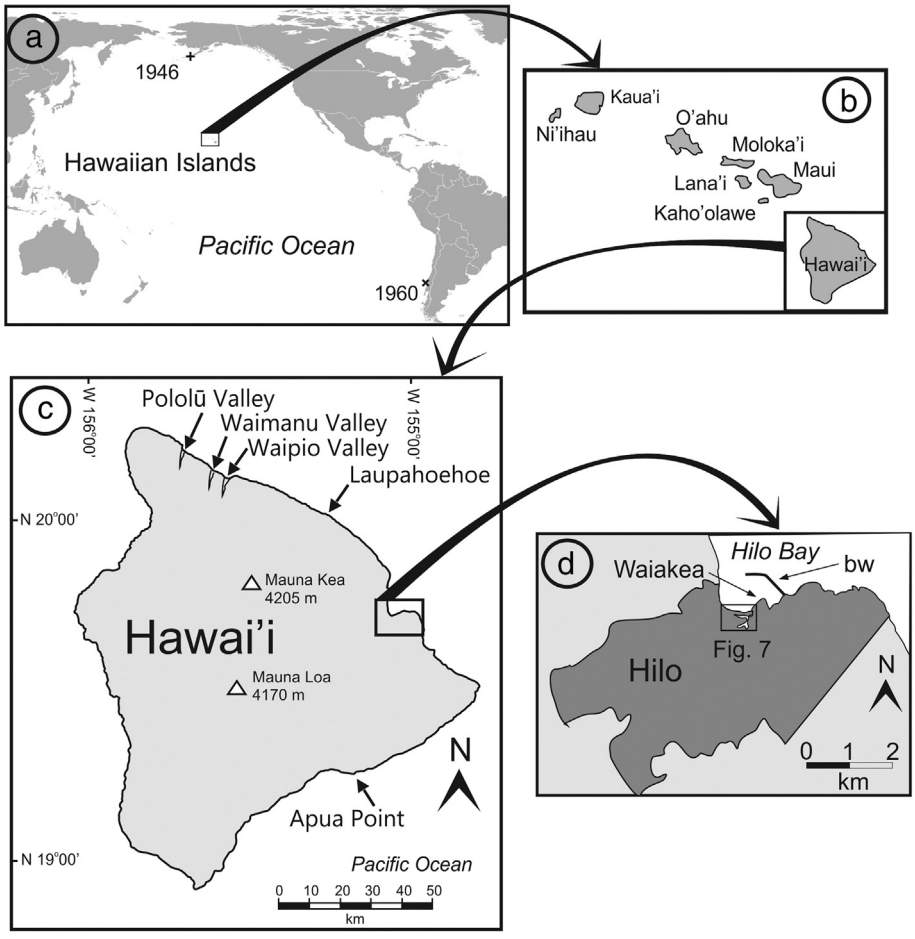

Fig. 1. (a) Hawaiian Islands in the Pacific Ocean. The epicentres of the earthquakes that generated the 1946 Aleutian tsunami (+) and the 1960 Chile (Valdivia) tsunami (x) are also shown; (b) Hawaiian Islands; (c) Hawaii (Big Island); (d) Hilo and surroundings. The breakwater in Hilo Bay (bw) and Waiakea are shown, as well as the extent of the area in Fig. 7.

California coast, although there are only records of one wave on the west coast of Hawaii, not Hilo (Lander and Lockridge, 1989). More detailed historical records for tsunamis in Hilo commence with the event generated by a Ms. 8.5 earthquake in Valdivia, Chile on 7 November 1837, which caused significant damage to infrastructure and resulted in 14 fatalities (Shepard et al., 1950). Since then there have been at least 130 tsunamis reported in Hilo from both historical and instrumental records (e.g., Anon., 1902; Cox and Morgan, 1977; Soloviev and Go, 1984; Lander and Lockridge, 1989; Fletcher et al., 2002; Lander et al., 2003; NGDC/WDS, 2017; J. Goff unpublished data).

Of particular note is Waiakea, an area east of downtown Hilo (Fig. 1d), which had often been damaged by tsunamis prior to 1946. Not only was damage reported as a result of the 1837 Chilean tsunami mentioned above, but also by the 1868 Arica (Chile), 1877 Arequipa (Chile) (5 people killed and 163 made homeless), 1922 Atacama (Chile) and 1923 Kamchatka tsunamis (e.g., Lander and Lockridge, 1989). There were also further tsunamis after 1946, including on 5 November 1952 when a 3.7 m (12 ft) tsunami generated by a Mw 9.0 earthquake in Kamchatka surged over Coconut Island (see Fig. 2 for location) (Dudley and Lee, 1998). Again, on 9 March 1957, a Mw 8.6 central Aleutian earthquake generated a tsunami that once more surged over Coconut Island (NGDC/WDS, 2017). Following the 1960 Chilean event, there have been further inundations, including the 1964 tsunami generated by a Mw 9.2 earthquake in Alaska (NGDC/WDS, 2017).

1.1. The 1946 tsunami

On 1 April 1946 at 4:28 am local time (12:28 UTC), a Mw 8.6 earthquake in the Aleutian Islands generated a tsunami that caused the most severe damage and the largest number of deaths in Hawaiian history. The earthquake occurred at approximately 2:00 am Hawaii local time. It was registered and recorded by the US Coast and Geodetic Survey at the University of Hawaii at Manoa, Honolulu, O'ahu and the Hawaiian Volcano Observatory at Kilauea, Hawaii shortly after (Dudley and Lee, 1998). The first wave from the tsunami reached the island of Kaua'i at around 6:00 am, Honolulu at 6:33 am and Hilo at 7:06 am (Shepard et al., 1950). Luckily the first wave was small, and as people had already risen at that time, many fled as it arrived, most probably saving many lives (e.g., Muffler and the Pacific Tsunami Museum, 2015). A total of nine waves inundated Hilo (Figs. 2, 3), with the 3rd wave described as the largest (Shepard et al., 1950; Dudley and Stone, 2000). It is worth noting that the measured tsunami heights were spatially variable, ranging from 2.7 to 9.8 m (Macdonald et al., 1947; Eaton et al., 1961) (Fig. 2). As the tsunami approached Hilo, it inundated Laupahoehoe Peninsula (Fig. 1c) killing 16 school children and eight adults. A total of 159 people lost their lives on the Hawaiian Islands, 96 of those in Hilo (Shepard et al., 1950). Extensive damage was reported in Hilo, including houses and business in particular on Hilo Bay front, rail tracks, shipping port, but also part of the breakwater, with property damage reaching $26 million in 1946 dollars (e.g., Muffler and the Pacific Tsunami Museum, 2015). This tsunami led to the creation of the first tsunami warning system that would eventually become the Pacific Tsunami Warning Center (PTWC) (Muffler and the Pacific Tsunami Museum, 2015).

1.2. The 1960 tsunami

The Mw 9.4–9.6 Valdivia (Chile) earthquake happened around 19:11 UTC on 22 May 1960 after several precursor events, starting

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