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Hawai'i Play Fairway: Phase 3 Results

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ABSTRACT

Phase 3 of the Hawai'i Play Fairway Project includes plans to i) conduct noble gas groundwater sampling in targeted locations across the state, and ii) deepen an existing water well on Lāna'i Island. This work builds on two earlier project phases that provided an updated statewide geothermal resource assessment via a newly established methodology to integrate multiple datasets into a resource probability calculation, or map. The deepening of this well is intended to validate our earlier work, while the groundwater sampling and analysis will improve confidence in our resource probability calculation and guide further exploration. Phase 3 work is in progress as of this writing, but is expected to be concluded by the end of March 2020. To date, we have deepened Well 10 on Lāna'i from 1400 to 3467 feet (~427 m to ~1057 m), with a measured downhole temperature of 66°C (151°F). This presentation will detail the results of Phase 3, which are obtained up to now.

1. INTRODUCTION

The primary goal of Hawai'i Play Fairway Assessment (PFA) Phase 3 is to validate the play fairway methodology established in the earlier two phases through drilling a test hole in a region the former phases found to be of high probability and confidence. A summary of the first two phases of the Hawai'i PFA is provided in Lautze et al. (concurrent conference paper; in review Geothermics).

Four locations in the state were investigated intensively enough in prior phases to be considered for drilling in Phase 3. These are: the north, east, and south flanks of Mauna Kea volcano (Hawai'i Island); Haleakalā Volcano's SW rift zone (Maui); and Lāna'i's summit caldera and rift zones. Of these four, the SE flank of Mauna Kea and Lāna'i were ranked top choices. Ultimately, focus centered on Lāna'i over Mauna Kea partly due to funding constraints and partly because Lāna'i's land management agency offered the project two reasonably-well located, >1000 foot (~305 m) deep wells to be deepened. A key positive about drilling on Lāna'i would be its high level project impact: this would be the first deep drill project off of Hawai'i Island such that project results, whether positive or negative, would have broad implications for Hawai'i's future statewide geothermal development strategy.

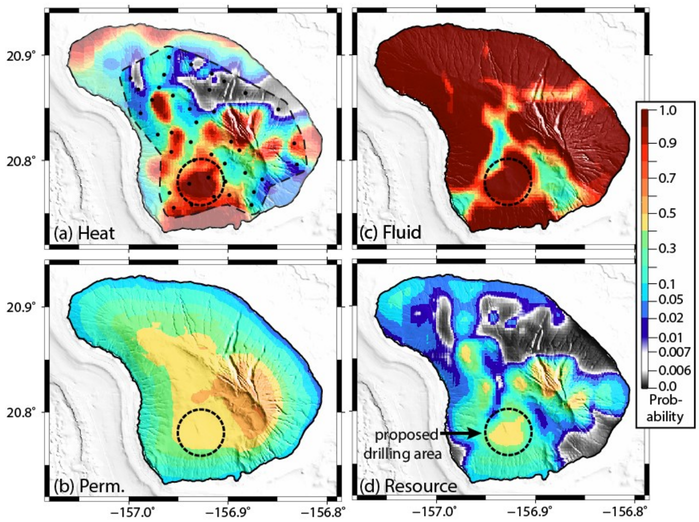

Figure 1: Local probabilities for Lāna'i of (a) heat, (b) permeability, (c) fluid, and (d) a geothermal resource. The reliable area for the MT results is contained within the footprint (outlined by dashed lines) of the MT stations (dots), both due to data coverage as well as the likelihood that salt water is highly conductive probably intrudes the crust near the shorelines. See Figure 5 for geographic and geologic structural details of the Pālāwai Basin.

2. BACKGROUND: PHASE 2 WORK ON LĀNA'I

In Phase 2 of the PFA on Lanai we conducted an island-wide geophysical survey (magnetotellurics and gravity) and analyzed groundwater from Lanai's water wells. These data were incorporated into a calculation of the combined probabilities for heat (Figure 1a), fluid (Figure 1b), and permeability (Figure 1c), which indicate several locations on Lāna'i that could host a resource between 2 and 3 km (Figure 1d). The area of greatest interest is within the Pālāwai Basin, a feature defined by the Lāna'i volcano caldera where our Phase 2 work shows that a high gravity signature and reduced resistivities at depth are co-located. Groundwater temperature elevations that are statistically notable are also located near this area.

