

## Update to the Hawai'i Play Fairway Project, now in Phase 3

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**Keywords:** Hawai'i, geothermal, Play Fairway, drilling

### ABSTRACT

The U.S. Department of Energy-funded Hawaii Play Fairway project has progressed over 3 phases. Now in Phase 3, the project aims to deepen one or two existing wells on Lanai Island in addition to performing geophysical and groundwater exploration activities in key areas around the state. In Phase 1 of the project, existing geologic, groundwater, and geophysical datasets relevant to subsurface heat, fluid and permeability were identified, compiled, and ranked. A statistical methodology to integrate these data into a resource probability map was developed. Phase 2 of the project involved the collection of new groundwater data in 10 locations across the state, and new geophysical data on Lanai, Maui, and central Hawaii Island, as well as modeling of topographically induced stress - the last to better characterize permeability. Here, we succinctly present results of the Phase 1 and 2 activities, and outline Phase 3 plans and progress.

### 1. INTRODUCTION

The primary goal of Budget Phase (BP) 3 is to validate the Play Fairway (PF) methodology established in the earlier 2 phases through drilling of a test hole in a region of high probability and confidence. At the conclusion of a large body of work during the prior two budget periods, four locations in the state were investigated thoroughly enough during BP2 to warrant a go/no-go on exploratory drilling: the north, east, and south flanks of Mauna Kea volcano (Hawai'i Island); Haleakala volcano's SW rift zone (Maui); and Lāna'i's summit caldera and rift zones. The team conducted a comprehensive screening of each of these sites based not only on probability of a resource, but also with respect to legal, institutional, economic, and socio-political barriers/incentives for future viability of a project should a resource prospect be confirmed. That screening process resulted in the identification of two "Go" locations for drilling during BP3 that had both encouraging resource probability as well as a minimum of adverse "intangible" considerations that could potentially preclude follow-on development, or possibly interfere with, or unacceptably delay, regulatory approval of our proposed investigations. These locations are: i) on Department of Hawaiian Homelands located south/southeast of the summit of Mauna Kea volcano on Hawaii Island, and ii) in the former caldera region of the privately-owned Island of Lanai.

A combination of scientific and logistical considerations ultimately led us to focus on the Lāna'i prospect for Phase 3 work. The probability for a resource in Lanai's caldera region at an accessible depth is supported by gravity, resistivity, and groundwater temperature data collected as part of BP2. The landowner is committed to the development of renewable energy, and the land management company offered us the possibility of deepening two existing >1000 ft water wells that are no longer in production. The regulatory process is streamlined due to existing cultural and environmental surveys, as well as prior use of the land for pineapple cultivation.

We plan to pursue the deepening of Lanai Well 10, and, should circumstances permit, Lanai Well 9. Lanai Well 10 is 1455 feet deep and has a bottom hole temperature of 111 °F. It is the warmest of Lanai's wells and located on the rim of Palawai Basin (Lanai volcano's caldera) and roughly in the center of our Phase 2 drilling target area. Caldera boundary faults are expected to allow propagation of warm fluids into the shallow groundwater system. Well 9 is 975 feet deep, 89 °F at its bottom, and located near the center of the Palawai caldera. The overall objective of this work will be to develop a better understanding of the hydrology of the Lanai caldera dike complex, as well as the impact of the inferred deep thermal activity on fluid circulation within it. Intended data collection include: an extended temperature gradient, fluid chemistry, and stratified core sampling to the total depth drilled. From these data we expect to be able to better define the deeper temperature gradients in the borehole, to infer the temperature of last fluid equilibrium using geothermometry computations, and to gain insights into the heat budget (and thermal decline curves) from basaltic calderas over time. This will be the first deep (>1 km) drilling project off of the Big Island of Hawaii, and provide important insight into how Hawaiian volcanoes cool with time; insight that will have broad implications for Hawai'i's future geothermal development strategy.

