Makapuʻu Field Trip Guide 16 September 2018

Prepared by Julia Hammer, borrowing substantively from field guides by John Sinton and Scott Rowland

Introduction

The geologic section exposed at Makapuʻu Point provides an excellent opportunity to observe the interior of a Hawaiian shield volcano at a range of spatial scales. During this field trip we will quantify the orientation of beheaded shield-stage lava flows; observe outcrop-scale variations in lava flow morphology associated with emplacement mechanism (pāhoehoe and ʻaʻā); and consider sub-cm scale features in a filled lava tube exposed on opposite sides of the Point.

Our provisional itinerary includes a view of Oahu's headland from afar and a loop hike (Stops 2 & 3), facilitating examination of many features shown in the annotated topographic map (Fig. 1, at the back of this guide) as the weather and sea-state permit.

Stop 1. Near Hawaiʻi Kai golf course

A pullout on the right-hand side of Kalanianaʻole Hwy (route 72) ~250 m after its intersection with Kealahou St.

Using an inclinometer (e.g., the iOS Compass app), measure the average slope angle (dip) of lava flows making up Makapuʻu Point. The dip of a lava flow is a function of both the general direction of flow from the source area (i.e., the vents from which the lavas erupted) and the slope of the ground over which the lavas flowed. *Are the angles you measure typical of shield volcanoes? In which direction was the eruptive vent, and what do you see when you look in that direction?*

Stop 2. Makapuʻu Lookout

Located on the right-hand side of Kalanianaʻole Hwy (route 72) ~200 m after Lighthouse Rd.

On a clear day, this vantage point affords an excellent panoramic view of the northwest-facing Ko'olau Pali (Fig. 2). The northernmost vents of the rejuvenation-stage Koko rift lie just offshore from the Makapuʻu lookout. The higher island is Mānana (also known as Rabbit Island).

It is a tuff cone produced by hydromagmatic explosions. The bench up to 45 meters wide, almost 2 meters above sea level on Mānana Island is thought to have been cut during the most recent inter-

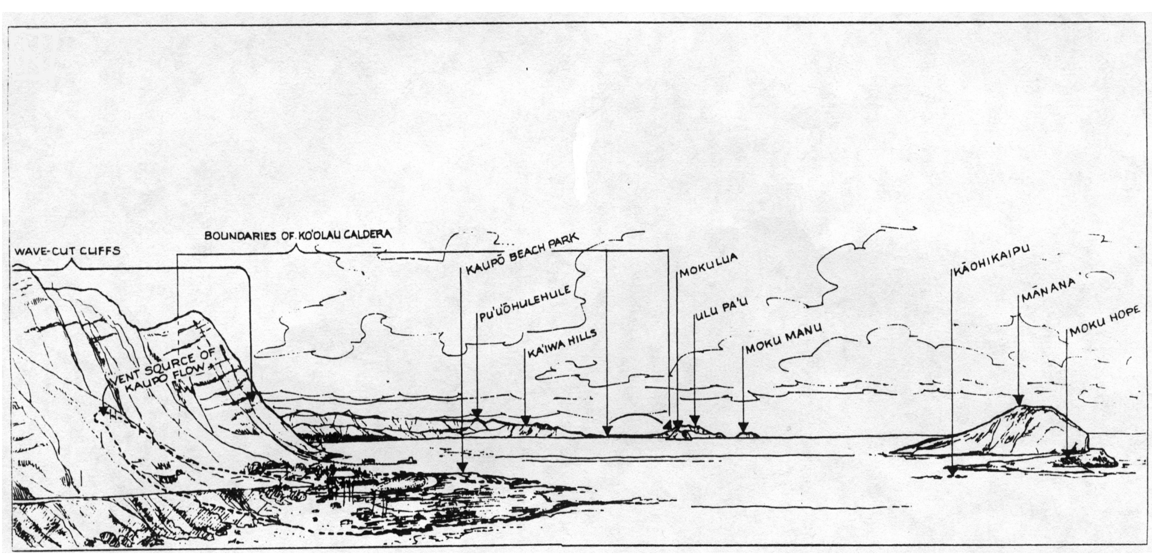


Figure 2. Kaupō, Mānana, and other Koʻolau features visible from the Makapuʻu lookout, rendered as a view plane diagram (by Lorin T. Gill).

