Play Fairway Analysis of Geothermal Potential across the State of Hawaii

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Track: Hydrothermal
Project Officer: Eric Hass
Total Project Funding: $1,567,732 (excl cost share)

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Project Objectives

Phase 1. Identify, compile, and rank geothermal-relevant data across the State of Hawaii. ✓
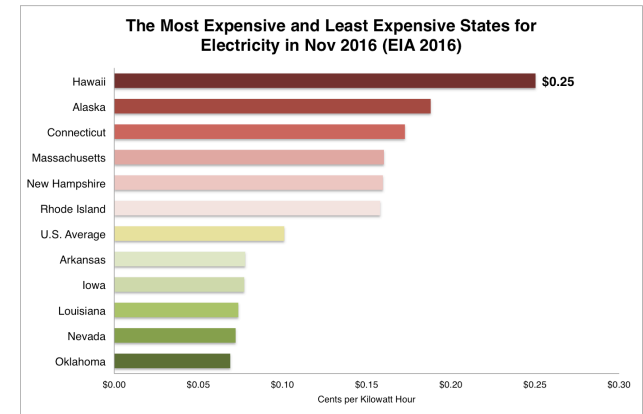Develop methods to integrate different data types into resource probability map

Phase 2. New geophysical and groundwater surveys in up to 10 target areas; methods for
3D data; model topographic stresses to improve Phase 1 probability map ✓

Phase 3. Validate resource through collaborative drilling in 1 of 2 targets

Impact / Innovation

- Hawaii pays **2.5x the national average** for electricity
- Unique geologic setting
- Last statewide geothermal assessment (1985) found potential resource on *all* islands. Little exploration since
- Policy objective that state is 100% renewable by 2045
- Geothermal is the only feasible base-load energy source. This is the only publically-funded geothermal project in the state
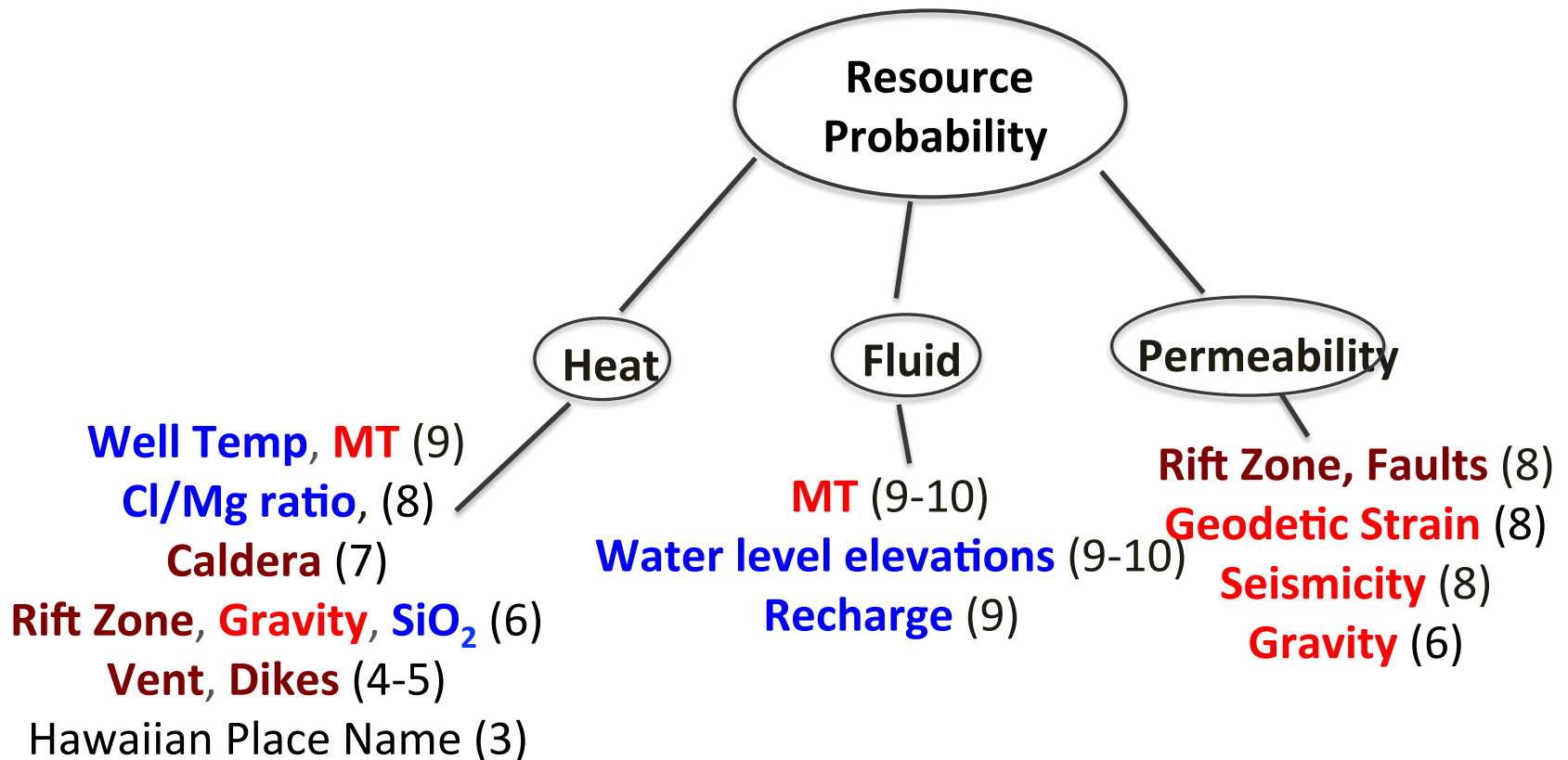
The Most Expensive and Least Expensive States for Electricity in Nov 2016 (EIA 2016)

