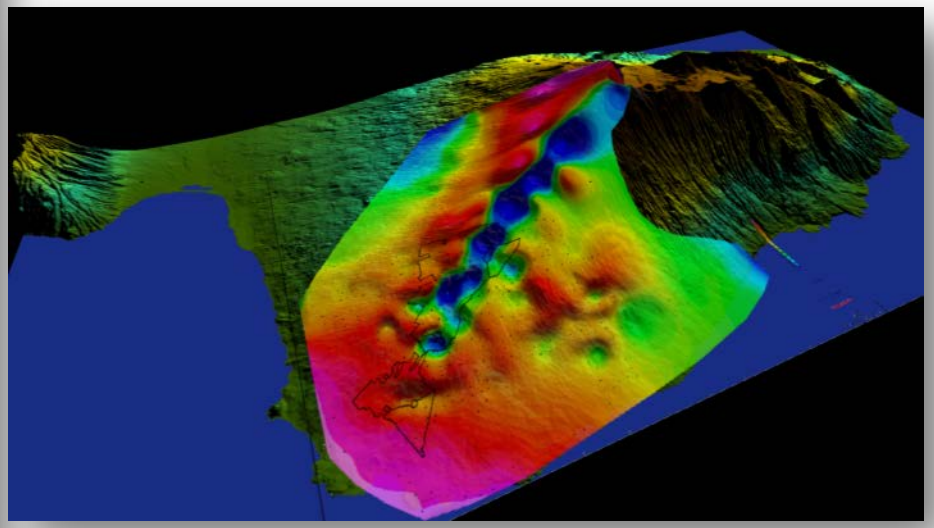

Blind Geothermal System Exploration in Active Volcanic Environments; Multi-phase Geophysical and Geochemical Surveys in Overt and Subtle Volcanic Systems, Hawai'i and Maui

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Innovative Exploration Technologies

Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Timeline
  - Project start date ***10/29/2009***
  - Project end date ***Q2 2013***
  - Percent complete ~**50%**
- Barriers
  - ‘Blind’ system
  - Culturally sensitive location
- Partners
  - Lawrence Berkeley National Lab

Relevance/Impact of Research

Blind geothermal exploration in young, basaltic volcanic environments

- Typically, basaltic environments are considered to be low heat-flux targets; young hot-spot volcanism is an exception
- This project uses a combination of:
  - Novel geophysical/geochemical synthesis of data in a blind/dormant basaltic terrain (Southwest Rift Zone – Haleakala – Maui)
  - Known geophysical/geochemical behavior at an overt/active, produced geothermal system (Kilauea Lower East Rift Zone – Puna- Hawai'i Island)

Ulupalakua, Maui

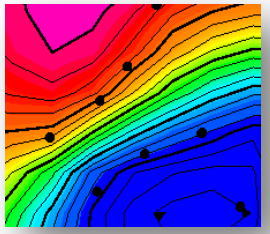
Puna, Hawai'i

Relevance/Impact of Research

Novel combinations of tested technology systems

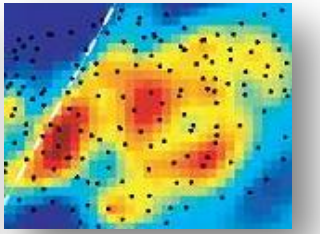
- Low-altitude, high resolution heli-magnetics
- High density ground-based gravity
- Targeted CO_2 flux grids (+/- shallow temperature)
- Targeted isotope sampling (Helium and Carbon)
- *Photogrammetry*

The synthesis of these datasets realizes a holistic model of Haleakala 'plumbing' (fluids and structure) and demonstrates geophysical/geochemical strengths and limitations in the hot spot environment

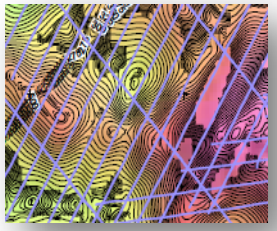


Gravity

CO_2 Flux

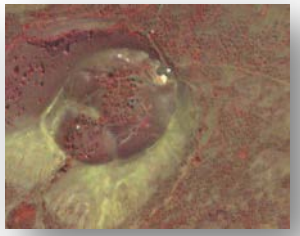


Soil Temp.