glacial period, when sea level was higher. Between Mānana and the coastline is the low, brown cinder cone of Moku Hope, which consists of cinders and lava, indicating that it was formed from a "dry" magmatic eruption (without significant involvement of external water). *How is this possible?* Also visible from the lookout is the Kaupō lava flow, underlying Sea Life Park, one of the youngest lava flows on O'ahu. The vent for this lava is upslope, above Sea Life Park. Makapu'u lookout sits in a natural pass formed in an old stream valley that drained to the south. The rounded boulders to the right of the lookout were formed by stream action when this steam was present. The present pass resulted from the sea cutting back the cliff until it beheaded the former steam valley. The valley is now dry, because the former headwaters have been removed. These headwaters, along with the entire northern flank of the Ko'olau shield were removed in a massive debris avalanche called the Nu'uanu landslide.

Even with numbers like 23,000 (the area of the deposit in km^2) and 2.9–3.8 $x10^3$ (the volume of material transported, in km^3) it can be difficult to comprehend the scale of the Nu'uanu slide, the largest landslide in the Hawaiian islands. This event transported approximately 40% of the volume of Ko'olau volcano to the northwest in dozens of coherent blocks, several exceeding 30 km in length, over a distance of ≥100 km (Fig. 3; [1,2]). Recall that Macdonald [3] considered a landslide interpretation [4], but rejected the idea, deeming the hills guyot-shaped and unreasonably large and far-flung to have detached from the island. Geochemical evidence obtained from drill cores (ODP Hole 1223A) confirmed the landslide materials' similarity to Hawaiian tholeiitic basalts (and dissimilarity to Cretaceous seamounts), putting this debate to rest. Amazingly, many of the distal blocks traveled up the gentle inner slope of the Hawaiian Arch, suggesting the slide possessed tremendous momentum. The entire event may have occurred in a matter of hours.

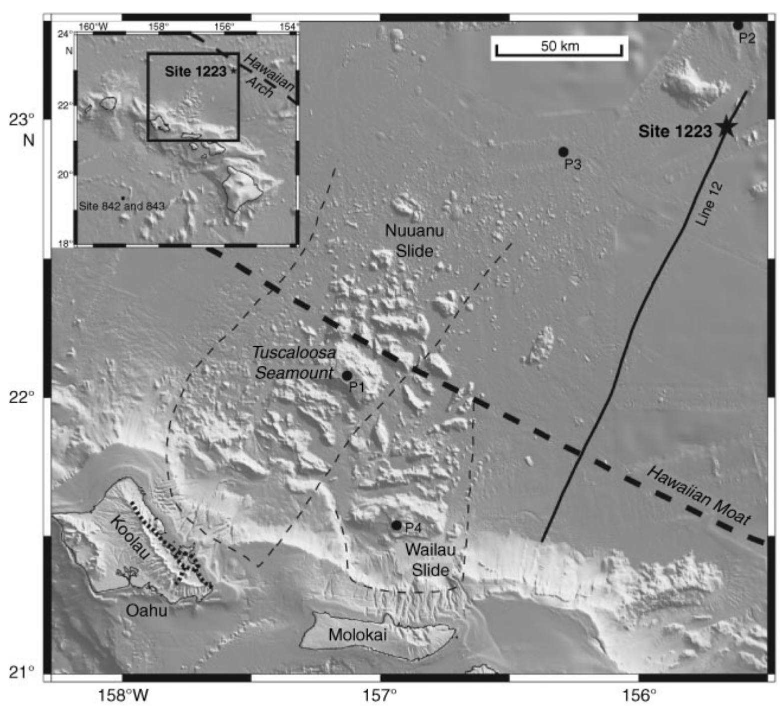


Figure 3. Avalanche debris blocks from the Nu'uanu and Wailau slides were examined by the Ocean Drilling Program in 1988 (Garcia et al., 2006)

Tsunamis generated during this landslide may have been devastating around the entire Pacific basin [5]. The timing of this catastrophic event shaping the island's northern perimeter is not well known; paleomagnetic analysis of turbidite sequences indicates 2.1-1.8 Mya ages [6]. Partial filling of the volume evacuated by the landslide by shield-stage lavas suggests the landslide occurred near the end of the shield-building stage [7].

