Underground Observations During the Pu'u O'o Earthquake, 4:06 P.M., August 8, 1990

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Abstract

On August 8, 1990, at 4.06 P.M., we experienced an earthquake of amplitude magnitude 4.7 in a lava tube of the Hilina Pali area, Kilauea, Ka'u District, Hawaii. The epicenter was 25 kilometers away from the cave. At the moment of the quake, Christhild was sitting on rocks, clearly feeling them moving underneath her, while Stephan stood upright having the perception as if a subway train were approaching up the tube. Possibly Christhild felt faint vibrations of the precursor shocks as well. No rock was heard falling from the roof, even though the cave, later called Earthquake Cave, is littered by breakdown blocks throughout.

Description of Earthquake Cave

While mapping a lava tube cave, later called Earthquake Cave, the authors experienced an earthquake on August 8, 1990 (Figure 1). Earthquake Cave is part of a tube system with a total mapped length of 338 meters (Figure 2) located at the end of the Hilina Pali road in Hawaii Volcanoes National Park, Ka'u District. The tube is accessible through two breakdown holes. The main entrance is a 16-meter-long and 9-meter-wide hole interrupting the cave. It is located near the brink of the pali, just *circa* 200 meters southwest of the Hilina Pali shelter. It was shown to us by Dr. John (Jack) Lockwood, geologist at the Hawaii Volcano Observatory and the cave was first entered by Jack and

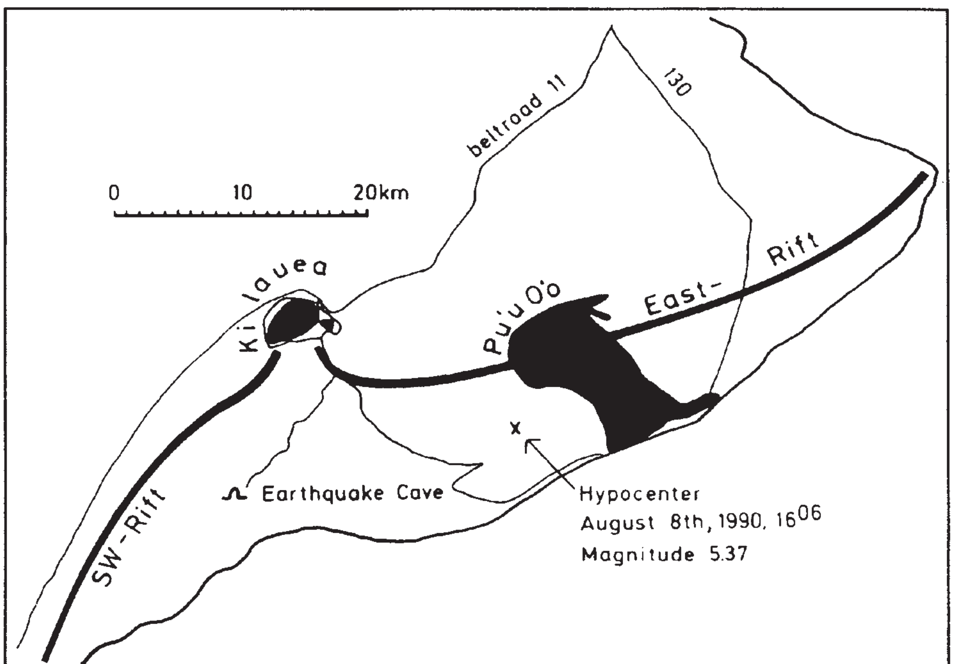


Figure 1 – Site of Earthquake Cave in relation to the Pu'u O'o Earthquake of August 8, 1990.