Aeromagnetics

Isotope Geochem



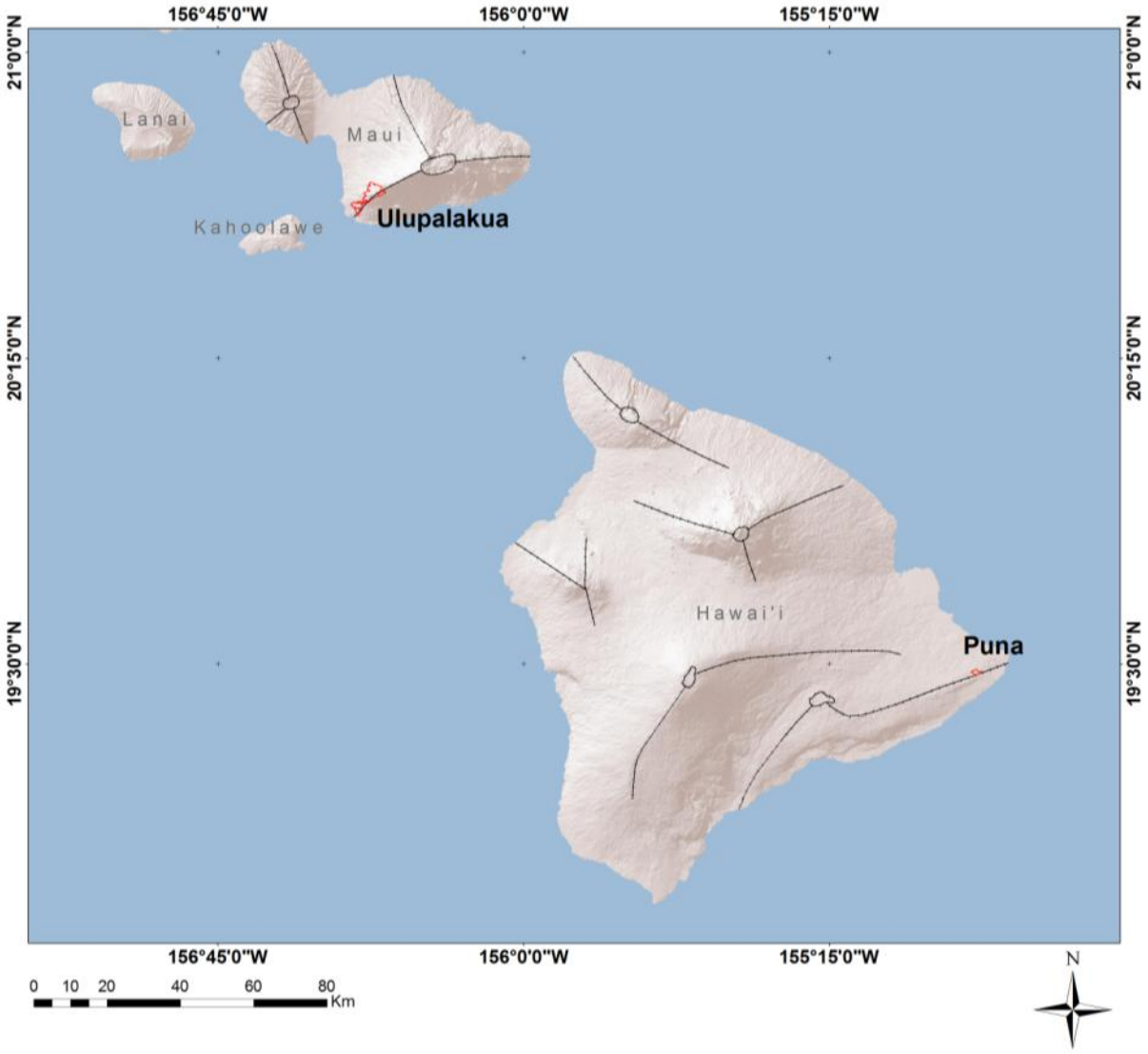
Photogrammetry

Relevance/Impact of Research

- Our research:
  - Provides a benchmark for exploration of other ‘blind’, dormant volcanic systems
  - Validates gravimetry and aeromagnetics for geothermal exploration in young, basaltic volcanic environments (including challenges)
  - Demonstrates success and challenges of CO_2 and isotope analysis in young, hot-spot volcanic systems for geothermal exploration
  - May ultimately result in baseload energy generation for Maui

