HISTORY AND STATUS OF THE MOILIILI KARST, HAWAII

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The Moiliili Karst occurs in Pleistocene reef limestone located in a populous, low-elevation area of Honolulu, Hawaii. A 1934 construction excavation intersected a previously unknown karstic master conduit at a depth of -7 m msl. Temporary dewatering of over 3.7 x10⁹ L caused considerable economic loss due to collapses and subsidences in a wedge-shaped area about 1 km on each side. These outline a previously unrecognized dendritic karst drainage. Considerable retrograde flow of salt water also occurred. Subsequent urbanization again lowered the water table and dewatering phenomena are still occurring. A section of Moiliili Water Cave is the only clearly karstic feature that remains available for study. It serves as a floodwater conduit. Surprisingly, its water quality has improved since 1983. Its protection should be a prototype for other Hawaiian karsts and pseudokarsts. Other sections of Honolulu also are underlain by reef limestone and may be at risk.

Located downslope from volcanics of Oahu's Manoa Valley in a densely populated section of Honolulu, the Moiliili Karst is the most important of several recently delineated in Hawaii (Halliday 1994, 1997). At an elevation of 2 to 5 m msl, it consists of a wedge-shaped area about 1 km on each side, with the narrow downslope (southern) angle near the intersection of University Avenue and Kapiolani Boulevard (Fig. 1). Prior to recent bibliographic studies, it was not recognized as karst. First published reference to its karstic nature apparently was in 1994 (Halliday 1994). It now is clear that a dendritic karstic drainage system (Fig. 1) extends from ill-defined swallets near the volcanic/limestone contact to the coast. Localized subsidences and conduit passages in the mapped area sharply differentiate it from adjacent sections of the lowland coastal plain, also underlain by reef limestone, and outline a specific underground drainage basin.

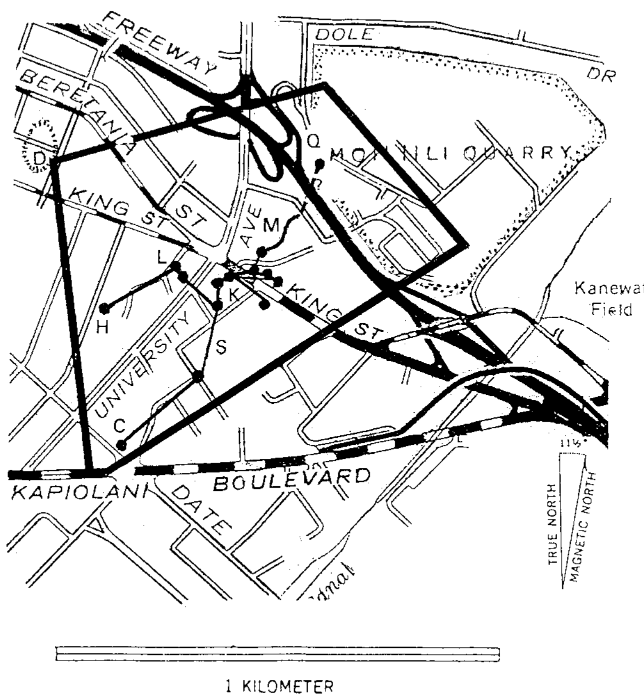

Figure 1. Re-creation of conduit drainage of Moiliili Karst, showing the wedge-shaped area in which karst features have been found. Base map from U.S. Geological Survey Honolulu Quadrangle (1983). C. Site of catastrophic 1934 excavation into master conduit below sea level, with upslope dewatering. Conduit continues seaward, presumably west or southwest. D. Shallow closed depression mentioned in text; possibly artificial. H. Hausten (Kumulae) Spring and fish pond at Willows Restaurant. K. South King Street complex of cave passages, collapses, and subsidences. L. Kuilei Lane complex of subsidence, caverns demonstrated by geophysical studies, and cave passage shown on 1935 Board of Water Supply map. M. Moiliili Water Cave. Q. University of Hawaii Quarry Cave. S. Area of maximum subsidence in 1934.

RELATION TO URBAN FEATURES

The wide upslope section of this karst is centered around the intersection of University Avenue and South King Street, downslope from the University Avenue interchange of "Interstate" Highway H-1 (Fig. 1). On the upslope side of the 6-lane freeway, it underlies the lower part of the main University of Hawaii campus. Downslope from the freeway, it underlies the Moiliili business and residential district serving the university. Because of its critical location, its economic importance far transcends its small size.