State	Cents per Kilowatt Hour
Hawaii	$0.25
Alaska	
Connecticut	
Massachusetts	
New Hampshire	
Rhode Island	
U.S. Average	
Arkansas	
Iowa	
Louisiana	
Nevada	
Oklahoma	

Alignment with GTO goals

- Lower risk of development
- Lower electricity costs
- Near term *blind* hydrothermal resource growth

Data Identification, Collection and Ranking – Phase 1
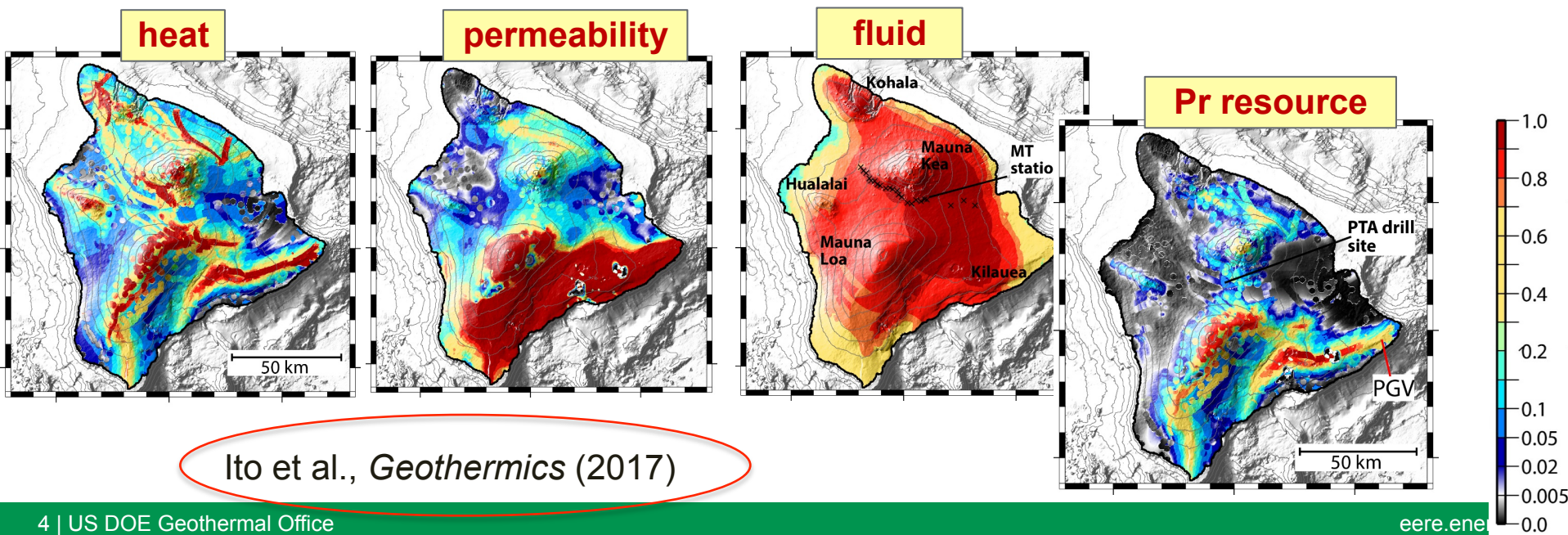
GEOLOGICAL, GEOPHYSICAL, and GROUNDWATER data