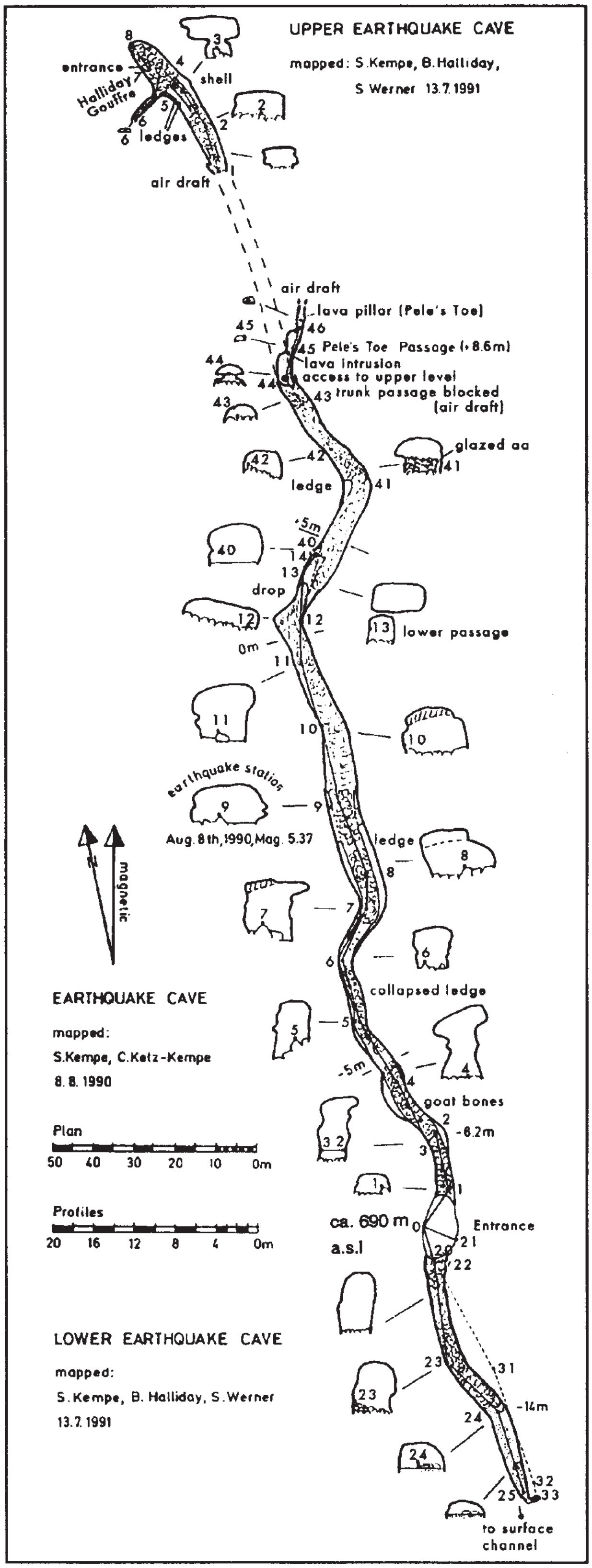
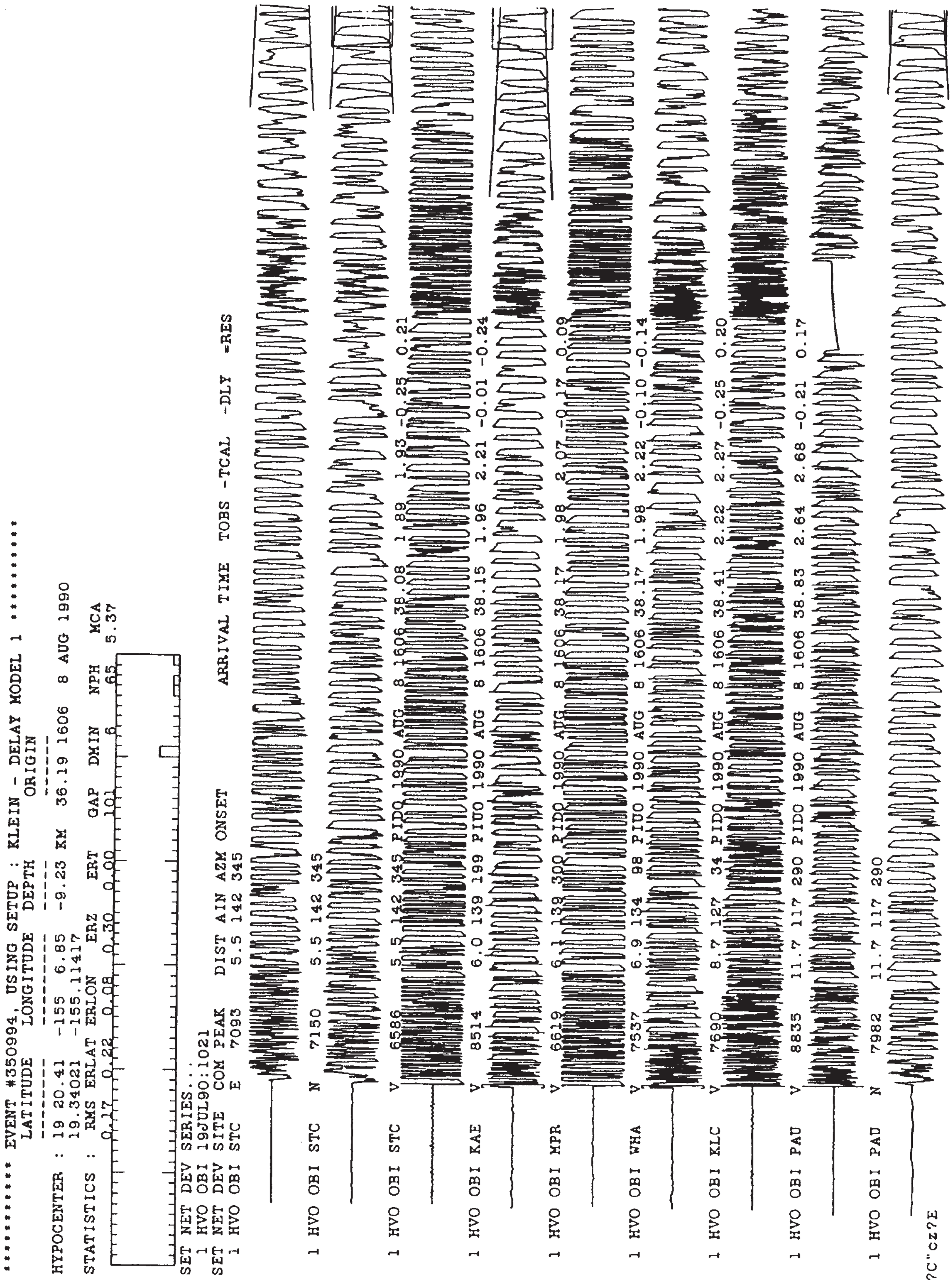