Haleakala SW Rift Zone

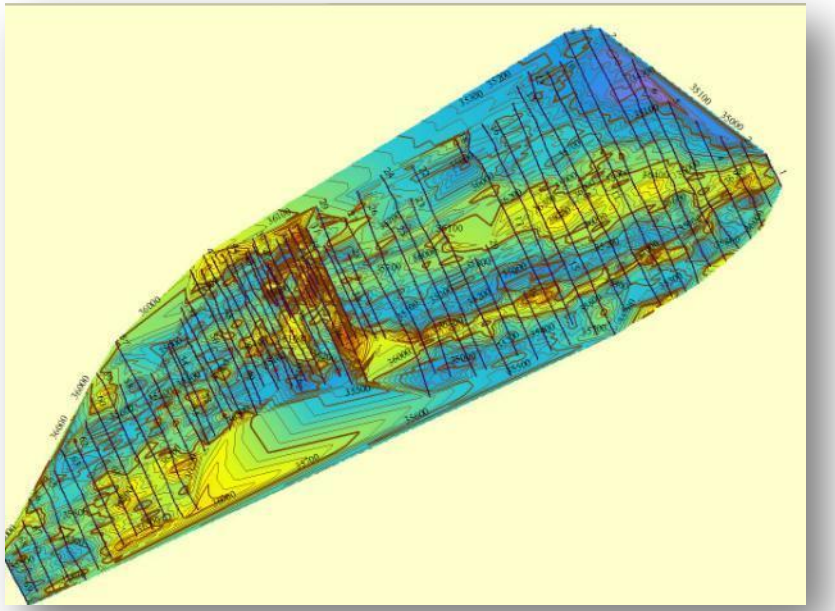
Study Areas – Maui and Hawai'i Island



Scientific/Technical Approach

- Compile historical geophysical and geochemical information for the Puna geothermal field
  - Status: Complete
    - Old gravity and aeromag were re-processed using modern algorithms and georeferenced to standard datums and projections
    - Geochemical data compiled; many sources over three decades