Especially in its upslope section, karstic dissolution caverns, resurgences, and spring-fed ponds have been known from early times. Although Moiliili Water Cave now is truncated by construction fill and is enterable only through a manhole or sewer grate, a boating expedition was photographed in 1897 (Williams 1935) in what probably was part of it. Urbanization has destroyed most surface karstic features. A large pond fed by a karstic spring was located upslope of Beretania Street west of what now is University Avenue. This street extends north on the bed of another (Williams 1935). The former Hausten (Kumulae) Pond farther downslope (discussed below in detail) was another famous feature. Until recently, the perched water tables causing these ponds were interpreted as nonkarstic, due to the reef limestone serving as a confining layer barring seaward escape of artesian water from upslope Manoa volcanics (Wentworth 1953).

The residential part of this district includes an apartment section and a larger, heavily populated area of small homes. Some of these houses may still rely on septic tanks or cesspools. The section south of South King Street was long famous for “cesspools that were notable for never plugging or overflowing” (Lao n.d.). Even limited observation in 1934 immediately revealed raw sewage entering the main karstic water table stream (Kunesh 1934).

STRATIGRAPHY AND SPELEOGENESIS

As in much of southern Oahu, the karstifiable bedrock is reef limestone of the Pleistocene Sangamon Interglacial Stage, deposited during a sea level stand 8 m above modern sea level (Stearns 1939). The type locality is at Waimanalo, near the

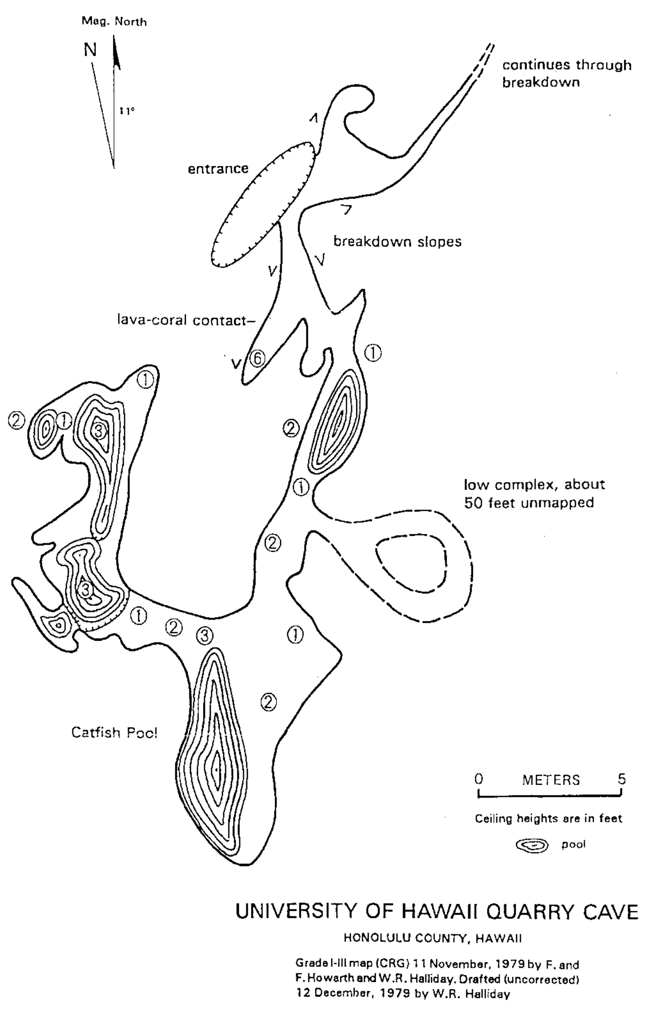

Figure 2. Map of University of Hawaii Quarry Cave.