Figure 2—Map of Earthquake Cave Tube System, Hilini Pali, Ka'u District, Hawaii.

Martha Lockwood and the authors on July 20, 1990. The other entrance is situated upslope in the bed of an occasional stream and is 2.1×1.8 meters wide, opening up into the tube below. It was indicated to us by James (Jim) Martin, chief ranger of the National Park. This entrance was entered July 13, 1991 by W. Halliday, M.S. Werner, and S. Kempe but has obviously been visited before (piled-up stones below the entrance).

This upper entrance leads into Upper Earthquake Cave, an isolated piece of the tube, just 38 meters long. It is blocked by breakdown at its upper and lower ends. At the ceiling a low surface tube with an air draft is accessible on the west side of the tube. The presence of pieces of wood, mats of dried grass, and bits of charcoal show that the tube floods occasionally up to the ceiling. The main entrance is roughly 280 meters away, distance and bearing between the two holes were estimated from aerial photographs kindly made available by J. Martin. From the main entrance both the Earthquake Cave proper and the Lower Earthquake Cave are accessible. The Earthquake Cave starts down a steep breakdown cone and leads into a slightly winding, six-meter-high canyon-like passage. The floor is covered with ceiling or wall breakdown throughout almost all of the tube. Often older lava beds and oxidized soil are exposed behind the collapsed wall linings. The total length is 228 meters. The tube rises roughly 10 meters above the entrance. At station 12, the tube splits into two levels, the lower of which ends after a few meters. The upper level is closed by a boulder choke at station 44. There a hole in the ceiling which offers access to a narrow surface tube which is constricted by columnar intrusions of lava (Pele's Toe on map). Air draft indicates connection to cavities further