### 2. BP 2 RESULTS

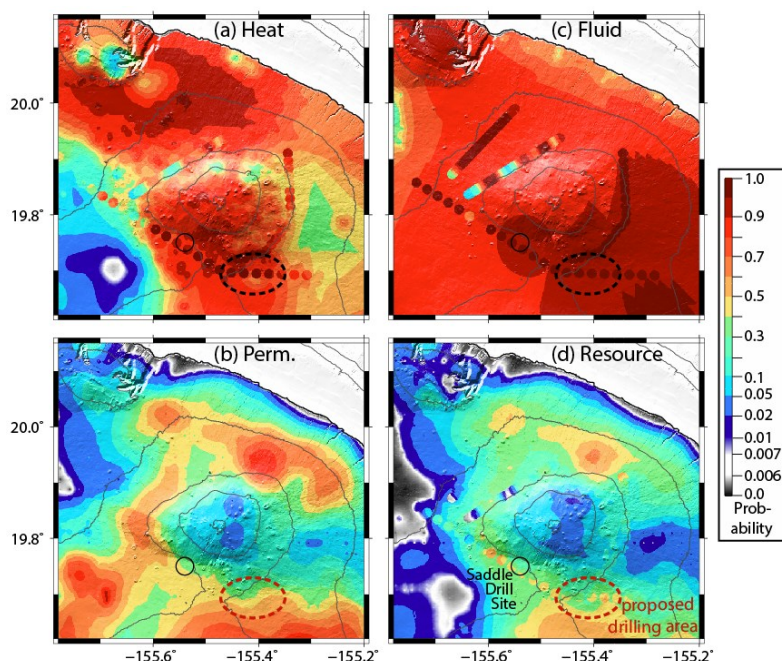
Of the four sites, Mauna Kea's south-southeast flank and Lāna'i's caldera region rose to the top for BP3 drilling targets, with Lāna'i's caldera region being ultimately selected. Below we include a description of each site, with more attention on the selected Lāna'i caldera region.

#### 2.1 Mauna Kea Prospect

Mauna Kea is the third-youngest volcano on Hawai'i Island. It last erupted between 4 and 6 ka, and is in its post-shield phase of activity. The younger volcanoes of Kilauea and Mauna Loa are in their shield building stage, whereas Mauna Kea's shield stage ended ~150,000 years ago. Our assessment of Mauna Kea's resource potential aims to identify areas with evidence of geologically recent intrusive activity (e.g. elevated gravity, reduced resistivity, groundwater anomalies).

Mauna Kea has been the focus of a substantial amount of recent research led by D. Thomas under non-DOE funding. This includes magnetotelluric (MT) and audio-frequency magnetotelluric (AMT) surveys on all flanks except the volcano's northeast (some of this data had not been analyzed at the start of BP2), and drilling of 2 deep (1.8 km) boreholes with downhole fluid sampling on the south-southwest and west flanks. Encouraging geophysical results on the southeast flank that were obtained during BP2 stimulated the attainment of additional gravity and groundwater data included, but not originally planned, as part of BP2.

A number of considerations including the newly discovered corroborating evidence provided by the geophysical data, and our probability analyses, leads us to the southeast flank of Mauna Kea as a high priority target for BP3 drilling (**Fig. 1**). In this location, both elevated gravity and reduced resistivity point to thermal activity at favorable resource depths. The gravity signature is interpreted to be part of a robust dike system that extends across the Humu'ula Saddle region between Mauna Loa and Mauna Kea (Flinders et al., 2013). While the reduced resistivity values could be attributed to a variety of factors (including secondary mineralization, clay formation, saltwater intrusion), several factors argue strongly in favor of warm fluid as the primary source for the low resistivity in this location. In particular, one of the 1.8 km deep boreholes, located approximately 12 km to the northwest, identified high elevation (>1000 m amsl) fresh and hot groundwater. Results of the completed well include water with temperatures of 140 °C at a depth of 1760 m and a temperature gradient of 165 °C/km as the electrically conductive formations were approached. Hence, it is likely that heat as well as the fluid components of a resource are present in this top priority BP3 drilling target. According to our modeling of permeability, the BP3 target site would have similar permeability as the completed test well. The deep formations in the test well were not flow tested due to its small diameter, but the borehole did show evidence of internal flow from depth up into the shallower formations (resulting in sealing of the deep section of that hole with dense drilling mud to protect the upper aquifer from contamination).



