Exploring for Geothermal Resource in a Dormant Volcanic System: The Haleakala Southwest Rift Zone, Maui, Hawai'i

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Abstract: **Suites of new geophysical and geochemical surveys provide evidence for geothermal resource at the Haleakala Southwest Rift Zone (HSWRZ) on Maui Island, Hawai'i. Ground-based gravity (~400 stations) coupled with heli-bourne magnetics (~1500 line kilometers) define both deep and shallow fractures/faults, while also delineating potentially widespread subsurface hydrothermal alteration on the lower flanks (below approximately 1800 feet a.s.l.). Multi-level, upward continuation calculations and 2-D gravity and magnetic modeling provide information on source depths, but lack of lithologic information leaves ambiguity in the estimates. Lithology and physical property data from future drilling will improve these interpretations. Additionally, several well-defined gravity lows (possibly vent zones) lie coincident with magnetic highs suggesting the presence of dike intrusions at depth; a potentially young source of heat for a modern geothermal system. Soil CO_2 fluxes were measured along transects across geophysically-defined faults and fractures as well as young cinder cones along the HSWRZ; a weak anomalous flux signal was observed on one young cinder cone. Dissolved inorganic carbon concentrations and $\delta^{13}C$ compositions and $^3He/^4He$ values measured in several shallow groundwater samples indicate addition of magmatic CO_2 and He to the groundwater system. The general lack of observed magmatic surface CO_2 flux signals on the HSWRZ is is therefore likely due to a combination of groundwater "scrubbing" of CO_2 and relatively high biogenic surface CO_2 fluxes that mask potential magmatic signals. Similar surveys at the Puna geothermal field on the Kilauea Lower East Rift Zone (KLERZ) also showed a lack of surface CO_2 flux signals attributed to a magmatic source, while aqueous geochemistry indicated contribution of magmatic CO_2 and He to shallow groundwaters here. As magma has been intercepted in geothermal drilling at the Puna field, the lack of measured surface CO_2 flux indicative of upflow of magmatic fluids here is likely due to the aforementioned "scrubbing" by high groundwater flow and high background biogenic surface CO_2 flux. Deep temperature gradient core holes will be cited on the HSWRZ based on geophysical and geochemical datasets.**

I. Background

- While the Haleakala Southwest Rift Zone (HSWRZ) on Maui Island, Hawai'i is considered geothermally "blind" (i.e., without surface manifestation of hot water), volcanism here occurred as recently as 220-500 years ago, suggesting that magma is still actively being emplaced into the crust of Maui Island. Significant heat resources may therefore be available for geothermal production.

-Study goals:
  - Assess previous geophysics and new geochemistry and soil gas flux data at the well-characterized Puna geothermal field on the Kilauea Lower East Rift Zone (KLERZ), island of Hawai'i.
  - Determine lessons learned and apply integrated suite of geophysical, geochemical, soil gas flux, and remote sensing tools for exploration on the HSWRZ.