As we walk up the ridge, look for olivine-rich lavas (oceanite) exposed a short way along the trail; small, very glassy dikes just above the lookout; across-section views of many 'a'ā and pāhoehoe flows. Note the widespread presence of highly discolored rocks (mainly greys, yellows and reddish colors) and small veins in the rocks. If these rocks were altered by steam vents or fumaroles, then this area may be close to a former rift zone axis of the Ko'olau Volcano. Some distance above the lookout is an exposure of **a filled lava tube**.

We'll discuss how this happens at the next stop, along with a related process of thermal erosion. While we have this vantage, it's a good time to think about the story of compositional variation in the Ko'olau shield. The composition of basalts making up the Ko'olau shield are stratigraphically discontinuous. The deeper sections recovered during construction of the H3 tunnel [8], samples collected from submarine flanks [9,10], and scientific drilling in the lower Kalihi Valley [7] are similar to Mauna Loa and Kilauea in major element composition, whereas the uppermost several hundred meters are somewhat exotic, having higher concentrations of SiO_2, Al_2O_3, Na_2O, Sr, La, and Zr than is typical for Hawaiian volcanoes (Fig. 4). The rocks we'll see at Makapu'u are of the latter type. You'd be hard-pressed to discern these differences in the field, although the orthopyroxene crystals typical of Ko'olau basalts is a mineralogical clue pointing to higher SiO_2. The shift in the composition of erupted magma toward the end of shield-building may reflect involvement of plagioclase-rich cumulates and sediment in the source rock as the volcano moved away from the plume [7].

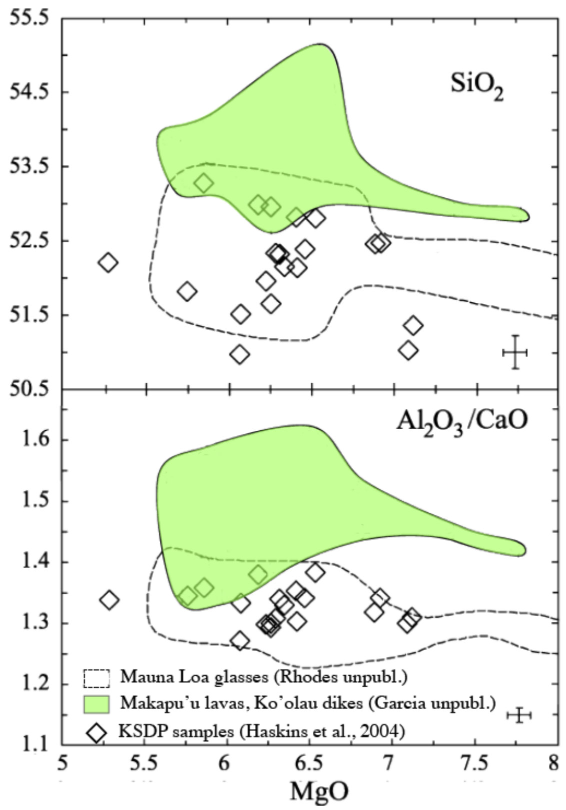


Figure 4. The compositions of Ko'olau shield lavas presently near the surface (Makapu'u lavas and feeder dikes) differ from those recovered from drilling at >250 m depth (KSDP). After Haskins et al., 2004.

If the Makapu'u Point lava accumulated at an average of 13-24 mm/y as has been suggested for shield-stage Hawaiian volcanoes [11], *what amount of time is represented by the thickness of the exposure (from sea level to the summit) at Makapu'u?*

Continue along the dashed route (Fig.1) unless otherwise advised, trying to find each of the geologic gems marked on the map. Don't lose sight of the individual or group behind you. If everyone follows this guideline, we won't get too spread out (or lost).