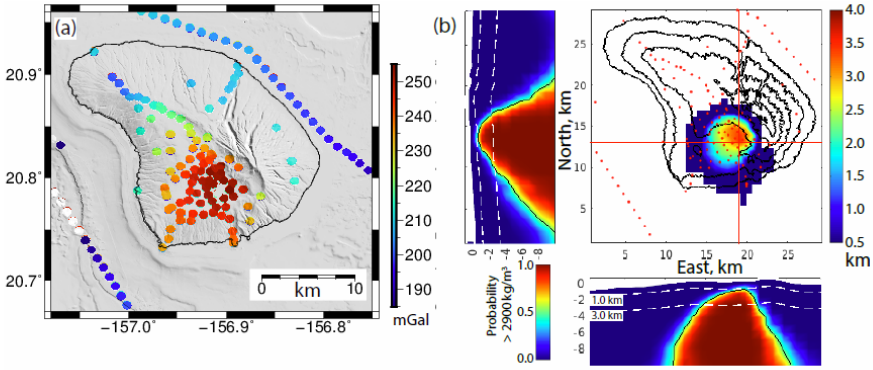

Figure 2: (a) Local complete Bouguer anomaly of Lānaʻi using ρ0 = 2600 kg/m3 (colored patches at measurement locations). Topography is illuminated from the NE and the shoreline outlined. (b) Map of the depth below the surface to 90%-probability of densities ≥2900 kg/m3. Subaerial topography is contoured (100 m intervals) and gravity stations are marked with red dots. East-west and vertical cross sections along the lines in (b) showing probability of density >2900 kg/m3; black contour is for median density of 2900 kg/m3. Vertical axis is elevation relative to sea level. See Figure 5 for geographic and geologic structural details of the Pālāwai Basin.

The Phase 2 gravity data clearly delineates the dike complex associated with Lānaʻi volcano's central magma conduit (Figure 2a, 2b). Less clearly evident in the gravity data or density models is the dike complex associated with the rift system, located to the northeast of the Lānaʻi caldera and striking in a generally northwest-southeast direction (Figure 2b). That rift system has been mapped in detail through surface exposures of dikes as well as through drilling for high-level dike-impounded groundwater in this location.

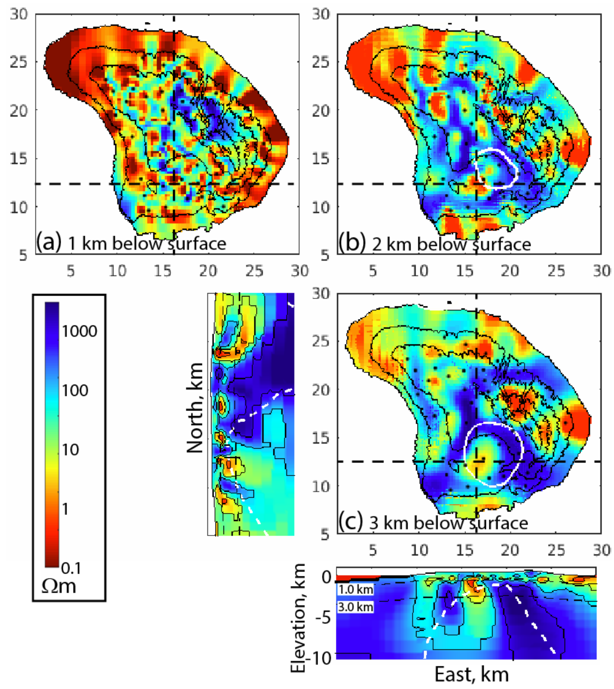

Figure 3: 3D resistivity structure from inversions of MT data shown at (a) 1 km, (b) 2 km, and (c) 3 km below the surface. Vertical sections along dashed lines are shown. White curves outline a median density of 2900 kg/m3 from the gravity inversions. See Figure 5 for geographic and geologic structural details of the Pālāwai Basin.

The 3-D resistivity modeling shows a complex distribution of resistivity values across the island and at depth, which requires a correspondingly complex interpretation. It is appropriate to discount all of the low resistivity features around the distal edges of the island due to seawater (Figures 3a and 3b). Similar to the situation with Haleakalā Volcano, Lānaʻi has, since the end of its shield building stage of activity, subsided by about 2 km, such that the formerly subaerial and permeable lavas are now saturated with seawater. Shallow groundwater drilling in most of the coastal areas of the island further substantiate this inference and have found either (a) a very thin freshwater basal aquifer, or (b) an aquifer that is entirely brackish to saline. Hence, the near-shore conductive features are of no interest to the PFA investigations. We conclude, however, that the intrusive complex associated with the central magma conduit of Lānaʻi volcano can serve as an effective barrier to infiltration of seawater to the interior of the caldera. Furthermore, the presence of high level (~300 m asl) groundwater within the caldera region of the island likely further impedes seawater intrusion into the complex. Based on this analysis, the conductive feature that extends on the resistivity anomaly cross section from ~1 to 3 km depth at around the 16 km mark (Figures 3c) could correspond to an anomaly with least seawater saturation. We note also that this feature is flanked by much more resistive formations, which may reflect a low permeability dike complex.