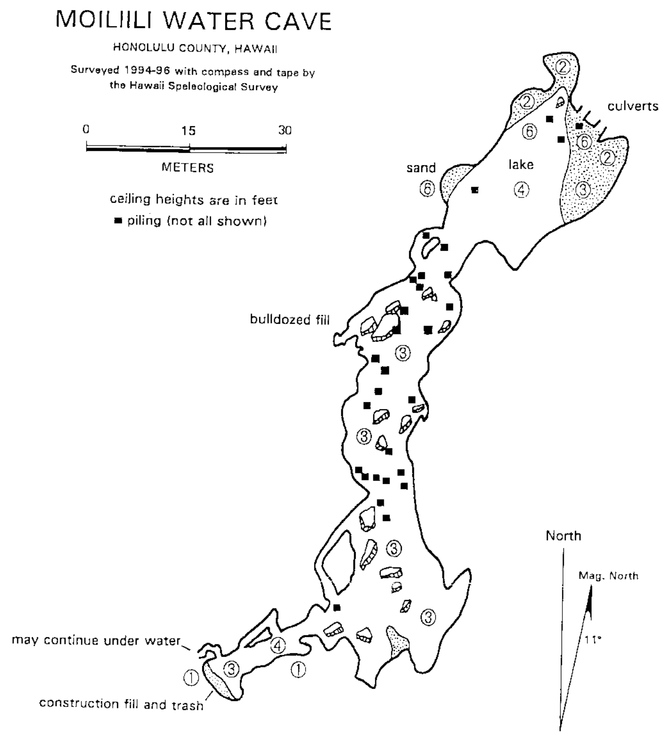

Figure 3. Map of Moiliili Water Cave.

south end of Oahu’s eastern coast (Stearns & Vaksvik 1935). In the Moiliili Karst, the little that is visible today (i.e, in the walls of Moiliili Water Cave) is well cemented and massive. This is not typical of the Waimanalo formation as a whole, and may not be representative of the Moiliili Karst in general.

Atop some of the upslope part of the limestone, Sugarloaf lava (66-68 Ka) cooled in thicknesses of up to 12 m just below Dole Drive at what now is the University of Hawaii parking garage. It tapered rapidly downslope; one edge is just upslope from Highway H-1 at the site of the former entrance of University of Hawaii Quarry Cave which is partially roofed by the lava (Fig. 2). An eastern finger of this lava more than 300 m wide extended seaward across South King Street and Kapiolani Boulevard just east of the karst. Eventually it dipped into an existing channel where it is overlain by reef limestone. This lava diverted the lower part of Manoa Stream from its original course. Lao (n.d.) suggested that the cave system represents the old channel of that stream. Based on the morphology of Moiliili Water Cave (Fig. 3), another possibility is that it formed in the shallow phreatic zone beneath that stream where flow velocity and, hence, dissolution would be expected to be greatest. Two older lava flows also are interbedded with reef limestone at greater depth (Lao n.d.) but appear unrelated to karstification.

After cooling of the Sugarloaf lava, alluvium and marshy lagoon sediments accumulated atop much of the limestone. These were especially thick downslope from any manifestation of the karst, in an area behind a beach berm which developed at Waikiki. Here, the Ala Wai Canal now exposes reef limestone at low tide, but its excavation did not intersect the karst's master conduit and the canal has little or no effect on its water table. Accumulations of similar sediments overlie the limestone farther west. The best-known geological map of the island (Stearns 1939) shows these sediments in most of the coastal strip between Diamond Head and Pearl Harbor, rather than the underlying karstifiable reef limestone.

In the Moiliili Karst, most of the limestone was covered with soil. Its thickness was described as a few inches (Honolulu Board Of Water Supply 1933-34). Between Kapiolani Boulevard and South King Street adjacent to the lower part of the principal conduit, some bare limestone was exposed. Its karstic features evidently were obscure to absent, and none were recognized.

BASIC HYDROGEOLOGY OF THE HONOLULU LOWLAND COASTAL STRIP

The Moiliili Karst is immediately west of Manoa Stream and its channelization, the Manoa-Palolo Drainage Canal. The gully of this stream and/or an adjacent lava flow is the eastern boundary of the study area. On the opposite side of this stream gully, the name of Kanewai Field perpetuates the memory of a long-filled karstic pond; the easternmost of several perched water table ponds between Diamond Head and Punchbowl Crater. Westward toward and beyond the latter, buried or surficial reef limestone extends many kilometers, to and beyond Pearl Harbor, where Ford Island is entirely calcareous (Stearns 1939). Romantic journalism (e.g., Williams 1935) refers to "miles and miles" of caves here. Although considerable artesian water has been obtained by drilling, a few long drained ponds are the only karstic features known to have existed between the Moiliili Karst and Pearl Harbor. No clearcut surface drainage exists here, and the gully of the next perennial stream (Nuuanu Stream) is more than 5 km west of Moiliili, on the opposite side of the downtown business district. Several upland streams sink into alluvium in this area. Minimal traces of karstic ponds are the only residual of karstic features originally present. Urbanization is so extensive that it is not even certain that the shallow closed depression at the northwest corner of the area mapped as the Moiliili Karst (Fig. 1) is a natural feature.