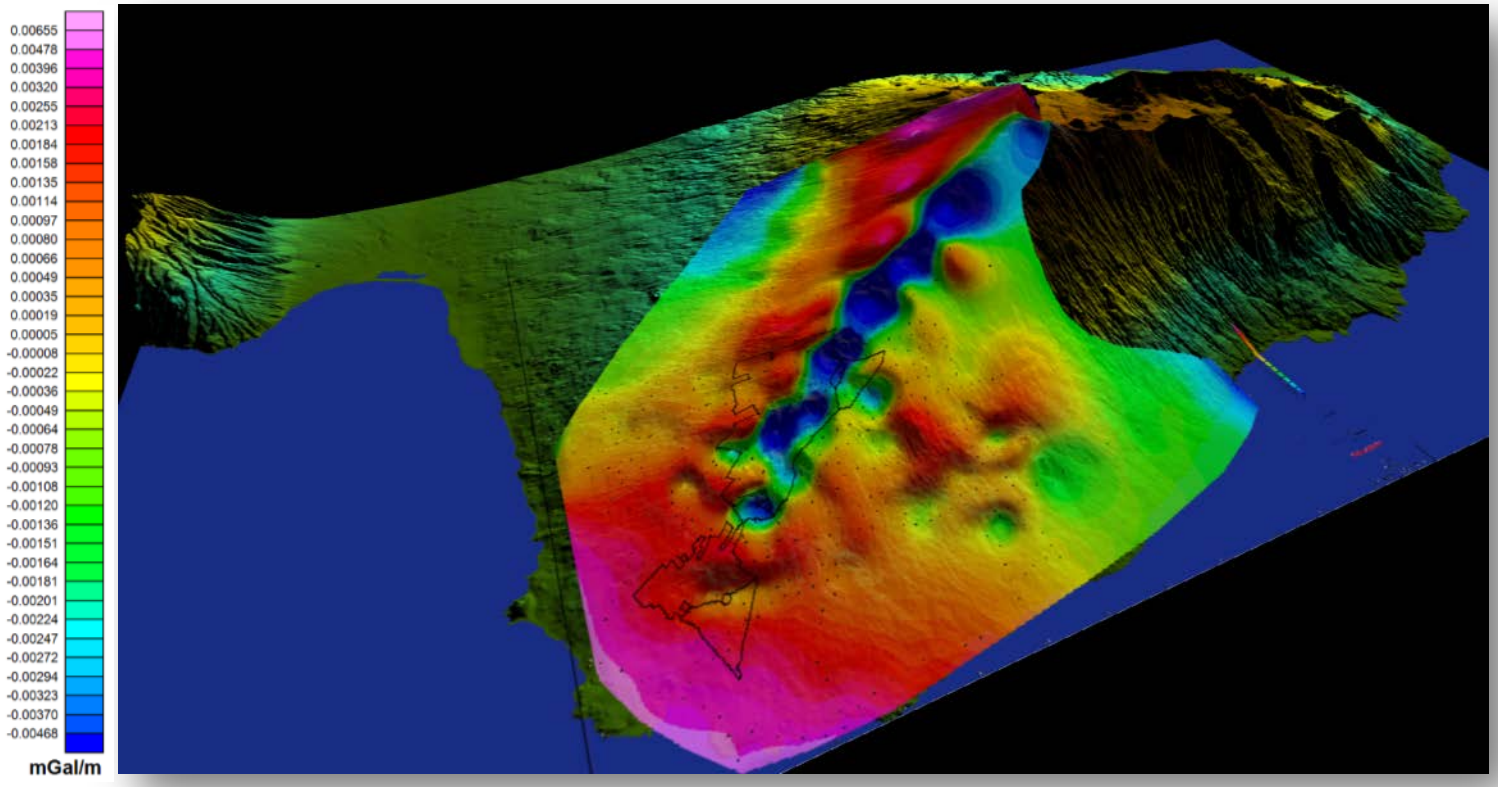
Archiving and re-processing makes sure we're comparing 'apples to apples' between Maui and Hawai'i geophysics and geochemistry



Re-processed TMI (archival USGS data) - Puna, Hawai'i

Scientific/Technical Approach

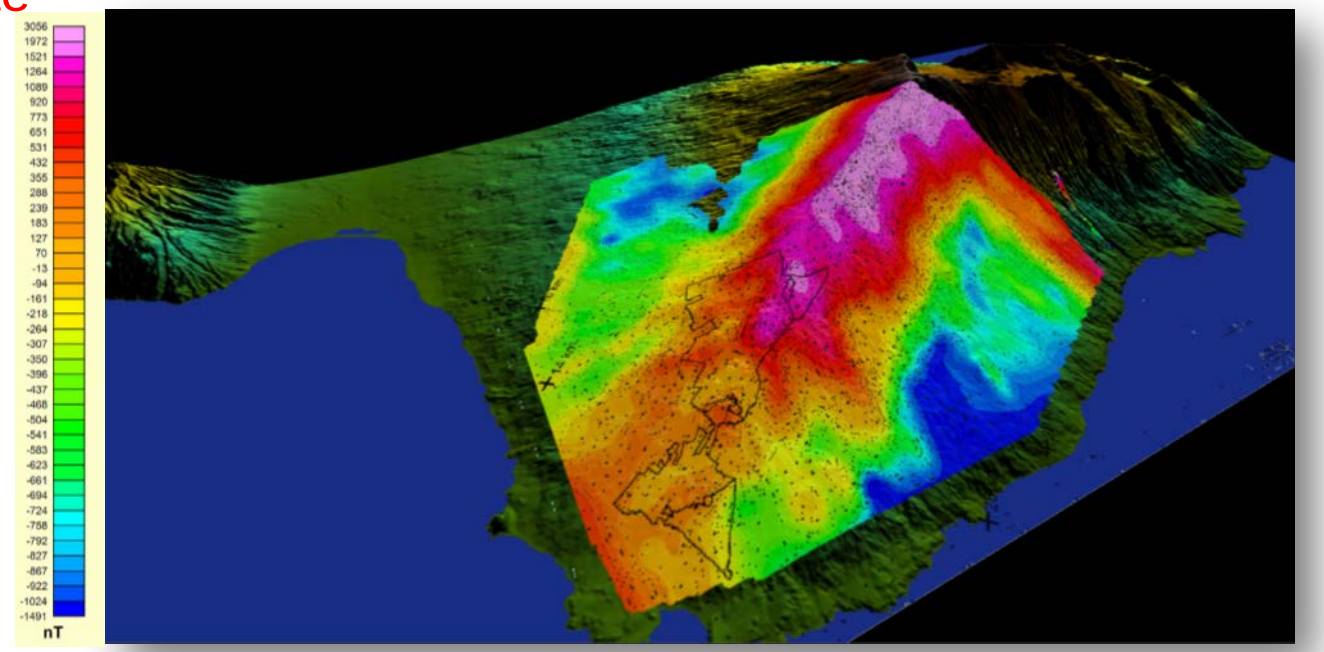
- Acquire ground-based gravity of Ulupalakua Ranch and surrounding land on Maui (~400 stations at 400 m spacing)
  - Status: Complete