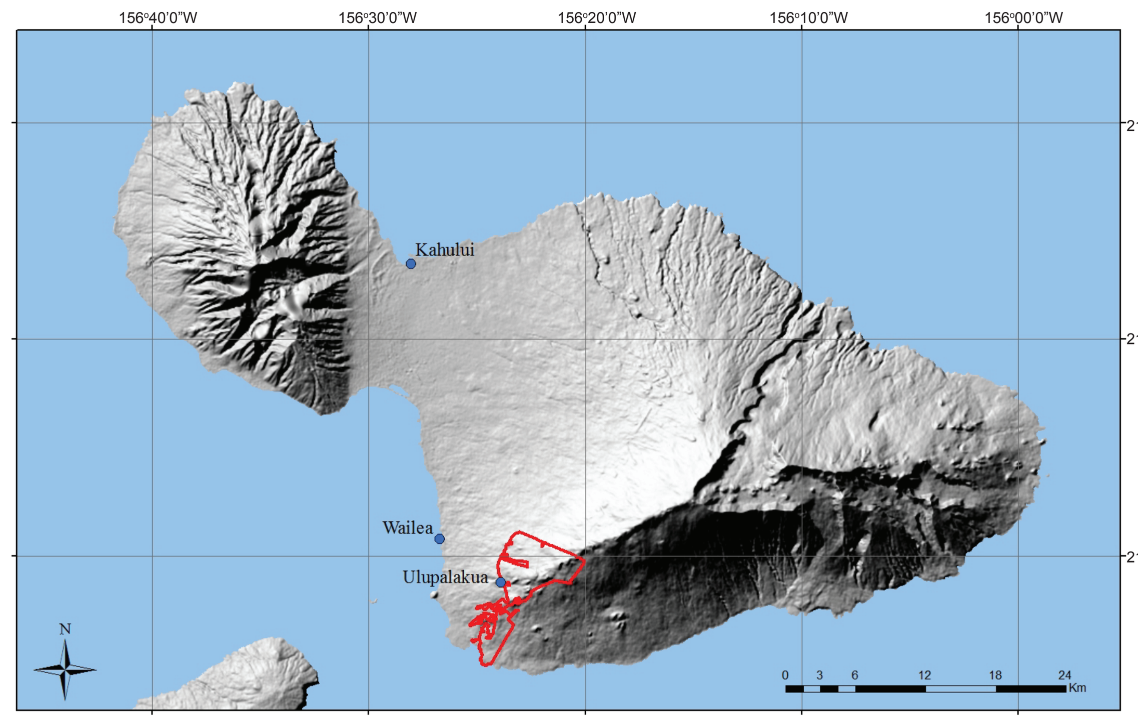

Figure 1. Digital elevation model of Maui Island, Hawai'i showing location of Ulupalakua Ranch lease boundary (red line) on the HSWRZ.