Two resistive formations separate the abovementioned geologic structures of the Pālāwai Basin from the seawater saturated rocks flanking the island (Figures 3b and 3c). These resistive formations are less compelling and of secondary interest as there is a likelihood that non-thermally induced conductivity is somewhat reduced. Further work on these features could be pursued (outside of PFA) if a heat source was confirmed within the Pālāwai Basin. As with the other resistivity datasets, we recognize the potential for the conductive features present in Lānaʻi's dike complex to reflect secondary mineralization and clay formation in a now-exhausted hydrothermal system. However, the presence of thermal anomalies argues that there is residual heat remaining within Lānaʻi's magma conduit.

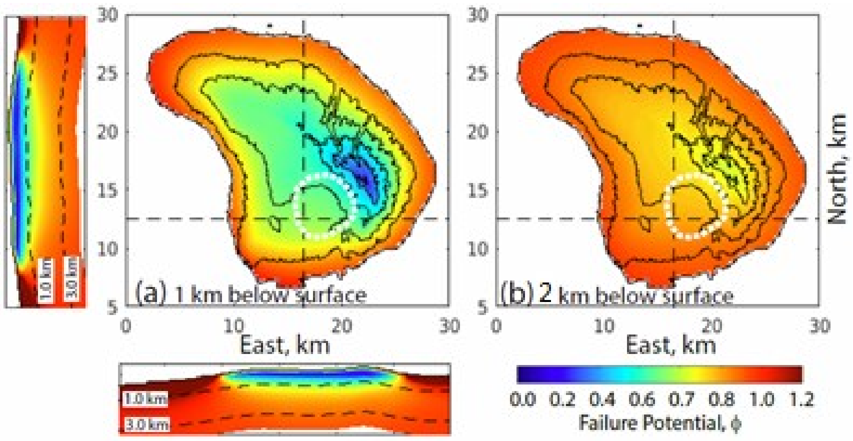

Figure 4: Failure potential ϕ due to topographic stresses at Lānaʻi at (a) 1 km and (b) 2 km below the topographic surface. Vertical cross sections are taken along dashed lines. The white dashed oval outlines a region with a median density of 2900 kg/m^3 at 3 km depth, as determined from inversions of gravity data (see below). See Figure 5 for geographic and geologic structural details of the Pālāwai Basin.

Failure potential computed from topographic stresses beneath Lānaʻi are lowest within 1 km of the surface and increase with depth (Figure 4a), reaching values of 0.7-0.9 at the resource depths of 1-3 km (Figure 4b). This finding is consistent with that for an idealized conical topography and leads to moderate probabilities for permeability (Pr_p = 40-50%) in the area of the gravity high in the south-central part of the island.

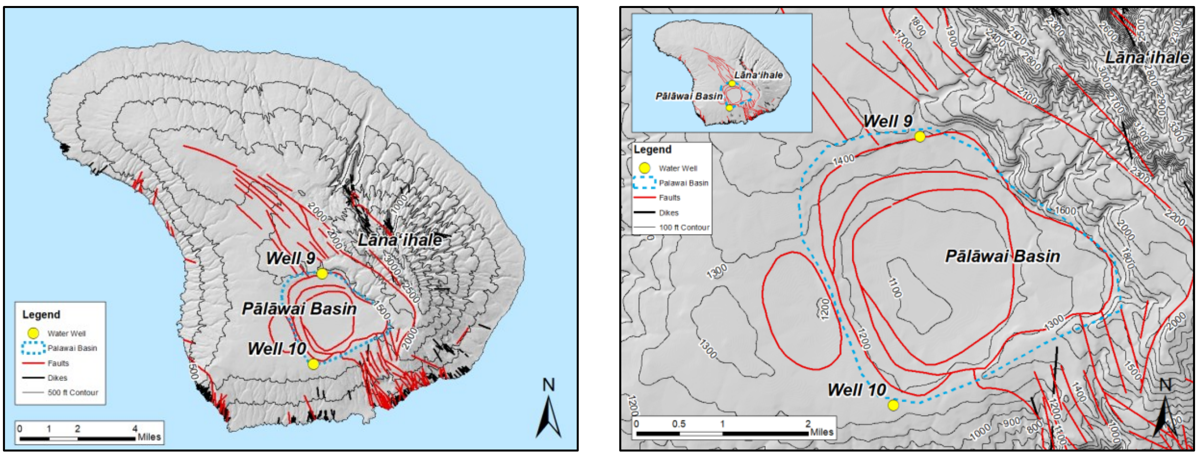

Figure 5: (Left) Map of Lānaʻi Island, Hawaiʻi. Contour interval is 500 feet (152.4 m). The Pālāwai Basin is detailed in blue; Lānaʻi Wells 9 and 10 are marked in yellow. (Right) Map of Pālāwai Basin with 100 feet contour intervals (30.48 m) depicting the mapped faults and dike complex of Lānaʻi.