Resource Probability

Heat

Fluid

Permeability

Well Temp, **MT** (9)
Cl/Mg ratio, (8)
Caldera (7)
Rift Zone, **Gravity**, **SiO$_2$** (6)
Vent, **Dikes** (4-5)
Hawaiian Place Name (3)

MT (9-10)
Water level elevations (9-10)
Recharge (9)

Rift Zone, Faults (8)
Geodetic Strain (8)
Seismicity (8)
Gravity (6)

Lautze et al., *Geothermics* (2017a)

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Statistical Approach – Phase 1

Each ***processed*** data type a_i is weighted and combined with other data using a generalized linear model with expit function. For example, the ***probability of heat*** at location *x* is given by,

$$\Pr(H|\vec{x}) = \left[1 + \exp\left(-w_{0H} - \sum_{i=1}^{n} w_{iH} a_i(\vec{x})\right)\right]^{-1}.$$

The probability of a resource at a given location is the joint probability of H, F, P, approximately equal to the product:

$$\Pr(H,F,P|\vec{x}) \approx \Pr(H|\vec{x})\Pr(F|\vec{x})\Pr(P|\vec{x}).$$

Ito et al., *Geothermics* (2017)
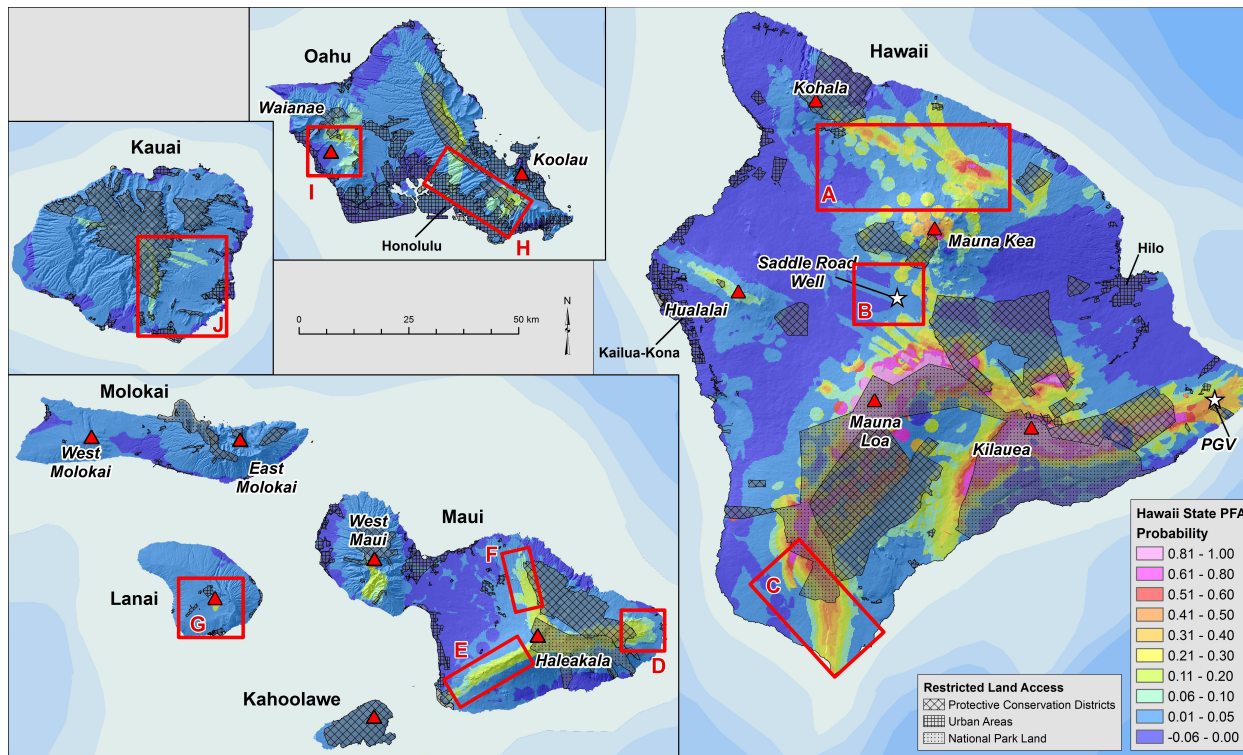
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Probability Map - Phase 1