II. Geophysical Surveys

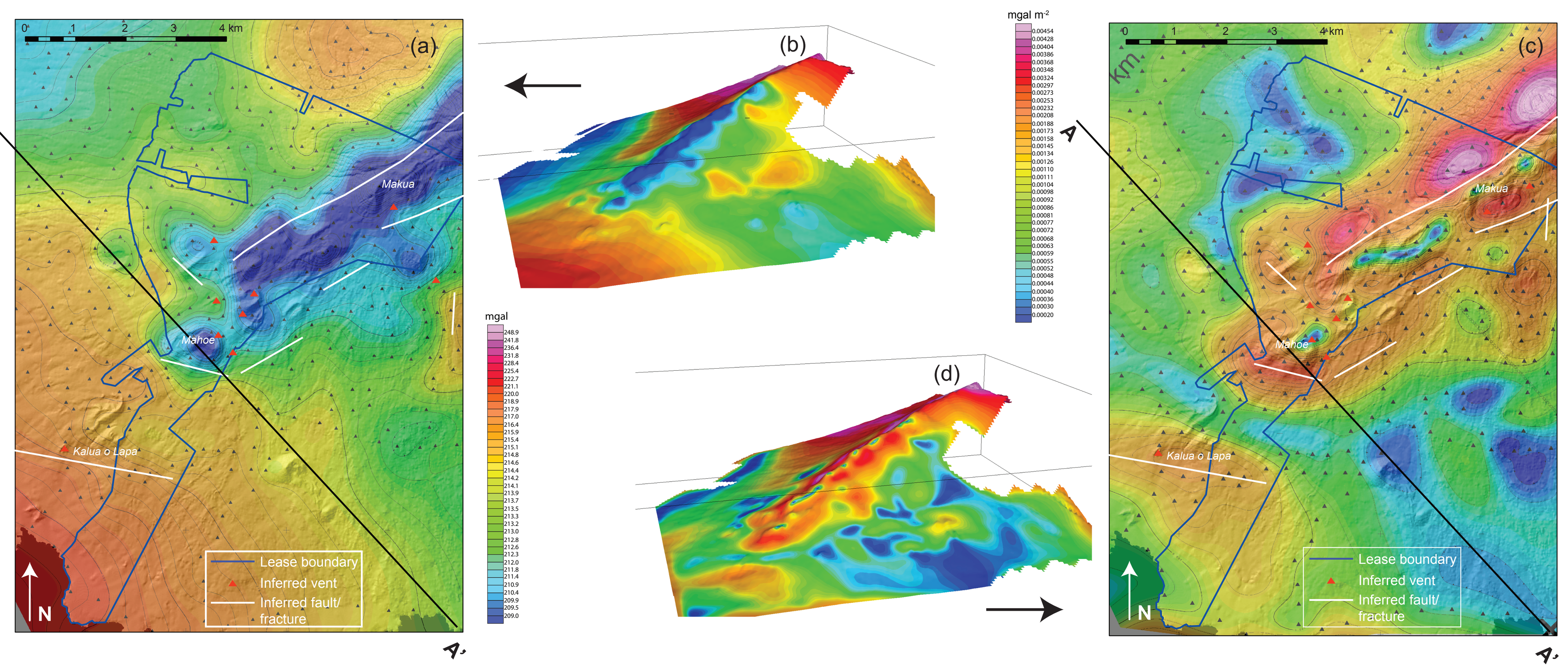

Figure 2. Maps of (a) Bouguer anomaly and (b) Bouguer anomaly draped over topography. Upward continuation (400 m) maps of (c) horizontal gradient in Bouguer anomaly and (d) horizontal gradient in Bouguer anomaly draped over topography. Faults/fractures inferred based on spatially correlated high horizontal gradients in Bouguer and magnetic (not shown) anomalies. Vent zones inferred based on spatially correlated low Bouger and high magnetic (**Figure 4**) anomalies.

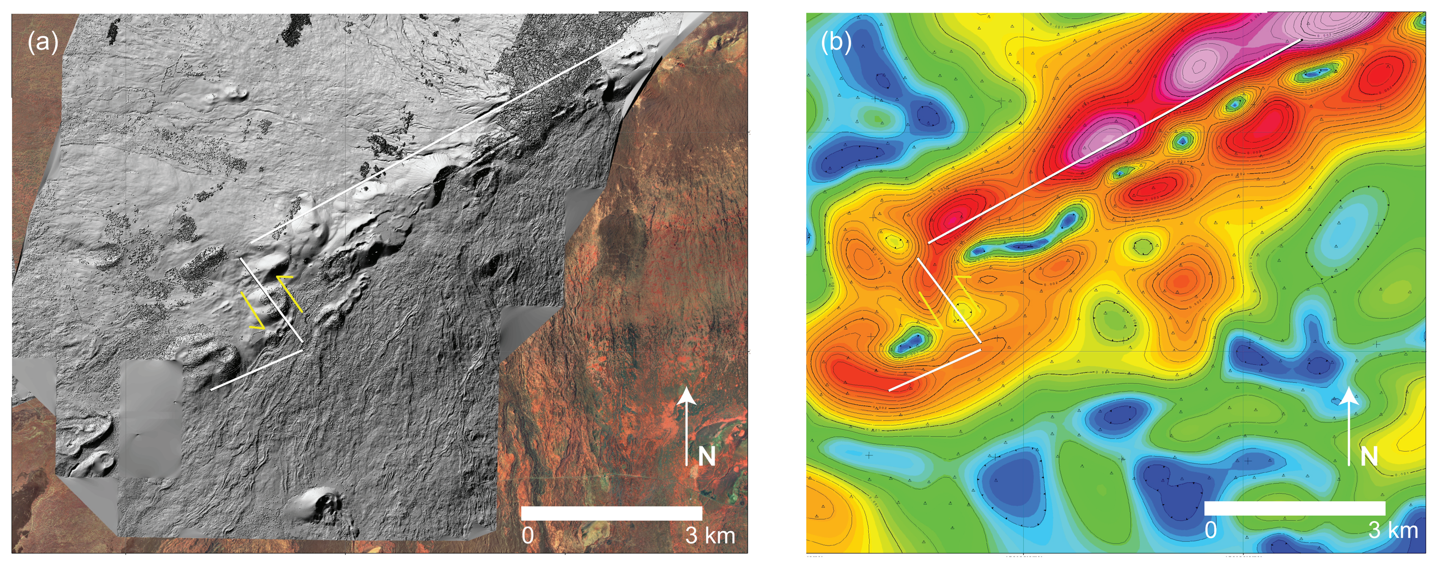

Figure 3. (a) Digital elevation model showing fault step-over inferred based on (b) upward continuation (400 m) map of horizontal gradient in Bouguer anomaly.