First Vertical Derivative of Complete Bouger (2.4 gm/cc) – Upward continued to 400m

Scientific/Technical Approach

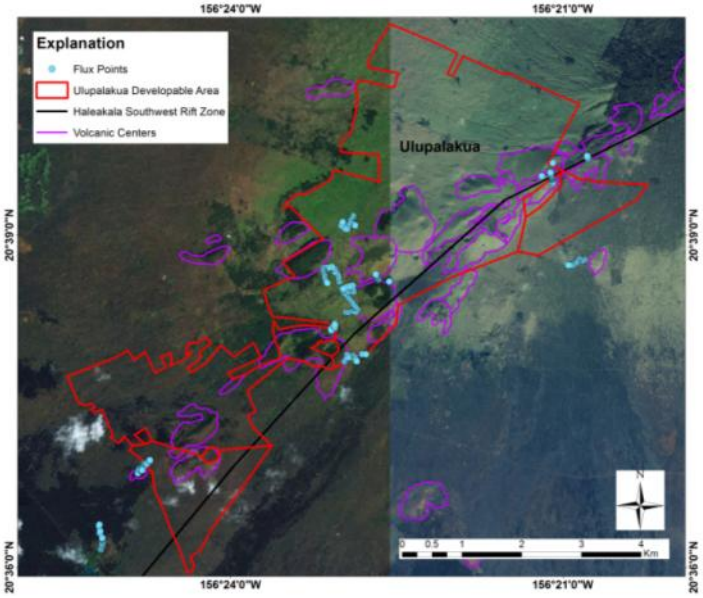
- Acquire aeromag of Ulupalakua Ranch and surrounding land on Maui (~1500 line kilometers @ 400 m spacing) – combine with gravity to generate fault/fracture maps for flux and exploration targets
  - Status: Complete

