Geological Engineering Contributions to the Retrieval of Cultural Artifacts from Lava Tube Caves In Hawaii

Edmund Medley, PhD, PE, CEG, F.ASCE, Senior Consultant, and Julien Waeber, Senior Staff Engineer; Geosyntec Consultants, Oakland, California

Introduction

This Case History describes the Geological Engineering contributions to the retrieval of rare Hawaiian cultural artifacts that were sealed into lava tube caves in 2000. The project is an example of the application of basic geological principles to the resolution of a controversial litigation. This project is amongst the most unusual in the senior writer's experience.

•1905: Judge David Forbes explored a series of ancient lava tubes used by Native Hawaiians as burial caves and discovered the artifacts, which became the Forbes Collection of the Bishop Museum in Honolulu.

•2000: During deliberations under the 1990's Native American Graves Protection and Repatriation Act (NAGPRA), the collection was lent to Hui Malama, a native Hawaiian group specializing in the reburial of Hawaiian remains. The collection then disappeared.

•2005: Hui Malama and the Bishop Museum were sued in Federal Court by native Hawaiian Groups seeking the return of the collection.

•2005-2006: Hui Malama revealed that the collection had been reburied and sealed within the Forbes Cave and nearby Mummy Cave. They claimed the "geologically fragile" caves would "implode" if any attempt were made to breach the constructed grouted rock barrier seals and recover the artifacts.

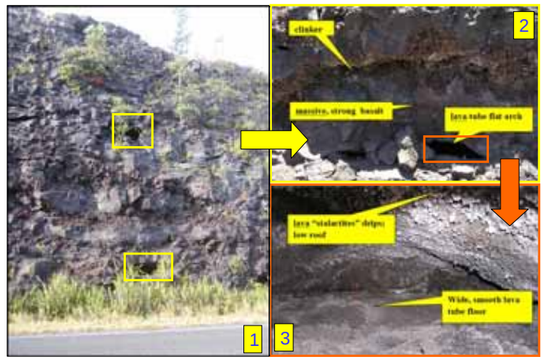
•2006: Geosyntec was retained by the Court to advise on the geological engineering ramifications of retrieving the artifacts, such as the potential for cave collapse. Geosyntec's role subsequently expanded when we accepted the challenge of safely breaching the barriers and leading efforts to retrieve the Forbes Collection.

Hawaiian Lavas and Lava Tube Morphology

There are two main types of Hawaiian lavas: ***pahoe'hoe*** and ***a'a***. Figure 1 is a road cut within a stack of pahoe'hoe lava flows and inclusions of friable basalt clinker (rubble) which forms at the surfaces of the massive lava cores. Clinker is more characteristic of a'a flows. *Lava tubes* are common in pahoe'hoe flows.

Typical characteristics of lava tubes (orange box in Figure 2) include a flat arched roof with lava "stalactite" drips, wide and smooth floors, and wall "ledges", which are relicts of former lava levels (Figure 2 and Figure 3).

If original lava tube relicts such as drips and ledges are observed, then the lava tube has been stable for as long as the tube has existed: in the case of the lava tubes discussed here, the lava was about 1 to 2 million years old. During the project this geological premise was the basis for our confidence regarding short-term stability of the caves' roofs and walls.

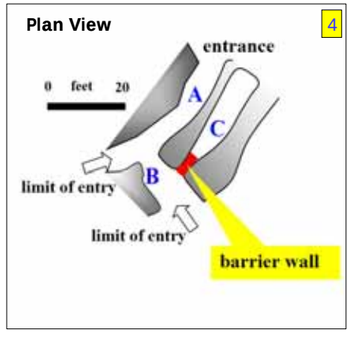


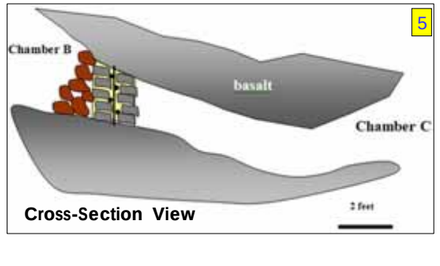
FORBES CAVE: Accessing Chamber C

The only information available to us on Forbes Cave, was previous archeological data presented in a confidential report and Hui Malama's testimony and declarations.

Figure 4 is a sketch map indicating the area where work was performed in Forbes Cave. Based on testimony, the artifacts had been reburied in Chamber C, and a 2 ft. thick grouted rock and rebar wall had been built in the 3 ft wide and 2ft. tall passage way between Chamber B and Chamber C. Figure 5 illustrates the assumed geometry of the barrier based on the information provided.

To test equipment and procedures, prior to mobilizing to Hawaii, a grouted rock and rebar wall was built at a Bay Area site with a geometry similar to that assumed at Forbes Cave. The trial wall was then demolished using stonemason tools and low-vibration electrical hand tools.





The project Health and Safety Plan required proper Personal Protective Equipment which included Level B Personal Protective Equipment, P-100 half-mask respirator, rope harness, and head lamp (Figure 6). The caves were narrow and cramped (Figure 7) and Confined Space Entry training and certification was required.

Characteristic and intact lava tube traits were observed in the caves as well as few signs of roof collapse.

The project was completed using low-vibration hand tools to reduce the risk of dislodging roof falls in the caves (Figure 8). Dexpan™, a non-explosive demolition agent was also used to help break up the wall. Dexpan™, a fine cementitious powder, was mixed with water into a slurry, poured into holes drilled into the grouted rock wall barrier, and left overnight to induce cracking.

Figure 8: Low arched roof with little collapse.