KARSTIC FEATURES KNOWN IN MOILIILI PRIOR TO 1934

The Sugarloaf lava was quarried extensively, exposing some underlying limestone. Evidently in the early or mid-1920s, a cavern about 8 m wide and up to 5 m high was found in limestone originally overlain by lava, at 2 m msl (Stearns & Vaksvik 1935). Apparently this was a short distance east of University of Hawaii Quarry Cave, whose entrance opened spontaneously in 1978 or 1979 beneath an office building (although fish and invertebrates were observed, authorities soon filled the entrance). The earlier quarry cave is not known today, and may have been filled or destroyed in University development of the quarry floor. In the first decade of the century, another dissolution cave (not mentioned by Stearns) was entered upslope from South King Street. It is not clear whether this was part of Moiliili Water Cave, or another, now lost. In 1928, still another cave containing a large flow of water was intersected by sewer construction a short distance farther east. Its stream elevation was about 1 meter (Williams 1935; Stearns & Vaksvik 1935). Two pumps yielding 1.5 x 10^{10} L per day did not appreciably lower its water level, and special beams had to be installed to support sewer lines (Chester Wentworth, quoted in Williams 1935).

The best-known of the perched water-table ponds was Hausten (Kumulae) Pond, at what became the Willows Restaurant, about 0.3 km southwest of the King-University intersection. Mr. Hausten purchased and cleared the land in the early 1920s, and stocked the pond with koi which interbred with existing fish. This produced a large school of colorful fish which came on signal to be fed. The large clear fishpond quickly became a noted attraction.

THE 1934 DEWATERING

In the autumn of 1934 the karst and its drainage were altered profoundly. Five hundred meters downslope from the King-University intersection, construction activities struck a karstic master conduit -7 m msl. The excavation was 18 m^2 and ~8 m deep (Lao n.d.). A "gushing flow" quickly filled it. A telephone pole lowered into the hole found a bottom at -10 m msl (Kunesh 1934). The flow was not recognized as karstic, and was attributed to "a lamina of shallow secondary artesian water" (Honolulu Board of Water Supply 1933-34). For more than four months, an average of 3.8 x 10^7 L was pumped daily before the hole could be sealed and construction resumed: a total of more than 3.8 x 10^9 L.

Upslope, the results of this dewatering were dramatic. The Hausten pond disappeared without warning, draining in less than 24 hours. What was described as "a huge outlet" appeared in its bottom, -2 m msl (Kunesh 1934; Wentworth 1953). Some of the famous fish were stranded. Others disappeared into the conduit system. New sinkholes developed. "People living in the vicinity made their way into the caves through holes in their yards and speared fish by the hundreds" (Williams 1935). Several houses "lurched" and settled. Sidewalks cracked and water and gas mains ruptured. Some trees sank almost 1 m (Kunesh 1934; Lao n.d). No accurate determination of the total economic loss is known, but it must have been considerable.

THE KING STREET COMPLEX

Aside from the Hausten Pond area, the most serious effects were southeast of the King-University intersection. "Huge caverns were exposed to view", seemingly continuous from the conduit rupture to a point above South King Street—a distance of 0.5 km (Honolulu Board of Water Supply 1933-34). About

30 m downslope from the King-University intersection, "a room-sized cavern" suddenly appeared, 3 m below the surface. Some of the restaurant's missing koi were seen, and a hip-booted party found a passage extending 30 m downslope to another entrance. Still another passage extended east under South King Street to the 1928 cavern (Fig. 1).

In both upslope branches, water flow was toward the King-University intersection, thence down-slope along what became the southward extension of University Avenue. Direction of ordinary flow of the Hausten Spring branch is less clear. During the dewatering it flowed toward the University Avenue conduit. This may have been a reversal of its normal flow, which was unrecorded. A 1935 map shows another branch or a separate cave beginning beneath Kuilei Lane (between Hausten Pond and the King-University intersection) and crossing beneath the planned southward extension of University Avenue. The latter was rerouted, but its construction probably unroofed and filled part of the master conduit (Wolfe 1975).