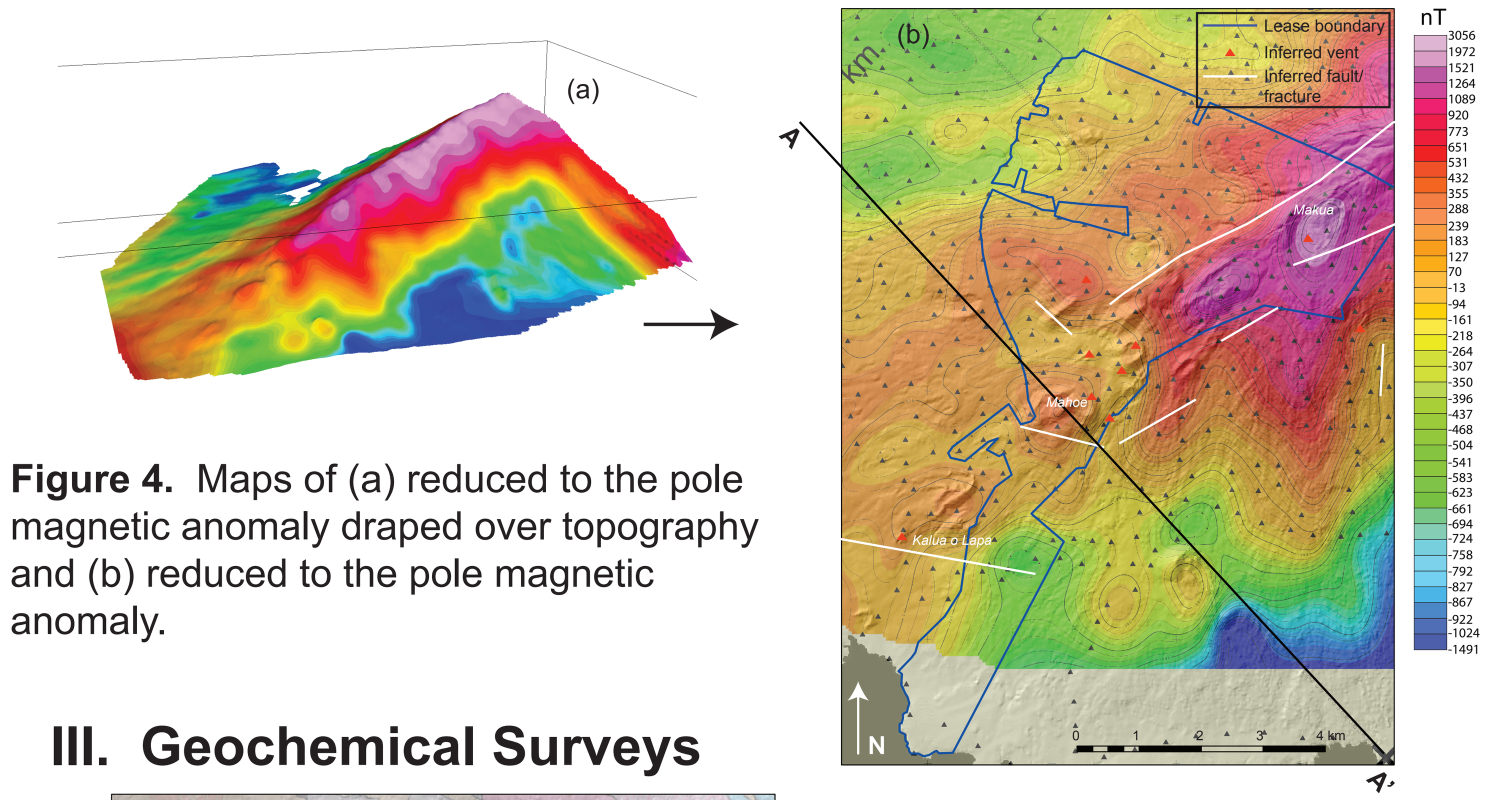

Figure 4. Maps of (a) reduced to the pole magnetic anomaly draped over topography and (b) reduced to the pole magnetic anomaly.