Stop 3. Filled lava tube at the coastline

We will spend some time at this filled tube (Fig. 5) examining it in as much detail as time affords. This tube is somewhat unusual. First, it is not at all cylindrical, being much taller than it is wide. Lava tubes form in pāhoehoe lava flows by several mechanisms. (1) At the flow front, the lava behaves much like a river delta, forming small distributary tubes that continue to branch until they consist of the same type of single flow-unit tubes (toes) that have been forming the flow the whole way downslope. Small toes filled with lava may coalesce (Fig. 6a). (2) Because pāhoehoe advances relatively slowly, the "skin" or crust that forms on a channelized flow as the lava cools is maintained as a smooth, well-insulating surface. If the surface crust thickens further, it becomes the roof of a tube (Fig. 6b and [12,13]). Either way, lava tubes are self-forming within a flow field, and like channels they develop downflow during an eruption. Lava tubes are very efficient transporters of lava from the vent to the flow front [14,15]. *What do you think about the formation mechanism for this tube? Mark this locality on your map (Fig.1) and have a close look at the outcrop. What is the elevation here? From this point measure and take note of the dips of lava flows behind Sea Life Park and also those below the lighthouse on Makapu'u Pt.*

Figure 5. Lower exposure of filled lava tube (phot by Scott Rowland).

Lava may thermally erode the ground that it flows over, whether it be a different type of rock, an old lava flow, or a previously emplaced lobe in the same eruptive episode. Factors that control whether downcutting occurs and also its rate include (a) the temperatures of the flowing lava and the floor rock; (b) the dynamics of flow—with turbulent flow being much more erosive than laminar flow; and (c) thermophysical properties of both materials: the heat capacities, softening/solidification temperatures, latent heats of crystallization, and thermal conductivities, which are sensitive to vesicularity. Kauahikaua et al., [16] observed downcutting rates near skylights of 4-10 cm d^{-1} during the Pu'u 'O'o-Kupaianaha eruption of Kilauea (Fig. 7a). A general fluid dynamical model of thermal erosion by laminar lava flows developed by Kerr [17], recovers the field observations and shows that erosion velocity decreases as $x^{-1/3}$ with distance x downstream from the vent, from a lava tube a breakout, or a lava fall (Fig. 7b).

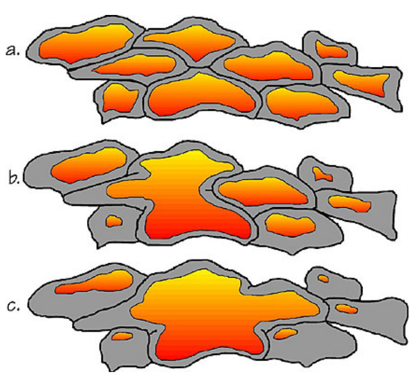


Figure 6a. Small toes filled with lava may coalesce into a master tube, as shown in this illustrated time series of a pāhoehoe field in cross section (Rowland via Volcano World).

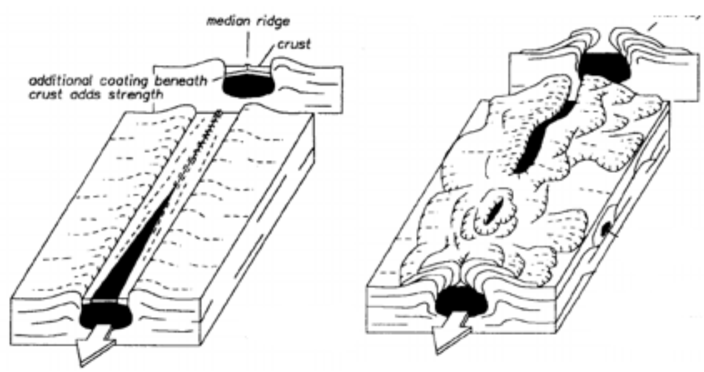


Figure 6b. In slow-moving flows (left image), a surface crust grows progressively across the channel. In turbulent flows (at right), overflow or spatter builds levees that arch over the channel and eventually roof it. Adapted from Grimes [18].