Figure 3—Seismometer traces of the Pu'u O'o Earthquake of August 8th, 1990 (courtesy, US Geological Survey, Hawaii Volcano Observatory). Note the sharp onset of earthquake (left) at 16.06 hours and 38.08 seconds. Stations are arranged according to increasing traveling time (top to bottom). Station codes stand for STC Steam Cracks, KAE Kaena Point, MPR Makaopuhi, WHA Wahaula, KLC Kalalua Cone, PAU Pauahi, all within the E-rift zone. Real amplitude of signal is too large to be shown and is suppressed in the plots. Station HVO OBI STC is given with eastern (E), northern (N) and vertical (V) components of movements while for most other stations only the vertical component of movement is plotted.


*********** EVENT #350994, USING SETUP : KLEIN - DELAY MODEL 1 **********
LATITUDE LONGITUDE DEPTH ORIGIN
HYPOCENTER : 19 20.41 -155 6.85 -9.23 KM 36.19 1606 8 AUG 1990
19.34021 -155.11417
STATISTICS : RMS ERLAT ERLON ERZ ERT GAP DMIN NPH MCA
0.17 0.22 0.08 0.30 0.00 101 6 65 5.37
SET NET DEV SERIES...
1 HVO OBI 19JUL90:1021
SET NET DEV SITE COM PEAK DIST AIN AZM ONSET ARRIVAL TIME TOBS -TCAL -DLY =RES
1 HVO OBI STC E 7093 5.5 142 345
1 HVO OBI STC N 7150 5.5 142 345
1 HVO OBI STC V 6586 5.5 142 345 PIDO 1990 AUG 8 1606 38.08 1.89 1.93 -0.25 0.21
1 HVO OBI KAE V 8514 6.0 139 199 PIUO 1990 AUG 8 1606 38.15 1.96 2.21 -0.01 -0.24
1 HVO OBI MPR V 6619 6.1 139 300 PIDO 1990 AUG 8 1606 38.17 1.98 2.07 -0.17 0.09
1 HVO OBI WHA V 7537 6.9 134 98 PIUO 1990 AUG 8 1606 38.17 1.98 2.22 -0.10 -0.14
1 HVO OBI KLC V 7690 8.7 127 34 PIDO 1990 AUG 8 1606 38.41 2.22 2.27 -0.25 0.20
1 HVO OBI PAU V 8835 11.7 117 290 PIDO 1990 AUG 8 1606 38.83 2.64 2.68 -0.21 0.17
1 HVO OBI PAU N 7982 11.7 117 290
?C"cz?E