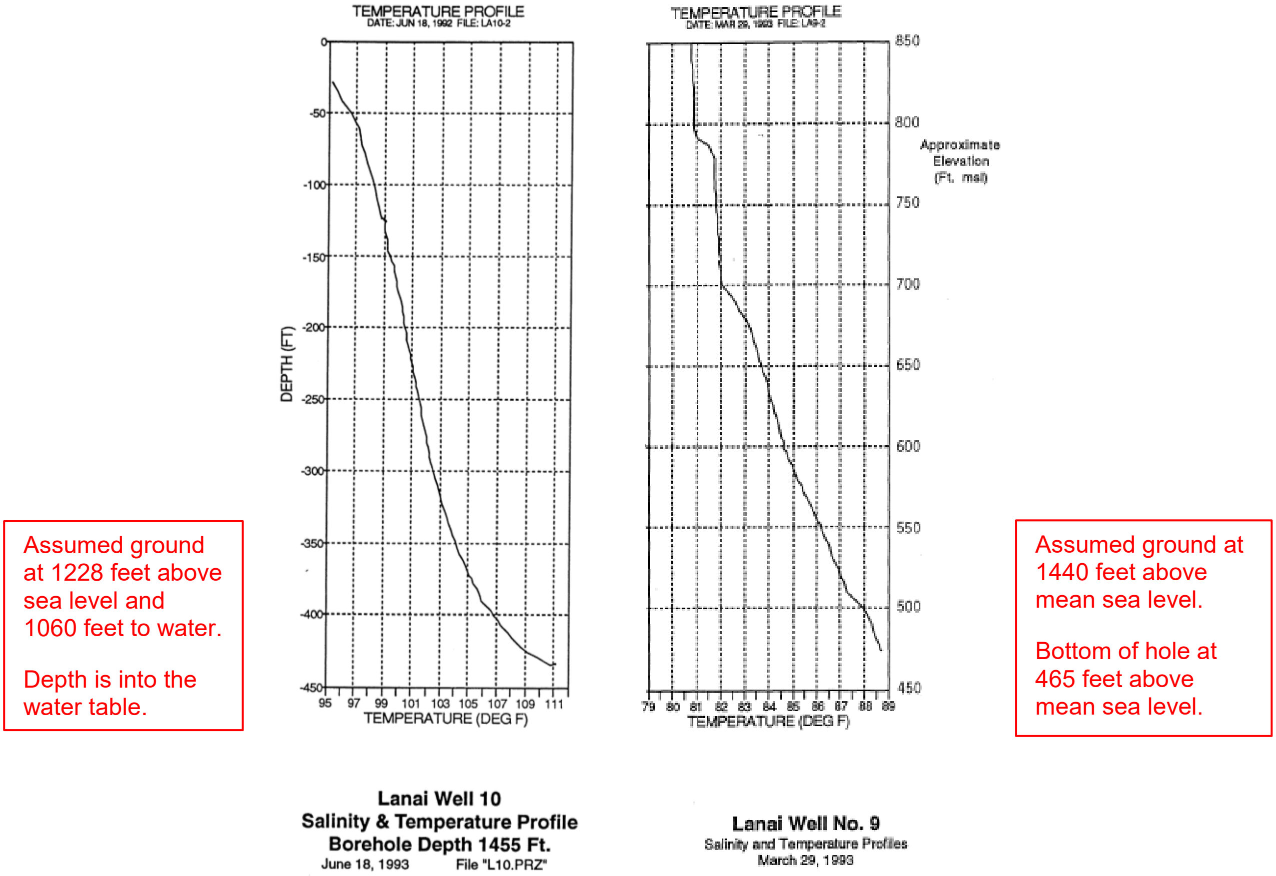

Figure 6: Temperature profiles of Lāna‘i Wells 10 (left) and 9 (right) from 1993. The Lāna‘i Well 10 profile expresses depth into the water table, whereas the Lāna‘i Well 9 profile expresses elevation above mean sea level.

3. PRELIMINARY STEPS TO DRILLING

The Lāna‘i land management agency offered two wells, i.e., Lāna‘i wells 9 and 10, which are located at the opposite sides of each other within the Pālāwai Basin, a feature that is defined by the rim of the unfilled Lāna‘i Caldera (Figure 5). As Well 9 has 500 feet (~152 m) of loose material at the bottom, Lāna‘i Well 10 became the primary target of the Hawai‘i PFA Phase 3 due to its more favorable drilling conditions. Additionally, Lāna‘i Well 10 was farther removed from the local community at Lāna‘i City and its water temperature was slightly higher (Figure 6) than Lāna‘i Well 9.

A single landowner presently owns ~98% of Lāna‘i. However Lāna‘i has large amounts of undeveloped land that remain as fallow or active agricultural land. To the northeast of the Pālāwai Basin is a wet forest covering the ridges of Lāna‘ihale, which is the highest point on the island at >1000 m. The Hawai‘i PFA Phase 3 drill site sits on land designated as “cropland and pasture” by the state of Hawai‘i Office of Planning.