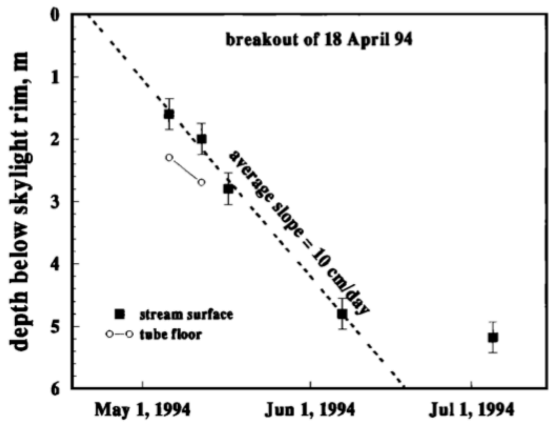


Figure 7a. Repeat measurements of channel depth below a skylight permit determination of channel erosion rate in a recent Kilauea lava flow [16].

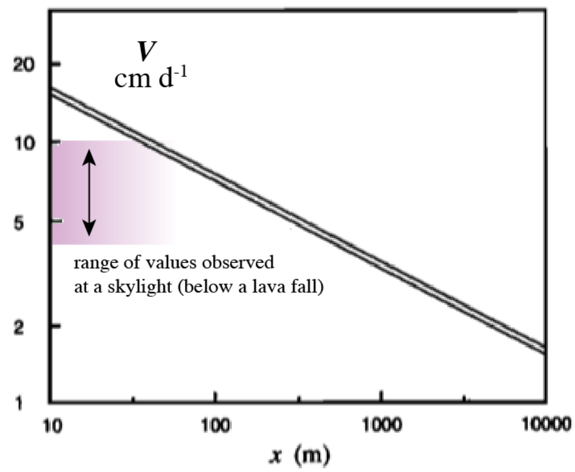


Figure 7b. Predicted melting velocity as a function of horizontal distance x from the skylight with vesicle vol. fractions 0.4 (lower line) and 0.5 (upper line). (After [17]**).**

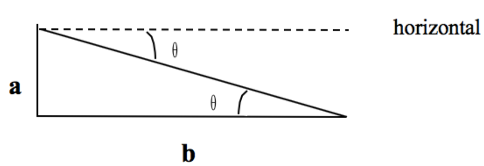
It is fairly obvious that the tube chilled from the bottom up, but how was it formed in the first place? Inspect this tube carefully, noting any evidence of thermal erosion. Can you determine the plunge of the lava tube here? Do you think that this is the same tube that outcrops near the Makapu'u overlook?

Summary Problem

Complete this in the field, if possible.

Assuming that the two filled lava tube localities are different exposures of the same tube, follow the steps below to evaluate whether the tube is coherent with the lavas.

0. What is the average dip of lava flows? (a) at Makapu'u Point: _____ (b) behind Sea Life Park: _______.
1. From the map, determine the horizontal distance between the two places where we found the tube. What is it?__________________meters.
2. What is the difference in elevation at the two places?_______________meters.
3. Determine the average plunge of the tube between these two places from the following relationship: $\tan\theta = \mathbf{a/b}$, where θ = plunge of the lava tube (in degrees), **a** = elevation difference (in meters) and **b** = horizontal distance (in meters).



4. Compare the average plunge of the tube with the average dip of the lava flows. Does this result require significant down-cutting (thermal erosion) by the lava tube through pre-existing flows? Reconcile this result with observations made at the two localities.

References Cited

[1] J.G. Moore, D.A. Clague, R.. Holcomb, P.W. Lipman, W.R. Normark, M.E. Torresan, Prodigious submarine landslides on the Hawaiian Ridge, J. Geophys. Res. 94 (1989) 17,465-17,484.