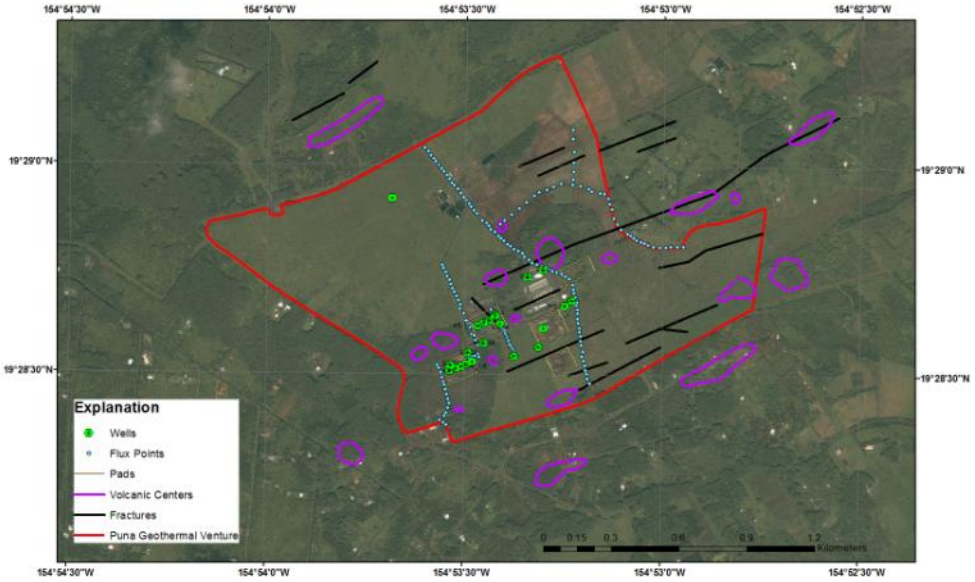


Total Magnetic Field – Reduced to North Magnetic Pole (Heli-bourne)

Scientific/Technical Approach

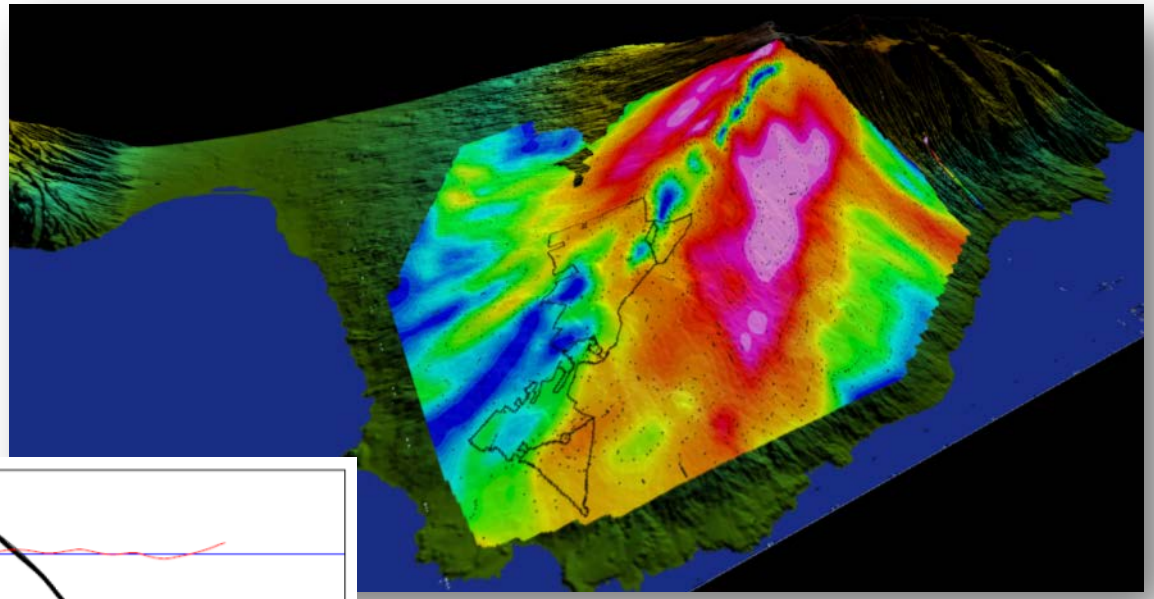
- Conduct flux surveys across geophysically defined structures at both Puna and Ulupalakua for potential CO_2 degassing
  - Status: in-progress (75% complete)
    - Flux measurements were taken during two separate trips within and directly adjacent to the Puna field during production and outage
    - Sites of recent volcanism and geophysically defined anomalies along the HSWRZ were sampled over four separate trips on Maui