3.1 Environmental Assessment

A major component to site preparation for the PFA Phase 3 work was to prepare an Environmental Assessment (EA) and submit to the Hawai‘i Department of Health (HDOH) Office of Environmental Quality Control (OEQC). The Draft EA was submitted on September 19, 2018, and public comments from a single individual were received at the end of the posting period. Pūlama Lāna‘i Conservation Directors and the Pacific Fish and Wildlife Office were consulted for biological survey information to create a system of mitigation measures for the project, particularly focusing on Hoary Bats and Hawaiian Petrels. A Final EA and Finding of No Significant Impact (FONSI) was submitted to the HDOH-OEQC and published on December 23, 2018.

3.2 Downhole Camera and Deviation Logging

Multiple downhole surveys were conducted on both Lāna’i wells 9 and 10 prior to the commencement of the drilling effort to determine the fitness of each well for the potential deepening. These surveys included both a video log and deviation log of both wells. In June 2016, an outside party conducted a video survey of Lāna’i Well 9. At the start of PFA Phase 3, we received this video from Pulama Lanai to aid in the reconnaissance of Lāna’i Well 9. Additionally, we coordinated with CWRM and Pulama Lāna’i to lower the state-owned camera down Lāna‘i Well 10 to conduct a similar video survey. This offered an inexpensive and relatively simple exercise to ensure the wells do not have any unexpected blockages. Both wells were found to be straight enough to justify performance of a gyroscopic log. A gyroscopic log and deviation survey was provided for Lāna‘i Wells 10 and 9 from December 2-9, 2018 by Frontier Logging Corporation. The results of the gyroscopic log determined both wells to be suitable for successful drilling exercise (Figure 7).

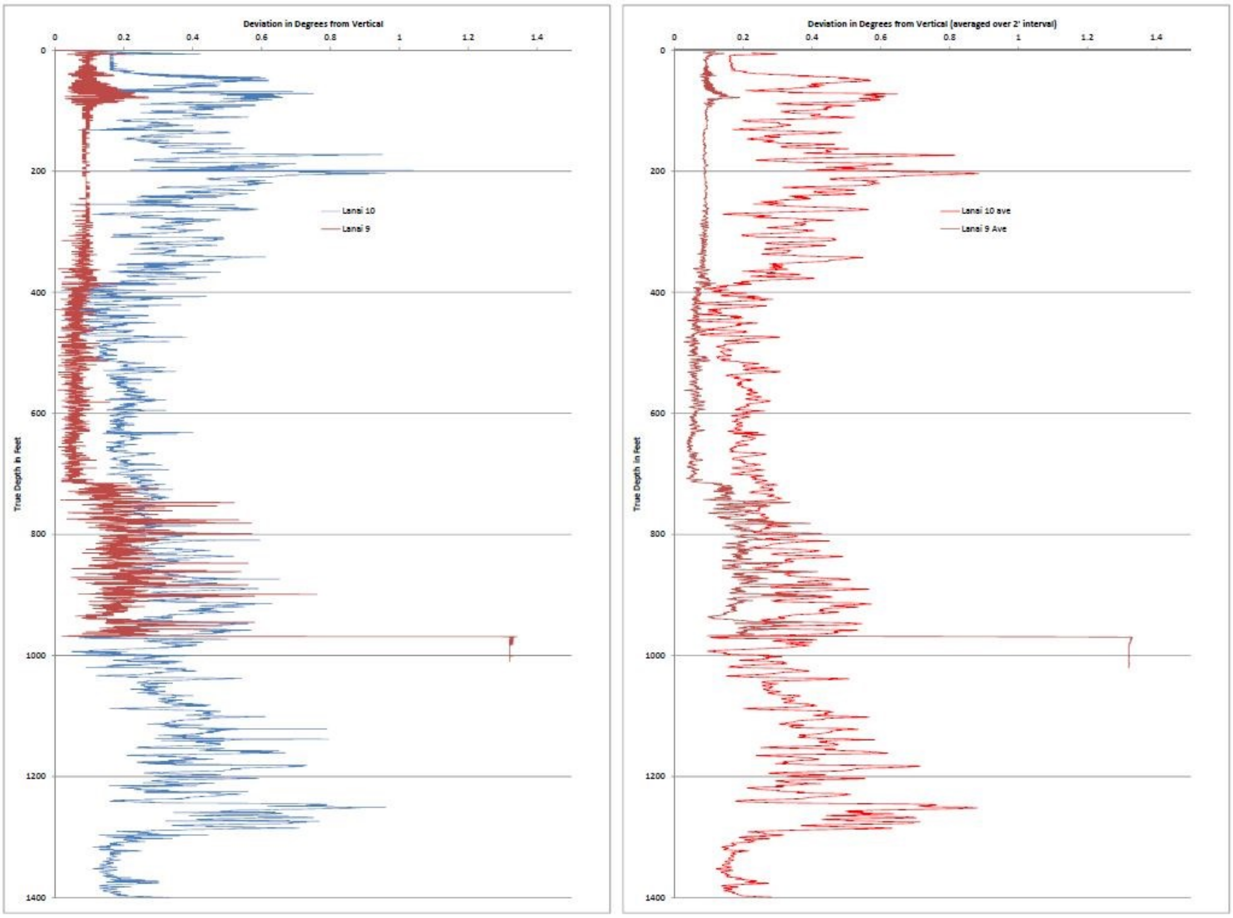

Figure 7: (left) Deviation logs for Lānaʻi Wells 9 and 10; (right) Deviation logs averaged every two inches for Lānaʻi Wells 9 and 10.