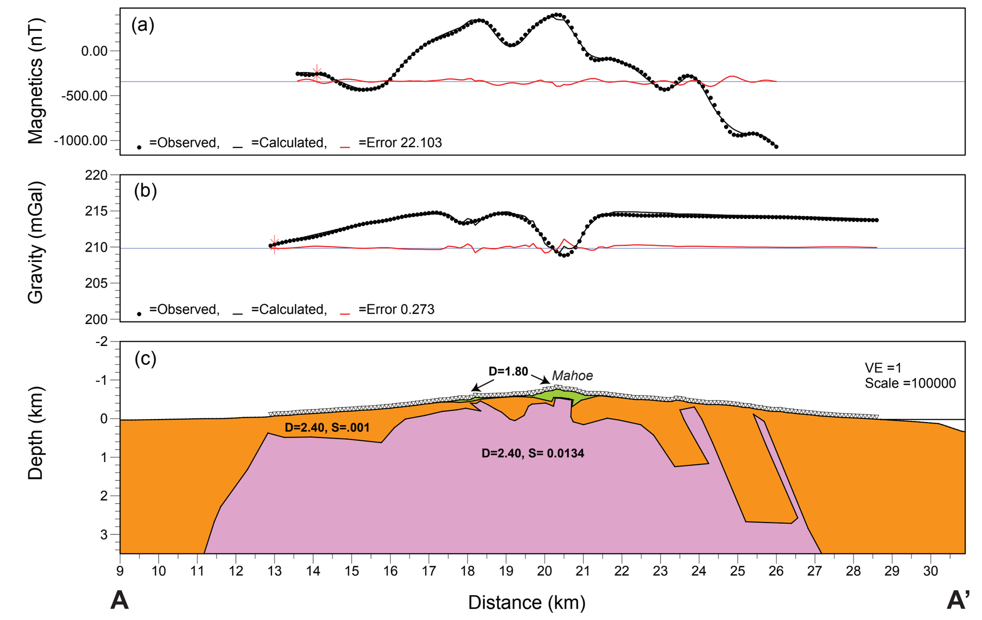

Figure 5. Preliminary two-dimensional gravity and magnetic model of subsurface (cross-section A-A' shown in **Figures 2-4**). Field data and synthetic curves shown in (a) and (b). (c) Modeled vent zones (green) underlain by dike intrusions (pink).

III. Geochemical Surveys

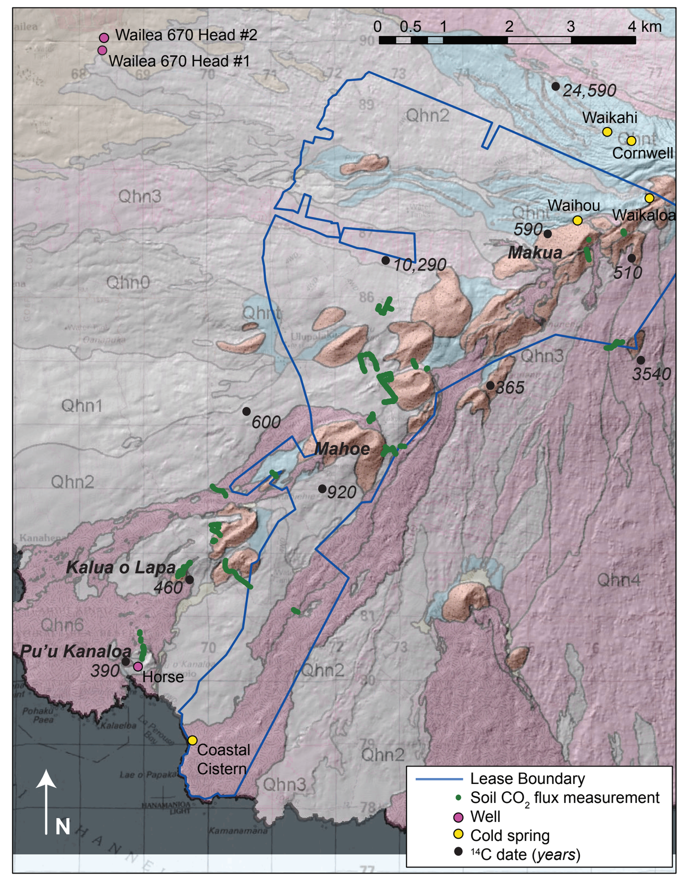

Figure 6. Map showing geology [*Sherrod et al.*, 2007], Ulupalakua lease boundary, and locations of soil CO_2 flux measurements (n = 406) and sampled wells and springs. Fluxes were measured near young lava flows and vents (selected ^{14}C dates shown in years [*Sherrod and McGeehin*, 1999]), plant stress identified in hyperspectral imagery, and geophysical anomalies.