3 Products: **Probability, Confidence, & Development Viability** used to select Phase 2 targets
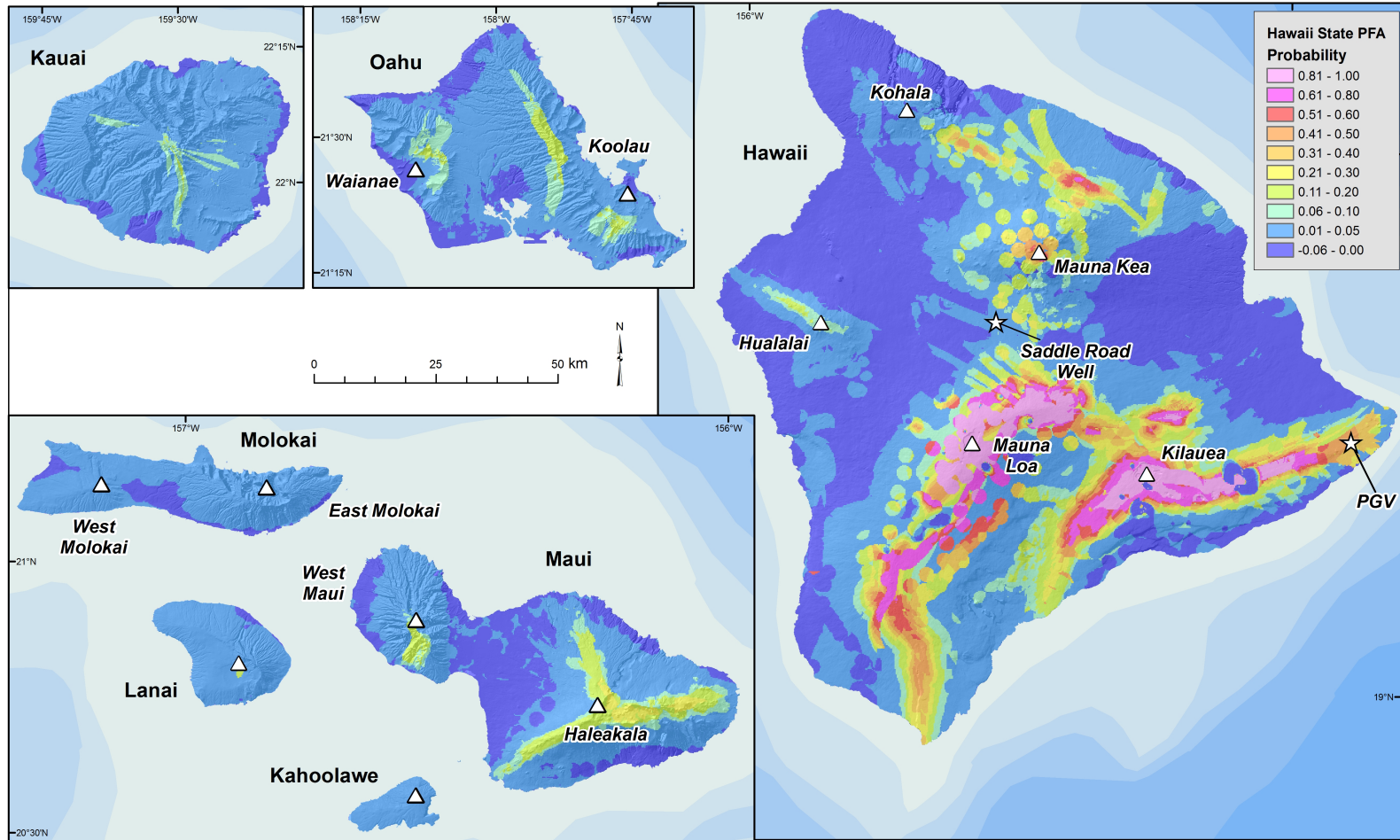
Development Viability - Phase 1