**Figure 1: Local probabilities for Mauna Kea of (a) heat, (b) permeability, (c) fluid, and (d) a geothermal resource. Our BP3, highest-priority drill site is marked by the dashed oval.**

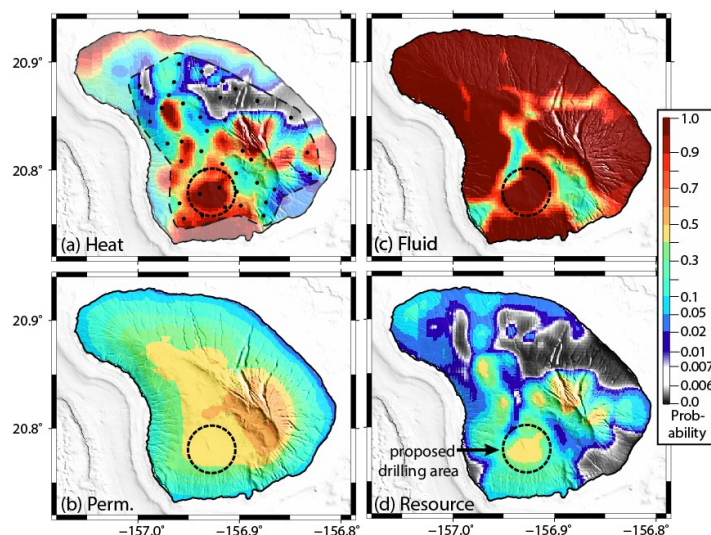
A number of other factors contributed to our selection of Mauna Kea as a top BP3 target. This land is controlled and managed by the Department of Hawaiian Home Lands (DHHL). DHHL enjoys a favorable regulatory status in terms of their compliance with environmental requirements and County zoning rules. Also, DHHL will receive 100% of State royalties from geothermal revenues. The Hawaiian Homes Commission, who establishes policy for the Department and provides guidance on new initiatives to Department staff, has been very supportive of our prior geothermal exploration work on their lands and, when the results of our exploration efforts were presented at a recent Commission meeting, we received a very favorable response from the Commissioners.

An additional factor favoring this site is that D. Thomas is very familiar with this region. Thomas managed the groundwater exploration program that was done in the Humu'ula Saddle. This work included development of an environmental assessment (EA) for two test borehole sites, acquisition of a drill rig and support equipment, and oversight of the drilling program for 2 slim holes drilled to ~1.8 km. Much of the environmental documentation done for those previous sites would be applicable here. The selected site would be logistically challenging in that no production wells exist within the Humu'ula Saddle, so water from Hilo (approximately 40 km distant) would need to be hauled in.

## 2.2 Lānaʻi Prospect

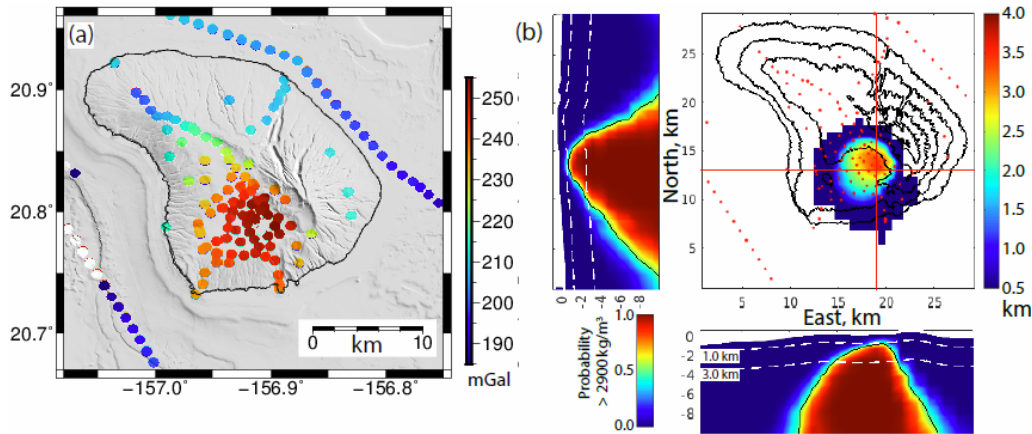
Lānaʻi is the third smallest of the eight main Hawaiian islands (West, 1992). The main mountain range of the island stretches in the northwest direction and has three known rift zones (West, 1992). Pālāwai basin is thought to be the remnant caldera of the island, which is 7 kilometers in diameter (Walker, 1990). It is formed by a single shield volcano, now extinct, estimated to be 1.3 Ma and active from approximately 2 Ma to 1 Ma. Lānaʻi volcano apparently stopped erupting during its shield stage, as inferred from the absence of a more commonly found alkalic cap and post erosional lavas (Walker, 1990). Growth of Lānaʻi is thought to have begun during the Tertiary and ceased ~1 Ma (Stearns, 1940; Herrero-Bervera et al., 2000). The Lānaʻi volcanics are tholeiitic and comprise all the volcanic rock units forming the island (Walker, 1990). The bioclastic Hulopoe Gravel is a carbonate-cemented gravel on the southern slopes of the island, with competing theories of origin, including sea level rise and megatsunami deposition. A rift zone extends from the northwest to the southeast of the island, radiating from the caldera of Pālāwai Basin. An additional rift zone extends southwest from the caldera. Both are marked by dike complexes.