[2] K. Satake, J. Smith, K. Shinozaki, Three-Dimensional Reconstruction and Tsunami Model of the Nuuanu and Wailau Giant Landslides, Hawaii, Washingt. DC Am. Geophys. Union Geophys. Monogr. Ser. (2002) 333–346.

[3] G. Macdonald, Volcanoes in the Sea, 1st ed., Univ. Hawaii Press, Honolulu, 1970.

[4] J.G. Moore, Giant submarine landslides on the Hawaiian Ridge, U.S. Geol. Surv. Prof. Pap. (1964) 95–98.

[5] G.W. Moore, J.G. Moore, Large scale bedforms in boulder gravel produced by giant waves in Hawaii, Sedimentol. Consequences Convuls. Geol. Events. Spec. Pap. GSA. 229 (1988) 101–109.

[6] E. Herrero-Bervera, E. Cañón-Tapia, G. P.L. Walker, J.C. Guerrero-Garca, The Nuuanu and Wailau giant landslides: Insights from paleomagnetic and anisotropy of magnetic susceptibility (AMS) studies, Phys. Earth Planet. Inter. 129 (2002).

[7] E.H. Haskins, M.O. Garcia, Scientific drilling reveals geochemical heterogeneity within the Ko'olau shield, Hawai'i, Contrib. to Mineral. Petrol. 147 (2004) 162–188. doi:10.1007/s00410-003-0546-y.

[8] M. Jackson, F.A. Frey, M.O. Garcia, Geology and geochemistry of basaltic lava flows and dikes from the Trans-Koolau tunnel, Oahu, Hawaii, Bull. Volcanol. 60 (1999) 381–401. doi:doi.org/10.1007/s004450050239.

[9] R. Tanaka, E. Nakamura, E. Takahashi, Geochemical Evolution of Koolau Volcano, Hawaii, Washingt. DC Am. Geophys. Union Geophys. Monogr. Ser. 128 (2002) 311–332.

[10] K. Shinozaki, Z.-Y. Ren, E. Takahashi, Geochemical and Petrological Characteristics of Nuuanu and Wailau Landslide Blocks, Washingt. DC Am. Geophys. Union Geophys. Monogr. Ser. (2002) 297–310.

[11] D. Depaolo, E. M. Stolper, Models of Hawaiian volcano growth and plume structure: Implications of results from the Hawaii Scientific Drilling Project, J. Geophys. Res. 101 (1996) 11643–11654.

[12] R. Greeley, Observations of actively forming lava tubes and associated structures, Hawaii, Mod. Geol. 2 (1971) 207–223.

[13] D.W. Peterson, D.A. Swanson, Observed formation of lava tubes, Stud. Speleol. (1974) 209–222.