Well/Spring	Name	$\delta^{13}C$-DIC (‰, PDB)	$(R/Ra)_c$
Puna Production	KS-6	-2.90	14.34
Puna Production	KS-5	-2.60	14.52
Puna Production	KS-14	-1.50	14.46
Puna Production	KS-10	-0.80	15.13
Puna Production	KS-9	-1.70	14.61
Puna Groundwater	MW-2	-3.49	10.77
Puna Groundwater	MW-1	-4.17	5.28
Puna Groundwater	MW-3	-4.64	10.81
Hualalai Groundwater	On-Rift	-2.24	8.53
Hualalai Groundwater	On-Rift	-1.71	9.20
Hualalai Groundwater	On-Rift	-2.54	8.02
Hualalai Groundwater	On-Rift	-2.36	9.27
Hualalai Groundwater	Off-Rift	ND	4.53
Hualalai Groundwater	Off-Rift	ND	4.47
Maui Groundwater	Horse	-5.40	3.15
Maui Spring	Cornwell	-11.37	ND
Maui Spring	Waikahi	-11.08	ND
Maui Spring	Waihou	-8.98	ND
Maui Spring	Waikaloa	-11.95	ND
Maui Groundwater	Wailea 670 Head #1	-7.74	7.63
Maui Groundwater	Wailea 670 Head #2	-10.22	7.43

Table 1. Stable carbon and air-corrected helium $[(R/Ra)_c]$ isotopic compositions for springs and wells sampled on LKERZ (Puna), Hualalai Rift Zone, and HSWRZ.

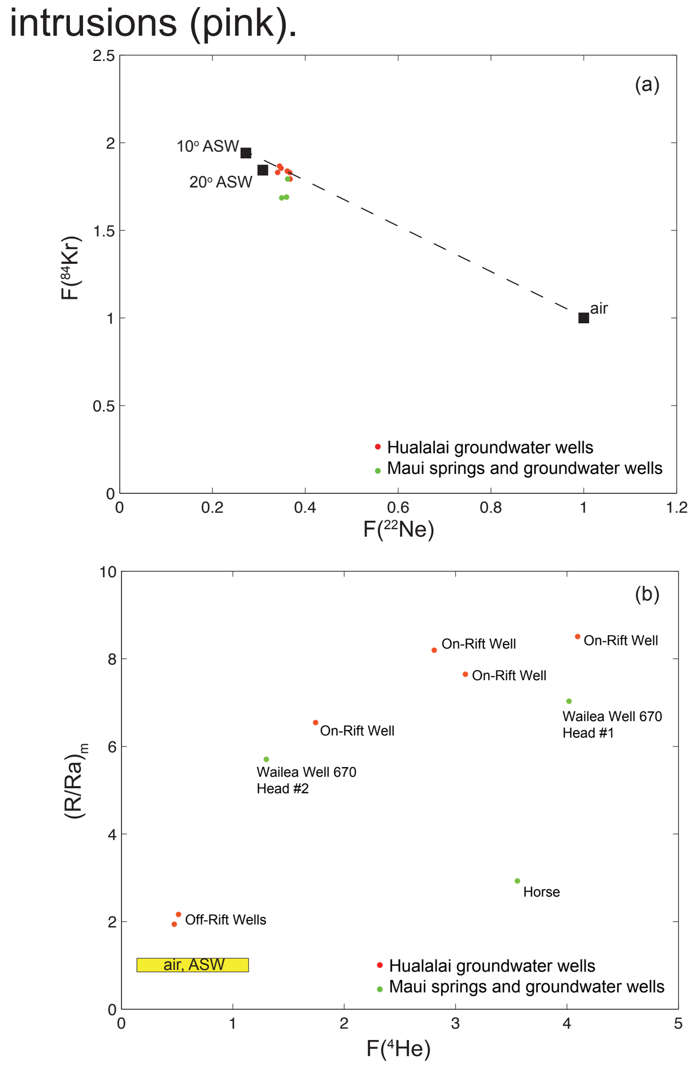

Figure 7. (a) Relative abundances of noble gases in waters compared to air-saturated water at 10 and 20°C and air. (b) Measured helium isotopic compositions $[(R/Ra)_m]$ in waters as a function of the ^4He enrichment factor $[F(^4He)]$. Data trend for Hualalai and Wailea samples is consistent with mixing a magmatic helium-enriched components with air-saturated water.