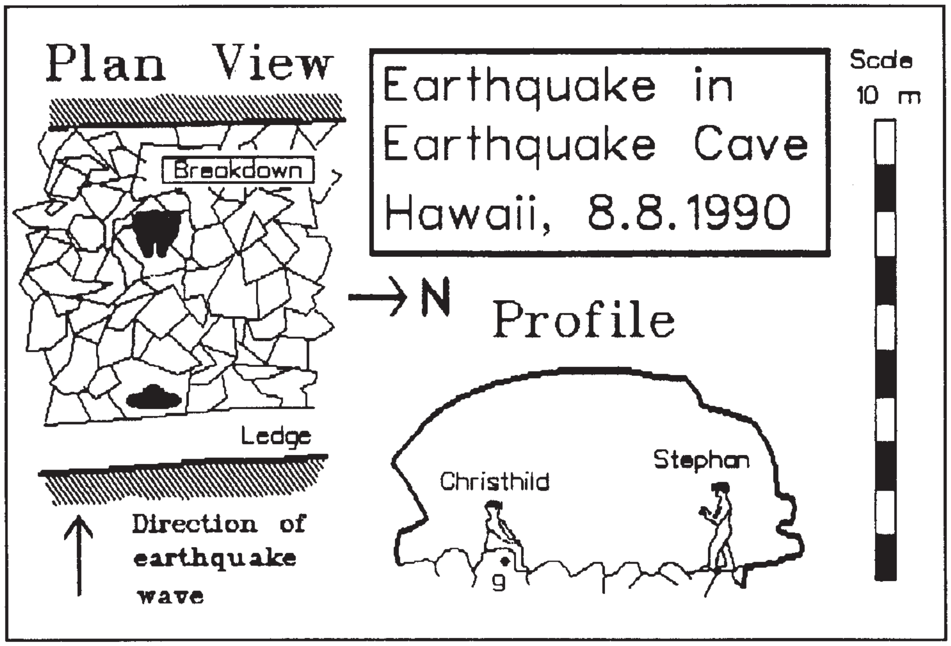


Figure 4—Sketch of the situation in the cave during the earthquake event.

uphill. Plenty of charcoal, partly in pockets high up on the walls, is found in the cave. This charcoal is similar to the plant remains in Upper Earthquake Cave, witness to an occasional flooding of the tube. In fact, it may derive from a fire which destroyed the trees in the Kipuka Bihopa area in the early 1980s. The Lower Earthquake Cave starts also as a six-meter-deep canyon and ends in a fluvial ash plug after 64 meters. A small hole connects to the surface. This hole probably serves as a drain of the cave at flood conditions. Below, the tube terminates and connects to an open channel which steeply dips over the brink of the pali. Geologically this is a unique example of a lava tube connecting to a channel. Both tube and channel appear to be cut down into older lava beds and must have transported lava over an extended eruption period.

The Earthquake

The earthquake was experienced while mapping the central part of the tube system. We entered the cave at 2:55 and left it at 5:23 P.M. The tremor occurred at 4:06 P.M. and its epicenter was just south of the Pu'u O'o vent on the East-Rift of Kilauea, Hawaii, (19°20.20'N / 155°6.77'W), i.e. *circa* 25 kilometers east of the cave (Figure 1). The shock wave must have hit the tube, which runs roughly north-south, at a right angle (Figure 2). Initially the Hawaii Volcano Observatory registered the magnitude of the earthquake as 5.37 (Figure 3), a figure which later was, according to Dr. Paul Okubo, seismologist from the Hawaii Volcano Observatory, corrected to 4.9. *The Hawaii Tribune Herald* (reporter J. Witty, August 9, 1990) related that the Pacific Tsunami Warning Center scaled the quake as M = 4.3 and that the National Earthquake Information Center, Colorado, registered it as 4.7 magnitude. The final corrected amplitude magnitude (MA) was 4.7 (pers. comm. J. Nakata, Hawaii Volcano Observatory). The hypocenter was at a depth of 9.14 kilometers. At around this depth the volcanic edifice rests on the sediments of the Pacific plate. Many earthquakes occur between 5 and 14 kilometers of depth including the 4.48 A.M. November 29, 1975 (M = 7.2) Kalapana earthquake (19°20.1'N / 155°1.4'W, depth 5 kilometers) (Tilling *et al.*, 1976). They are caused by a slip of the northeast-side of Kilauea towards the ocean on northeast-striking low-angle thrust faults (Klein *et al.*, 1987) (slip during the Kalapana earthquake was eight meters seaward). Because of its position and depth, the Pu'u O'o earthquake was seismic in origin, not directly related to volcanic activity but most probably caused by the ongoing loading of the Pu'u O'o area with fresh lava.

When the quake hit, we were at mapping station 9, 120 meters from the entrance. Christhild was sitting on the station point to rest, while Stephan stood facing her, a few meters away on the opposite side of the tube taking notes (Figure 4). While waiting for Stephan to finish, Christhild listened to the quiet tube and had the strange feeling of hearing distant voices. She commented on this and Stephan reassured her that nobody could possibly be in the cave except them. She kept on inquiring and suggested she might have felt vibrations from a car on a nearby road. Such a possibility was also rejected, since the Hilina Pali Road ends before reaching the cave area. We were still talking about Christhild's faint perceptions when the earthquake hit. Christhild felt the rocks moving uncomfortably against each other underneath her. Stephan, still standing, felt mostly the air rushing through the tube having the audible impression as if a subway train would approach. Possibly the air in the tube was compressed momentarily, producing a shock wave similar to the one felt when a train moves in a tunnel. The event passed in a few seconds leaving us perplexed. The anxiety which had been triggered by Christhild's first remarks, rose sharply and we listened intensively, frozen to our places, for rockfall. Thanks to Pele, we did not hear a single stone falling. After a while we discussed what to do, and decided that the chances of a second and even larger quake would be very low and continued mapping of the cave until almost to its end.