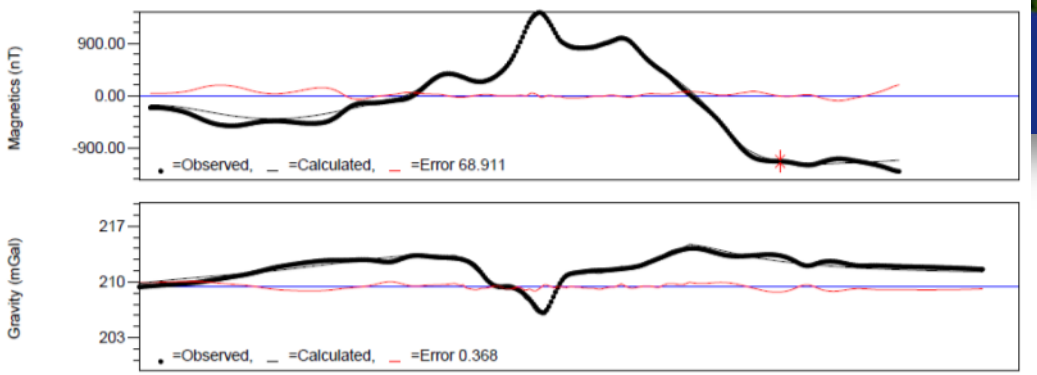




Scientific/Technical Approach

- Synthesis of gravity and magnetic datasets; creation of 3-D geophysical/structural model of the Ulupalakua project
  - Status: In-progress.

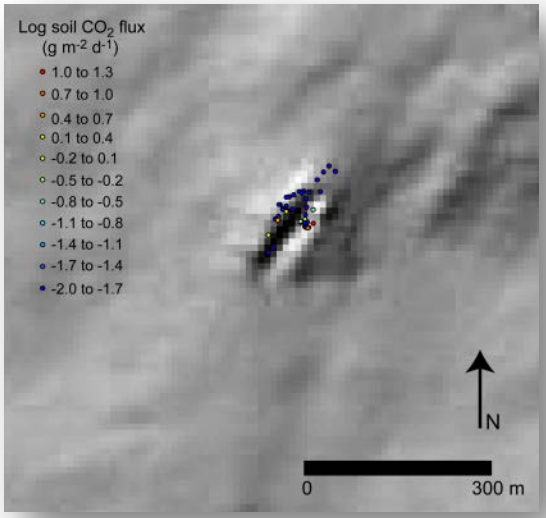




Horizontal Gradient of Pseudo-Gravity (actually magnetic data transformed to magnetic potential)

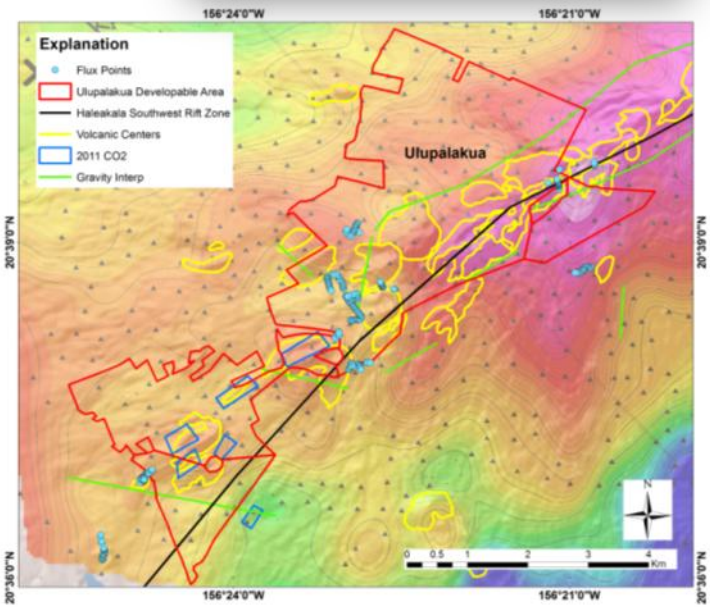
- Geochemical survey results have been mixed
  - The lack of observed flux at known fracture and volcanic centers at Puna may be explained by 'scrubbing' of CO_2 by the significant groundwater transport through the southeast flank of Kilauea; isotopic data bears this out
  - The lack of CO_2 flux on the Haleakala SW Rift Zone (with one notable exception) could be a function of 1) probable low overall flux in this dormant system, 2) similar groundwater scrubbing, 3) biogenic exhalation swamping magmatic flux

Small, albeit 'real' magmatic flux of CO_2 was measured in the Pakaka region – a zone of <600 ya cinder cones