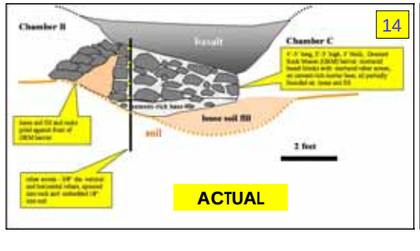
Figure 9: Low arched roof, with intact lava drips (circled) and prominent, overhanging lava ledges (arrowed).

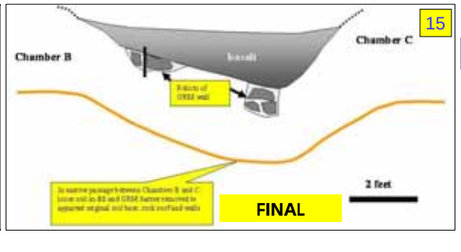
Images 11, 13 and 20 are 3D stereo photos. Red/Cyan stereo glasses are required to see 3D.

To monitor movement cave rock, informal wooden pegs or "tattle tales" were set upright within open joints. Pegs would have fallen if disturbed by rock mass movement (Figure 10), but none fell.

Based on the Hui Malama testimony, two days were estimated for demolition of the grouted rock and rebar barrier. However, <u>five</u> days of difficult and slow work was actually required. The highly resistant grouted rock barrier proved to be much thicker than testified by Hui Malama. The confined space also hampered progress (Figure 11). Dexpan™ aided breaching by cracking the very strong rock and mortar. Figure 12 shows typical cracks at yellow pencil.

After more than 4 days of work, a majority of the wall had been removed and Chamber C opened for safe retrieval of the artifacts. (Figure 13). Figure 14 and Figure 15 are sketches of the approximate barrier geometry and what was left after work completed. Relics of the wall were unavoidably and regrettably left in place to avoid further disturbance of the rock mass. The artifacts were discovered within a man-made stack of rocks. Following retrieval, the artifacts were returned to the Bishop Museum and the entrance to Forbes' Cave resealed.

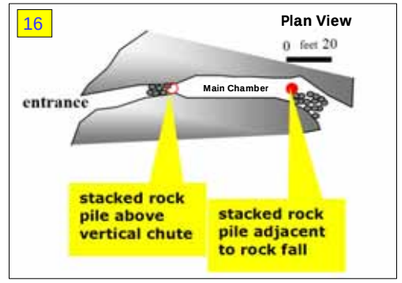




MUMMY CAVE: Access

After successfully completing the Forbes' Cave project, Geosyntec agreed to access Mummy Cave to recover the remainder of the Forbes Collection. Our work required appropriate sensitivity since the Mummy Cave contains human remains and is of unique cultural significance, Accordingly, Hawaiian cultural specialists native with considerable experience in working in burial caves, monitored our work and provided cultural counsel.

No testimony and little information was available with regards to Mummy Cave. Figure 16, a sketch map based on a confidential archeological map, indicates the area where work was performed. In contrast to the Forbes Cave, the entrance chamber to Mummy Cave showed significant roof collapse and large boulders of rock fall on the cave floor (Figure 17 and Figure 18). The red circle in Figure 18 shows traces of a relatively fresh rock fall

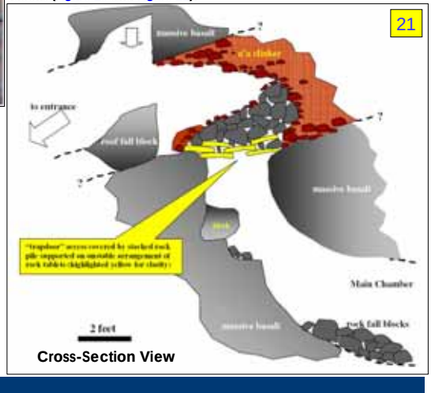


The rear of the Entrance Chamber ended at an apparent rock fall of blocks of massive basalt, as illustrated in Figure 18 (yellow arrow) and Figure 19. Figure 19 also shows a'a clinker at the cave roof above the rock fall. However, there were very few a'a clinker blocks evident in the pile; those present were scattered on the surface. The basalt blocks in the pile were of a variety of colors and textures, quite different from each other and from the roof rock of a'a clinker. Clearly, the "rock fall" was a pile of hand-stacked rocks. In removing the rock pile, a sub-vertical passageway into the cave's Main Chamber was uncovered. The rock pile had been constructed as a "trap door" using slabs of basalt precariously balanced over the opening, and then covered with loose blocks (Figure 20 and Figure 21).

Much as in Forbes' Cave, the Main Chamber of Mummy Cave exhibited typical lava tube characteristics with few roof collapses. The roof and side walls appeared stable. However, progress into the Main Chamber was interrupted by a large roof fall and a human torso blocking the sole access past the rock fall.

A small rock pile was discovered beside the large pile of roof-fall rocks. The rocks (red dot in Figure 16) were of a variety of basalts, located beneath a pristine lava tube roof with lava drip stalactites. Lack of evidence for any roof-fall above indicated that the small pile was a man-made stack. The artifacts were discovered buried within the stack. The artifacts were retrieved, the rock pile was reconstructed, Hawaiian prayers offered and the Mummy Cave was sealed.

In January 2007, NAGPRA negotiations resumed between Hawaiians to decide the disposition of the Forbes Collection.



Conclusions

• Basic Geological Engineering observations of lava tube morphology and rock falls supported our confidence in the rock mass stability of the working areas of the lava tube caves, and allowed discrimination of natural rock falls from man-made stacked rock piles.

•The project took longer and was more arduous than anticipated but resulted in successful retrieval of the artifacts, resolution of the lawsuit, and resumption of the NAGPRA proceedings.

Geosyntec consultants