We cannot be absolutely sure if the vibrations which Christhild took for voices or car noise were indeed some earthquake precursors or if she was just distracted by wind rushing through the tube. Because of the coincidence with the quake we think it is possible that she in fact felt precursors to the main shock. These tremors were, however, rather small, as we could see next day on the seismograms of the Hawaii Volcano Observatory. It was also quite interesting that Stephan, standing, did not feel the movement of the floor as intensively as Christhild. The same difference in the perception of an earthquake was noticed a few days before. On August 1, we witnessed a M = 4.7 quake while visiting Dr. William and Sis Halliday in their apartment, 9th floor, Hilo Lagoon. While Bill and Stephan were sitting on the sofa feeling the earthquake intensively, Christhild and Sis were standing and did not perceive the shock at all. Just the table lamp rocking showed them that a quake had occurred.

When we reached the parking lot after the earthquake in the cave at the Hilina Pali shelter, we heard a faint alarm and were speculating if there was a fire nearby. A few minutes later (5:45 P.M.) though, Jim Martin, together with his son, pulled into the parking lot and was very relieved to see us. He told that he had been sitting in the car when the quake hit, and that he had not felt anything. The park headquarters had informed him by radio about an M = 5.3 event. Headquarters also told him that tourists reported smoke in the Hilina Pali area. A park helicopter flew along the pali but could not see any fire. Jim Martin therefore thought that something might have collapsed at the pali and worried about us, knowing that we had signed up to map a tube in the area. He immediately left for the Hilina Pali lookout which he reached an hour and a half after the quake.

Conclusions

The most interesting observation of this event was that the cave roof apparently is stable enough to withstand tremors of up to magnitude 5 easily. This is even more astonishing because the floor of Earthquake Cave is littered with breakdown blocks throughout its entire length, indicating that the roof is relatively unstable already. One is therefore tempted to conclude that most of the breakdown we see in Hawaiian caves must be correlated to a few very strong quakes. Geologically speaking, quakes of 7.0 magnitude still occur frequently on Hawaii. The two last events were the South Point earthquake of 1868 (*circa* M = 7.5) and the Kalapana earthquake of 1975 (M = 7.2) (Macdonald and Abbott, 1970; Klein *et al.*, 1987, respectively). This suggests that quakes of M = 7 may be expected at frequencies of two per century. Speleogenetically only these earthquakes seem to be effective. It is, however, also possible, that even larger and rarer events are needed to dislodge large breakdown in the lava tubes of Hawaii.

One *caveat* has to be made though. It is conceivable that all or parts of the breakdown are due to other causes. In case of the Earthquake Cave the flooding of the cave during torrential storms could be such a cause. The lava is full of gas bubbles, which in part may be water-filled during the ponding of water in the cave by the talus cone at the main entrance. When the water drains these rocks will be heavier than usual and might therefore collapse into the cave. In other areas, the loading of the humus and rock composing the cave roof with rainwater, the increasing load of a growing forest, the pressure of roots or the loss of such pressure could also be forces which may account for breakdown.

We were not the first cavers to witness an earthquake in a lava tube. Wood (1980) mentions that they felt a quake in Kazamura Cave in 1979 and Dr. Marlin Spike Werner was the involuntary witness of a scary M = 6.1 event in Malama Cave recently. The reader is referred to his account in this volume.

Acknowledgements

We wholeheartedly thank Jim Martin from Hawaii Volcanoes National Park. It was lucky that his thoughtfulness and care was not needed in this instance but potentially we could have been in need of help desperately. We also thank Carol Brian and Jennifer Nakata for helping us to obtain the Hawaii Volcano Observatory seismometer data for the August 8, 1990 earthquake.

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