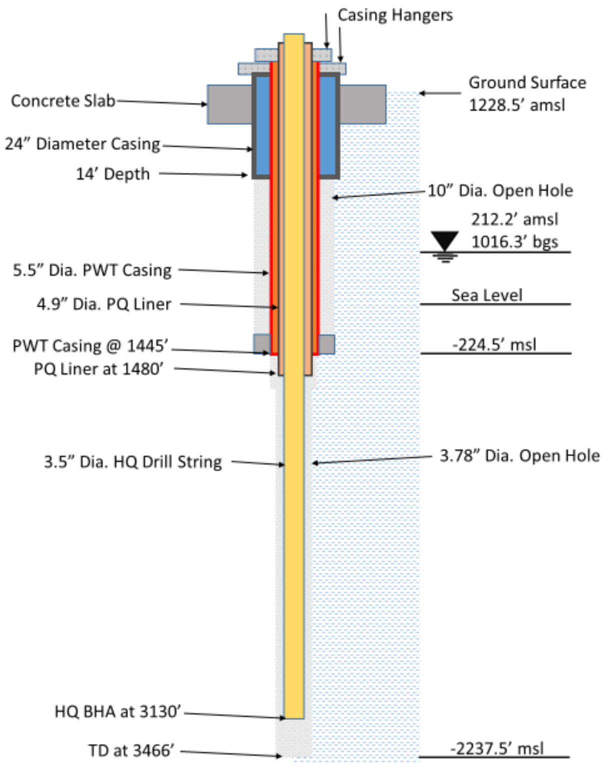

Figure 8: Downhole assembly for Lānaʻi Well 10 drill casing and drill rod, currently active and in place.

3.3 Drilling and Coring Program

Drilling was conducted for the month of June on a 24 hour basis, with nearly complete core recovery from 1400 to 3467 feet (~427 m to ~1057 m) (Figure 8; see https://www.higp.Hawai‘i.edu/hggrc/category/Lāna’i-island-project-updates/ for project updates). Onsite core processing facility was established on Lāna‘i adjacent to the well to allow for immediate core archiving. Rock core that is recovered from the drilling is taken to that core processing facility where it is cleaned, cut, and catalogued into core boxes (Figure 9). The boxes are currently palletized and prepared for shipment to a long-term storage facility. Funding will be sought for further analyses. Dynamic temperature measurements were taken nearly daily, with a measured 28°C (50°F) increase to 66°C (151°F). The actual temperature measured seemed to depend on the temperature and volume of drilling fluid being circulated.

At two stages throughout the drilling exercise – mid- and late-June, 2019 – hole stability issues were encountered within the newly drilled sections of Lāna’i Well 10. In both instances, loose, unconsolidated material was encountered by the drill bit and was unable to be cleared. These zones of unconsolidated material could have been sand or gravel formations, or, more plausibly, cave-in from the walls of the drill hole. We hypothesize that these unconsolidated sediments were in fact parts of friable formations of relatively unstable material that was milled up between the drill string and the borehole walls into a fine sand (Figure 9). To drill through these zones on both occasions, we cemented down the hole to stabilize the borehole walls and solidify the formation at the depth of interest, allowing us to drill through these zones and continue to deepen the well.

The original objective of the drilling exercise was to double the original depth of Lāna’i Well 10, drilling to a total depth of 2900 feet (~854 m). With this objective completed and limited funding remaining, the projects goals are now to purge the hole of drilling fluid, take more detailed downhole temperature measurements, and bring the well into compliance with CWRM standards in order to keep the well open for future activity. This will all take place prior to the project’s conclusion in March 2020. While continuous temperature logging has been conducted, these future temperature surveys are anticipated to provide a better understanding of the true thermal gradient of the well after the system equilibrates following the end of drilling activities.

Figure 9: Cleaned, cut, and boxed rock core recovered from the deepened Lāna‘i Well 10. (Left) Example of solid, consolidated units within the borehole Evidence of a high-angle dike intrusion into the surrounding rock (left-most column in the core box). (Center, Right) Example of friable formations downhole. Most of this material came out of the core tube in a fairly competent form but clearly broke apart as they dried. This was milled up in between the drill string and the borehole walls into a fine sand.