Accomplishments, Results and Progress

- Geophysical synthesis still in progress
  - Magnetics appears to be ‘seeing’ more shallow while gravity is picking up shallow and very deep anomalies
    - Both clearly map the rift and some fractures (LiDAR could fill in surface better)
    - Deep faults/dikes/’breaks’ seen strongly in gravity; less so in mag
  - Preliminary 2-D synthesized models of gravity and magnetics are encouraging but some problems
    - Topography in mag causing error; working on correction (*LiDAR may help*)
    - Very high measured susceptibilities – investigating veracity with field samples
    - Models are ‘floating’ without downhole lithology information – depth estimates thus questionable



Gravity anomalies plotted on RTP magnetics (with planned May 2011 flux measurements)

Project Management/Coordination Data Integration

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- Project Management
  - Martini (co-PI) is managing and overseeing all phases of database creation, geophysical acquisition, hyperspectral analysis, project logistics and budgeting
  - Lewicki (co-PI) is coordinating the geochemical surveys (CO2 flux and isotope)
  - Ezra Zemach (Ormat) project management/budget
  - Christopher Heaps (Ormat) project management/permitting
- Schedule
  - Phase 1 completion ***(early Q4/2011)***
  - Phase 2/3 completion – Permitting and drilling ***(Q1-2/2012)***
- Application of Resources
  - The remaining budget for Phase 1 will be spent in 2011
  - Considering follow-on LiDAR survey to help make up for the loss of usable hyperspectral data and to better map surface structure not mapped by magnetics (especially on the lower rift where geophysical signals become dampened)
- NGDS integration
  - Our database (that will include geophysical surveys and geochemical measurements) will be provided to the NGDS when drilling is complete

Collaborations

- Collaborators:
  - Dr. Jennifer Lewicki (Co-PI) – LBNL
  - Dr. Mack Kennedy (Investigator) – LBNL
  - Peter Drakos (Investigator) – Ormat
  - Chet Lide (geophysical interp/modeling, gravity sub-contractor) – Zonge International
  - Paul Spielman (Investigator – drilling/reservoir) – Ormat
  - EdCON-PRJ (magnetics sub-contractor)

- Jobs
  - 3.77 full time jobs (1 year)

Future Directions

- Final CO_2 flux surveys in May 2011 – testing remaining geophysically defined targets
  - Only in non-vegetated regions of Ulupalakua
  - Mapped flux will influence final drill locations; no mapped flux further supports hypotheses (biogenic, scrubbing, low flux, etc.)
- Final synthesis of gravity and magnetics plus 3D modeling of datasets
  - Will be completed in Montaj (Zonge) and Leapfrog (software recently purchased as part of the Glass Buttes DOE project, Walsh (PI)
  - *We expect to site drill targets in early Q4/2010*
- Permitting/Regulations
  - EA commenced in mid-April 2011
  - Maui drilling regulations in preparation
  - Expect permits by Q2/2012

Summary

	FY2010	FY2011
Target/Milestone	Acquire high density ground gravity and heli-bourne magnetics	Synthesize and co-model data to develop 3-D model of Haleakala SWRZ structure and potential hydrothermal system
Results	Completed 6/10	Preliminary modeling began 4/11; expect final models by Q4/2011
Target/Milestone	Archive historical geochemistry	Acquire fill-in geochemistry, new aqueous and gas geochemistry (including isotopic data from wells and springs)
Results	Completed 7/10	90% complete; two more wells on Maui set for sampling in 5/11
Target/Milestone	Archive and re-process historical geophysics	Re-process old Puna gravity/magnetics using new methods being developed at Ulupalakua
Results	Completed 8/10	On-going; started 5/11; expect completion Q3/2011
Target/Milestone	Make CO2 flux measurements along geophysically-defined targets	Make CO2 flux measurements along geophysically-defined targets
Results	50% completed in 2010	75% completed by 2/11; expect 100% completion by 5/11

GTP Goals (continued)

- **Innovative Exploration Technologies**
  - Confirm 400 MW of geothermal energy capacity
    - Hot spot volcanism similar to Puna Geothermal Venture
    - ~30 MW
  - Validate two new exploration methods
    - Synthesis of ground-based gravity with airborne magnetics in young, basaltic terrain
    - CO_2 flux as indication of present-day magmatic degassing via faults and fractures