In addition to this catastrophic dewatering, some retrograde flow came from the ocean. Ultimately the pumped water contained about 25% of the chloride content of the ocean (6500 ppm) (Kunesh 1934; Lao n.d.).

POST-1934 DEWATERING AND SUBSIDENCES

With resealing of the master conduit, the karst's water table temporarily recharged, but the karst never was the same again. Lao has admirably documented its later hydrological history, and much of its human side (Lao n.d.). Various sewer projects and other urbanization caused sequential lowering of the water table from 1935 to about 1955, and again in the late 1980s. Several relatively small "cave-ins" are well documented near the King-University intersection. One was in line with the lower end of Moiliili Water Cave. Economic loss was comparatively small, but on at least one occasion, a parked car had to be hauled out of a brand-new sinkhole. In 1991, the roof of a King Street cavern was deliberately breached in at least four places, with fill dumped in.

The continuing drop in the water table especially impacted the Willows Restaurant. The willow trees wilted and the remnant of the pond had to be lined with concrete. The restaurant lost its attractiveness and its customers. Today the property is tightly fenced and inaccessible.

Much of the basalt quarry was converted into athletic and other university facilities. Sewers were installed belatedly; for a time, the university gymnasium utilized septic tanks that evidently drained to Moiliili Water Cave. In 1983, the cave's water was warm, and soap scum was present (Lao n.d.).

SPELEOLOGICAL INVESTIGATIONS

In 1975, detailed gravity microsurvey revealed two water-filled caverns beneath Kuilei Lane, apparently unaffected by the dewatering. Apparently they are independent of the cave shown in this location in 1935. The larger of these is 9-11 m wide and up to 3.5 m high (Wolfe 1975).

The Hawaii Speleological Survey began investigations of Moiliili Water Cave in 1994. On all occasions, the water was cool, and clear until soiled by cavers feet. Despite further "cave-ins" as recently as 1997, it survives as a beautiful little cave currently 110 m long (Fig. 2). The limestone walls are relatively homogeneous and firm. It has the form of a karstic conduit with a little spongework and some protuberant corals. No cesspool nor petroleum odors have been found, nor any soap scum. Conditions have improved markedly since 1983. Floatable trash is stuck to its roof, indicating intermittent filling with flood waters. Construction fill is present in two areas, and numerous metal pilings extend downward through the cave from apartment buildings not far overhead. Nevertheless, it has returned to a state of beauty (Fig. 4 & 5). Due to installation of modern sewer lines, its bacterial count now is probably far less than during past ventures here and elsewhere beneath Moiliili, and fish are present.

IMPLICATIONS: PUBLIC HEALTH, PUBLIC SAFETY, AND ENVIRONMENT

With raw sewage dumped into the karstic reservoir, part of Moiliili's freedom from cholera and other water-borne epidemics must be partly attributed to pure luck. In comparison to parts of Honolulu underlain by volcanics, those underlain by limestone need much greater efforts to exclude sewage and the increasing burden of toxic and hazardous wastes.

Although theroretically feasible, artificial recharge of the Moiliili perched water table is not politically viable. Lacking such recharge, further subsidences and collapses are likely in Moiliili, although not at the 1934 scale. Elsewhere in the Honolulu coastal strip, such phenomena are not known to have been a significant problem. One costly 1989 subsidence in Waikiki, however, is on record (Lao n.d.) and in the present litigious era, future excavations in the reef limestone should be conducted in strict conformance with karstic engineering prin-

Figure 4. Solutional features, Moiliili Water Cave. Nearby water depth is 2 meters, so helmets are not worn.

Figure 5. Metal piling in main passage, Moiliili Water Cave.

ciples. The area downslope from the swallets of upland streams between Moilliili and Punchbowl Crater is at especially high risk of breaching unknown karstic conduits like the one intersected in Moiliili. Similar precautions are needed in some coastal areas elsewhere in Hawaii.

Environmentally, destruction and pollution in the Moiliili Karst speak eloquently for themselves. They especially reveal a need for a high level of public awareness and concern. The fortuitous improvement of water quality in Moiliili Water Cave is convincing evidence that even fragmented urban karsts need not be abandoned to whatever fate may bring. For their human values and as natural laboratories for a largely unstudied groundwater zone, its caves should be cherished and protected in every possible way. Protection of this resource should lead the way in popularizing the need for similar protection in other neglected karst and pseudokarst throughout Hawaii.

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