The combined probabilities for heat, fluid, and permeability indicate several locations on Lānaʻi that could host a resource at the depths of interest for geothermal production (**Fig. 2**). The area of greatest interest is within the Pālāwai Basin where a high gravity signature and reduced resistivities at depth are co-located. Groundwater of notably elevated temperature is present in this area.



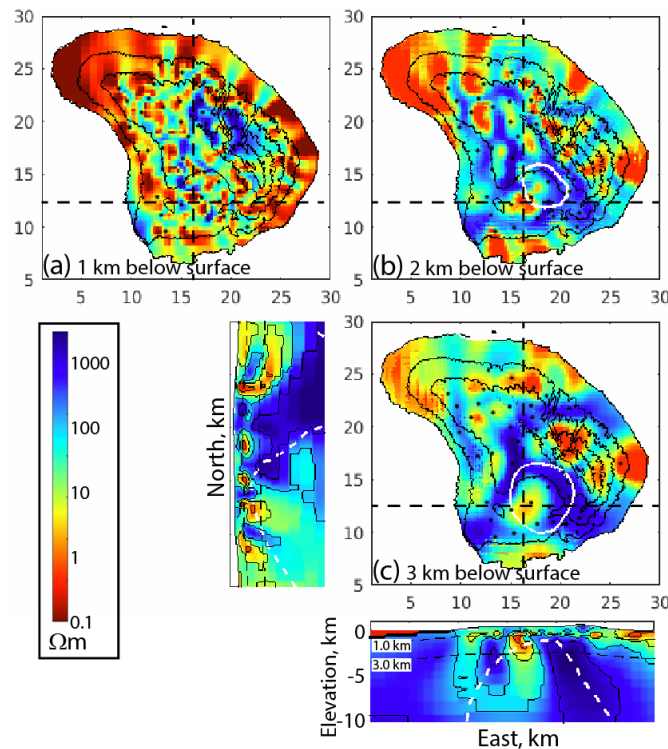
**Figure 2: Local probabilities for Lanai of (a) heat, (b) permeability, (c) fluid, and (d) a geothermal resource. The reliable area for the MT results is contained within the footprint (outlined by dashed lines) of the MT stations (dots), both due to data coverage as well as the likelihood that highly conductive salt water probably intrudes the volcano flanks near the shorelines.**

The BP2 gravity data delineates the dike and cumulate complex associated with Lānaʻi volcano's central magma conduit. 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 (**Fig. 3**).



**Figure 3:** (a) Local complete Bouguer anomaly of Lanai using  $\rho_0 = 2600 \text{ kg/m}^3$  (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  $\geq 2900 \text{ kg/m}^3$ . Subaerial topography is contoured (100 m intervals) and gravity stations are marked with red dots. (c) East-west and (d) vertical cross sections along the lines in (b) showing probability of density  $> 2900 \text{ kg/m}^3$ ; black contour is for median density of  $2900 \text{ kg/m}^3$ . Vertical axis is elevation relative to sea level.