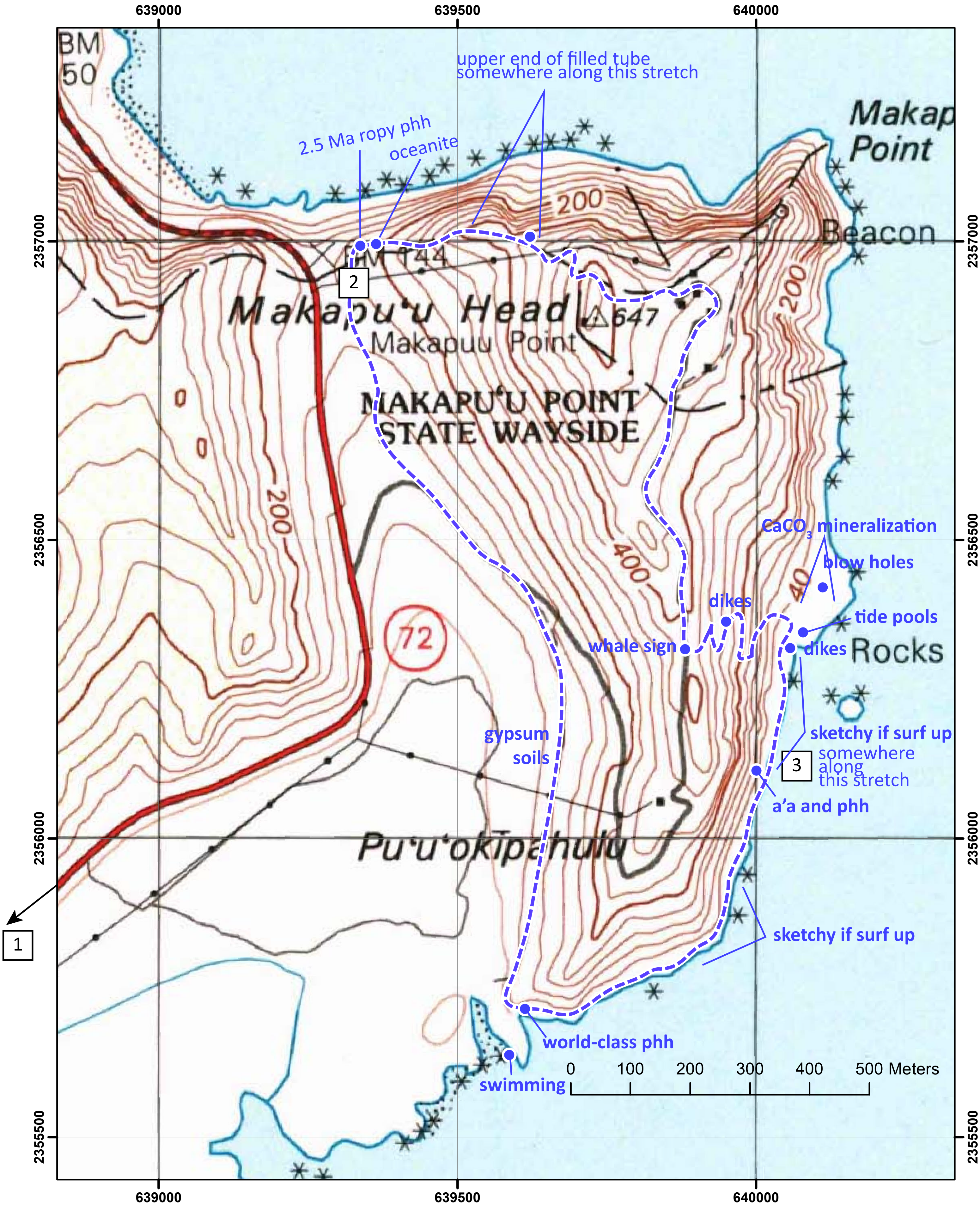
[14] A. M. Ho, K. Cashman, Temperature constraints on the Ginkgo Flow of the Columbia River Basalt Group, Geology. 25 (1997).

[15] L. Keszthelyi, A preliminary thermal budget for lava tubes on the Earth and planets, J. Geophys. Res. 100 (1995) 411–420.

[16] J. Kauahikaua, K. V. Cashman, T.N. Mattox, C.C. Heliker, K.A. Hon, M.T. Mangan, C.R. Thornber, Observations on basaltic lava streams in tubes from Kilauea Volcano, island of Hawai'i, J. Geophys. Res. Solid Earth. 103 (1998) 27303–27323. doi:10.1029/97JB03576.

[17] R.C. Kerr, Thermal erosion by laminar lava flows, J. Geophys. Res. B Solid Earth. 106 (2001) 453–465. doi:10.1029/2001JB000227.

[18] K. Grimes, Lava caves and channels at Mount Eccles, Victoria, (1995).


639000
639500
640000
2357000
2356500
2356000
2355500
BM 50
upper end of filled tube
somewhere along this stretch
2.5 Ma ropy phh
oceanite
Makapu'u Point
Beacon
200
BM 144
2
Makapu'u Head
647
Makapuu Point
MAKAPU'U POINT
STATE WAYSIDE
400
CaCO$_3$ mineralization
blow holes
dikes
tide pools
whale sign
dikes
Rocks
72
gypsum
soils
sketchy if surf up
somewhere
along
this stretch
3
a'a and phh
Pu'u'okipahulu
1
sketchy if surf up
world-class phh
swimming
0
100
200
300
400
500 Meters