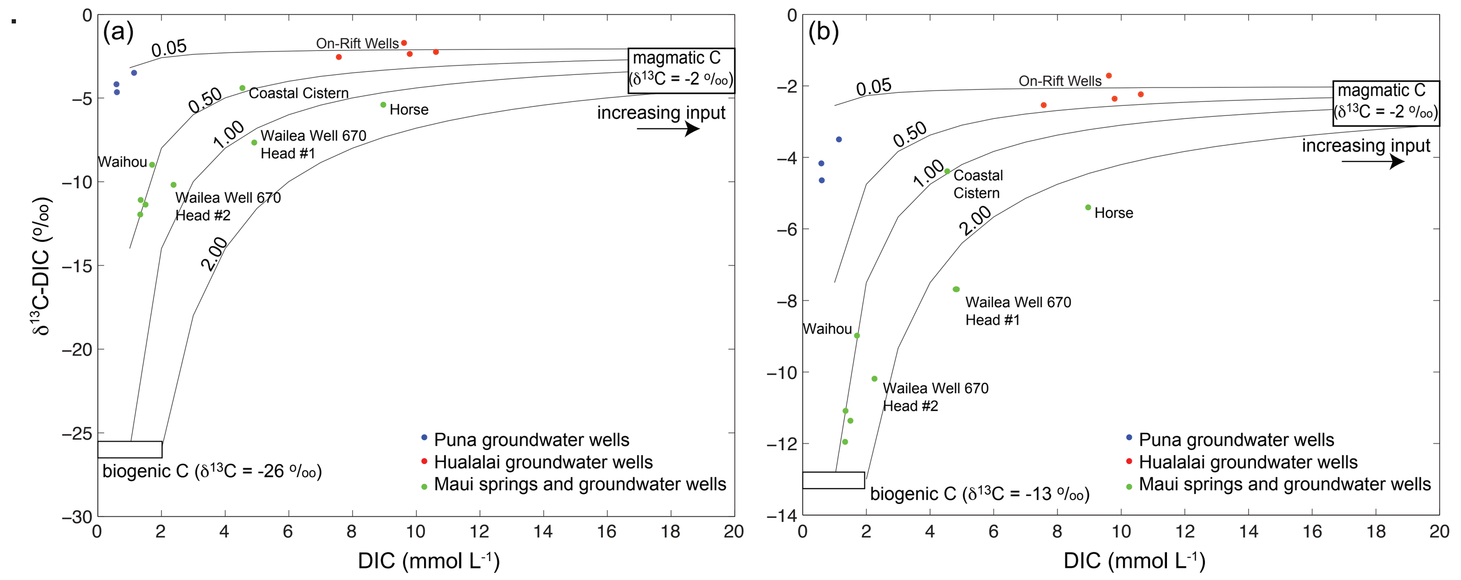

Figure 8. $\delta^{13}C$-DIC versus DIC concentration diagrams for groundwater and spring samples from LKERZ (Puna), Hualalai, and HSWRZ. [after *Chiodini et al.*, 2000]. Theoretical curves of mixing between (a) biogenic carbon with $\delta^{13}C$ = -26 ‰ and magmatic carbon with $\delta^{13}C$ = -2 ‰ and (b) biogenic carbon with $\delta^{13}C$ = -13 ‰ and magmatic carbon with $\delta^{13}C$ = -2 ‰ are shown for initial concentrations of biogenic carbon = 0.05, 0.50, 1.00, and 2.00 mmol L^{-1}.

IV. Summary

1) Locations and geometries of faults/fractures, vent zones, and dike intrusions within the HSWRZ were inferred based on ground-based gravity coupled with heli-bourne magnetics.

2) An airbourne LiDAR survey of HSWRZ was carried out in November 2011. Geophysical modelling of HSWRZ is ongoing and will integrate fault/fracture mapping based on LiDAR results.

3) Soil CO_2 flux measurements typically did not show evidence for upflow of magma-derived CO_2 to the surface within the HSWRZ and KLERZ. Spatial variations in flux were instead correlated with vegetation type and density and soil development.

4) Noble gas and carbon geochemistry indicated contribution of magmatic helium and carbon to shallow groundwaters within the HSWRZ, Hualalai Rift Zone, and KLERZ. Groundwater geochemistry may be a more successful indicator of magmatic fluid upflow than soil CO_2 flux measurement in areas with high groundwater flow, relatively deep vadose zone, and/or dense vegetation that may mask upflow of magmatic volatiles to the surface.

5) Deep temperature gradient core holes will be cited based on synthesis of multi-disciplinary data sets. Lithologic, physical property, and fluid geochemical data collected during exploratory drilling will further refine models of the HSWRZ geothermal system.

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