The 3-D resistivity modeling shows a complex distribution of resistivity values across the island and at depth, which requires a correspondingly complex interpretation (Fig. 4).



**Figure 4:** 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  $2900 \text{ kg/m}^3$  from the gravity inversions.

In addition to the Pālāwai Basin feature, there are two additional low-resistivity features located to the northeast and north-northeast, within the dike complex of Lānaʻi volcano's rift zone. The resistive formations separating these features from seawater saturated rocks flanking the island are less compelling and, hence, the likelihood of non-thermally induced conductivity is somewhat reduced. Therefore, these features are of secondary interest. Further geophysical work on these structures could be pursued (outside of PF) if a heat source was confirmed within the Pālāwai Basin.

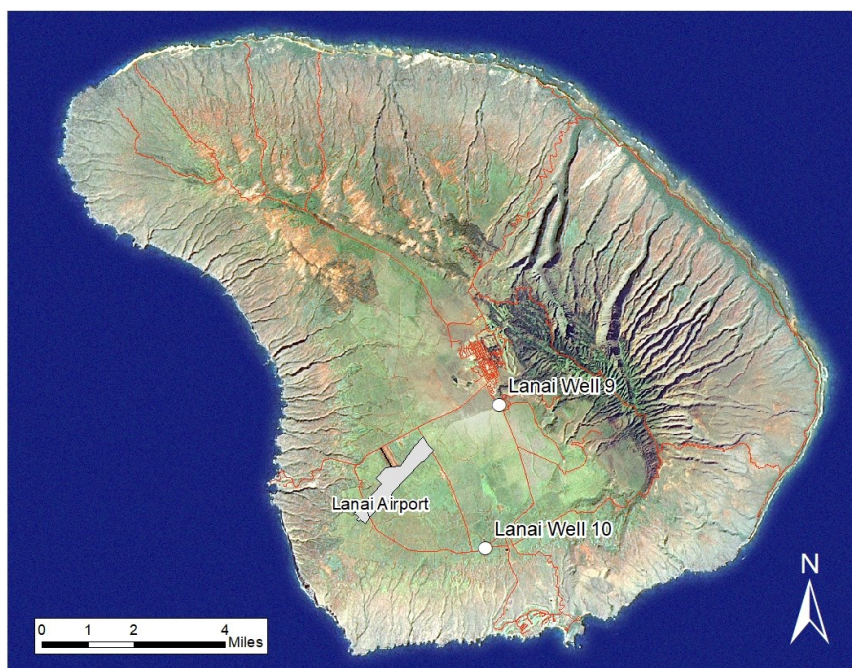
As with the other resistivity datasets, we recognize the potential for the conductive features present in Lānaʻi's dike complex to reflect secondary mineralization and clay formation in a now-exhausted hydrothermal system. However, the presence of thermal anomalies argues that there is residual heat remaining within Lānaʻi's magma conduit.

The Pālāwai Basin site is attractive to the project for a number of additional, non-geologic reasons. The authors have had extensive discussions with the land managers of the island (Pūlama Lānaʻi) and there is strong interest in the work that we have been conducting. Pūlama Lānaʻi and former landowners have performed extensive environmental, cultural, and land use documentation. The Palawai Basin was formerly used for pineapple agriculture for several decades.

Our interest in recovering deep thermal information on Lānaʻi is augmented by the fact that it will be the first time direct evidence of the long-term rates of cooling of the cores of Hawaiʻi's volcanoes will be recovered. All geothermal exploratory drilling to date has taken place on the youngest of island in the state: Hawaiʻi Island. Identification of a viable thermal source within Lānaʻi volcano will provide encouraging evidence that heat may exist on even older volcanic systems including: on Maui, Oʻahu (where the vast majority of the energy market resides) and Kauaʻi. Likewise, failure to find evidence of residual heat on Lānaʻi may indicate that, if geothermal heat is to provide electrical power to Hawaiʻi, it will have to be generated on Hawaiʻi Island.