3.4. Preliminary Temperature Profile

Temperature measurements were taken downhole daily during active drilling. After an 8-week break in the drilling exercise, a downhole temperature survey was completed to a depth of 2955 feet (~900 m) and reached a maximum temperature of 141 F (~61 C). This survey ended 512 feet (~156 m) from the bottom of the drill hole due to minor obstructions at the base of the well. Drilling fluids were still present within the drill string, but the formation had approximately two months to equilibrate after the drilling activities were temporarily halted. Based on this survey, the resulting temperature gradient in Lāna’i Well 10 is approximately 42 C per 1 km, which is more than double Hawai‘i’s background gradient of 18 C per 1000 m (Büttner and Huenges, 2003). Lāna’i Well 10 has a higher temperature at a depth of 2955 feet (~900 m) by about 25 C than the PTA-2 test hole (Figure 10, right). In the next 800 m of PTA-2, the bottom hole temperature increased to ~140 C at 1700 m depth, and the final temperature gradient reached gradient reached 165 C per 1000 m in its final stages. Lāna'i Well 10 also has a comparable temperature profile to the first 600 m or more of the SOH-1, 2, and 4 wells in Kīlauea East Rift Zone (KERZ) on Hawai'i Island (Figure 10, left). The KERZ is an area of a known geothermal resource and volcanic activity, and is currently the site of Hawai'i's only geothermal powerplant, Puna Geothermal Venture.

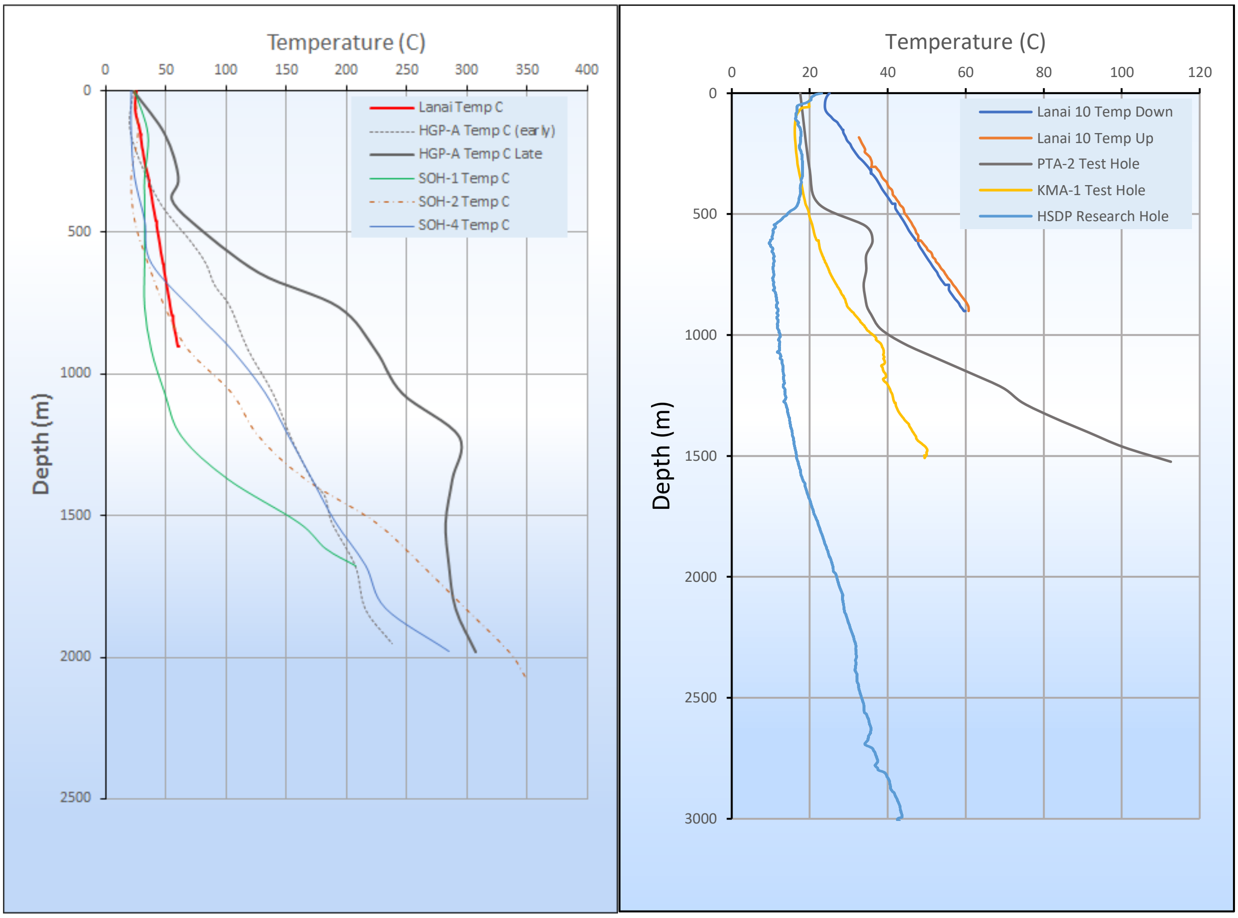

Figure 10: (Left) Temperature profile of Lāna'i Well 10 as compared to geothermal exploration wells drilled on Hawai'i Island at Kīlauea's East Rift Zone, an area of active volcanism. (Right) Temperature profile of Lāna'i Well 10 as compared to deep wells drilled on Hawai'i Island.