### 3. PROJECT SCOPE

We plan to drill 1 or 2 temperature gradient hole(s) to a depth of  $> 1$  km below the ground surface using diamond wireline core drilling techniques. Lanai Well 10 has not been in operation since Pulama Lanai took over management of the island (2012), and they recently took Well 9 out of production because the water was problematically warm for the wells' intended purpose. Well 10 appears ideal to deepen because: i) it is in the center of our elevated probability target area, ii) it is distant from Lanai City such that drilling will have little to no effect on the community, iii) it is open to the total depth drilled (1455 ft) and therefore is suitable for deepening (Figure 5). Well 10 is the warmest well on Lanai and is located on the volcano caldera's boundary faults. These faults offer the potential of having served as a conduit for transport of deep fluids toward the surface. Lanai Well 9 is located near the center of Lanai caldera and is an interesting potential second deepening target. The pilot hole for Lanai 9 was drilled to 1462 feet, however 500 feet of the well are infilled with loose rock, which may present a drilling challenge to the UH-owned coring rig. Well 9 is cased to 775 of its total 975 feet depth and at this depth has a temperature of 89 °F (below which is approximately 500 feet of loose material). Well 9 is also in close proximity to Lanai City, which may present a social challenge (Figure 5).



**Figure 5: Map of Lanai showing location of Wells 9 and 10**

Although having access to the existing well(s) provides a significant advantage by having drilled through the shallowest, and often the most difficult formations for core drilling, we developed a step-wise project plan that included lowering a State-owned camera down the well (to ensure no blockage were present), and performing a gyroscopic (deviation) log on both wells. Both have been completed and results appear favorable for deepening these holes using wireline coring equipment. We also published an Environmental Assessment and Finding of No Significant Impact with a relatively muted public response.

In the near future for the project, the project will transport the UH-owned drill rig and temporary casing, from its current location on Hawaiʻi Island, to Lānaʻi. Additionally, other equipment must be inventoried and shipped, or otherwise purchased or rented for the project. Along with Drilling Supervisor Ron Fierbach, D. Thomas and N. Lautze assessed site access, power supply, water supply, lodging, and shipping, among other items. Upcoming action items include: finalization of the NEPA review, submission of a Well

Modification Permit to Hawaii's Department of Land and Natural Resources, submission of a Temporary Noncovered Source permit to the Hawaii Department of Health, registration of the truck-mounted drill rig as a UH vehicle, finalizing lodging and personnel requirements, and completing all site modification and preparation work. Target for the start of drilling is April 2019.

During drilling we will make "dynamic" temperature measurements using a memory temperature logger installed inside the core tube; this method was used in the prior drill holes and found to provide an indication of rising temperatures. Downhole temperature surveys will be conducted during breaks in drilling. Formation fluid samples will be collected, post drilling, as the borehole fluid chemistry approaches equilibrium with the formation fluids.

Upon successful completion of drilling, we will contract to perform downhole geophysics, and will archive and analyze the drill core to the extent time and funding allows.

#### 4. CONCLUSION

BP1 of the Hawai'i Play Fairway project led to the identification of 10 priority locations for BP2 activities. BP2 of the project involved the collection of new groundwater data in 10 areas from around the state, and the collection of magnetotelluric and gravity data on Lāna'i, Haleakala Volcano's SWRZ (Maui), and central Hawai'i Island. The project also modeled topographically induced stress in order to better characterize subsurface permeability during BP2. Ultimately, all data were incorporated into updated resource probability maps for the State of Hawai'i.

Work in BP3 is designed to validate the Play Fairway methodology established in BPs 1 and 2. To complete this, the primary objective of BP3 is to drilling a temperature observation well, augmented by additional geophysical surveys and noble gas groundwater sampling. In addition to complying with our updated BP2 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 during BP2 to warrant a decision on exploratory drilling, with Lāna'i's summit caldera being ultimately selected for the test well. Gravity, resistivity, and groundwater temperature data collected as part of BP2 suggests the probability for a resource in this area at an accessible depth. The results of test drilling in this location will impact the future geothermal development strategy of Hawai'i.

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