4. STATEWIDE GROUNDWATER WELL SAMPLING

Groundwater data collection was scheduled on Lāna'i and other sites around the state of Hawai'i to be completed with remaining available time and funding. South Point Hawai'i Island, East Rift Haleakalā, and Kaua'i Island were PFA Phase 2 targets for groundwater analyses, the results of which show a positive indication of a subsurface resource. We obtained Helium isotope data for two areas in Hawai'i from previous work funded by the DOE. These are informative and suggest that more Helium data statewide will improve our PFA probability and confidence maps. As part of Phase 3, we have begun to collect groundwater samples for Helium isotope analyses in the Phase 2 target areas. To begin this stage of Phase 3, the project initiated contact with land and well owners for permission to access the site and corresponded with selected labs to coordinate plans for future groundwater sample collection and analysis. We have also reviewed Phase 2 data to prioritize wells of interest to be targeted for groundwater sampling in PFA Phase 3.

The primary purpose of groundwater sampling for the third phase of the PFA is to test and refine the existing statistical model from prior phases. This will be accomplished by sampling sites located by the model across five islands, and additional targets in areas with limited or no data (Figure 11). Samples have already been collected from Lāna'i Island, before Phase 3 drilling began. Sampling includes dissolved noble gases, major ions, and trace metals. The objective of this groundwater sampling is to identify tracers unique to the mantle, such as primordial 3-Helium isotopes, which are related to fluids and volatiles associated with Hawaiian volcanism. When these primordial isotopes overlap with a thermal anomaly, and elevated chemical tracers such as silica and chlorine, the waters are likely thermally enhanced. Further, mantle noble gas signatures can tell us a great deal of relevant geologic information, such as structural controls like deeply penetrating faults allowing for fluid circulation when heat is low or absent, groundwater residence times, and potentially stored magma on the older islands. This data could lay the groundwork for more detailed geochemical or geophysical studies which would further explain the presence of these tracers.

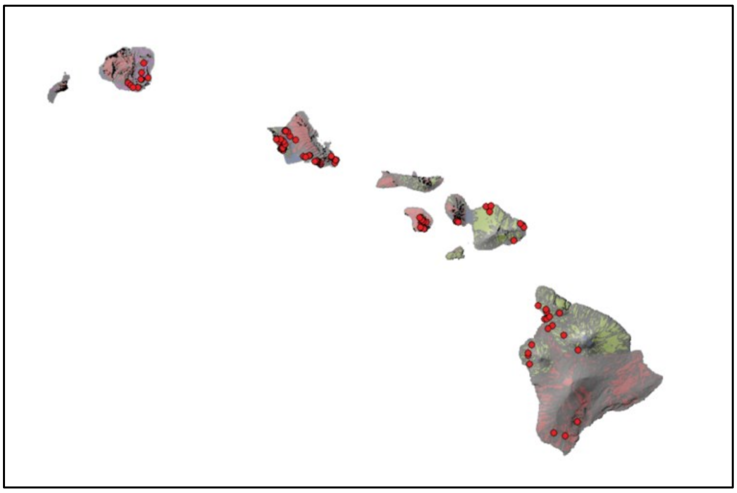

Figure 11: Locations across the state of Hawai‘i of groundwater well sampling targets for PFA Phase 3 Helium isotope analysis.

5. CONCLUSION

Work in Phase 3 was designed to validate the Play Fairway (PF) methodology established in Phases 1 and 2. To complete this, the primary objective of Phase 3 was to drill a temperature observation well, augmented by noble gas groundwater sampling. In addition to complying with our updated Phase 2 probability and confidence maps, drilling prospects had to account for anticipated regulatory timelines, landowner interest, scientific impact, and the viability of development. Four locations in the state were investigated extensively to warrant a decision on exploratory drilling during Phase 2 through the collection of gravity, resistivity, and groundwater temperature data. Lāna‘i’s summit caldera was ultimately selected for the test well, and the project chose to deepen of Lāna’i Well 10 in the Pālāwai Basin. Prior to drilling, video and gyroscopic logs were conducted on Lāna’i Well 10 to ensure there were no blockages and the well was straight enough for drilling. At the time of this writing, Lāna’i Well 10 has been deepened to 3467 feet (1057 m) with a maximum measured downhole temperature of 151°F (66°C).

6. ACKNOWLEDGMENT

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