if a resource is identified, what is the plausibility of development?

- Level of community acceptance
- Vulnerability to natural hazards
- Compatibility of land use/zoning
- Integration into electrical grid

Lautze et al., *Geothermics* (2017b)

Prioritization of Phase 2 Tasks

Table 4. Proposed Phase 2 Targets and Priority Ranking

Site	Phase 1 Rankings			Rankings of Priorities for Phase 2			
	Resource Probability	Confidence	Dev. Viability	Water Surveys	Stress Modeling	Geophy. Surveys	2-D/3-D Modeling
North M.Kea (Hawaii)	70-120%, H	35-53%, M	M	H	H	M	H/M
SW M. Kea, Saddle (Hawaii)	10-70%, L-H	12-24% L	L-M	L	H	L	H/M
SW Haleakala (Maui)	24-43%, L-M	11-36% L-M	H	H	H	H	H/H
Lanai	10-24% L	35-42% M	H	H	H	H	H/ H
SW MLoa (Hawaii)	95-120% H	35-47% M	L-M	M	H	L	H/L
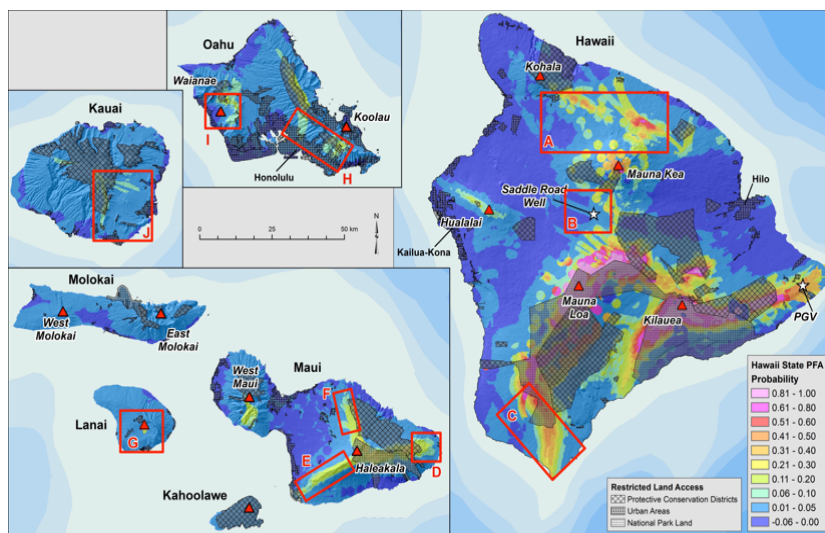
Four BP2 Tasks
(1) Geophysical Surveys ✓
(2) Groundwater Sampling & Analyses ✓
(3) Stress / Failure Potential Modeling ✓
(4) New probability maps from 2D/3D information ✓

COMPLETED 110% OF BP2 OBJECTIVES!*

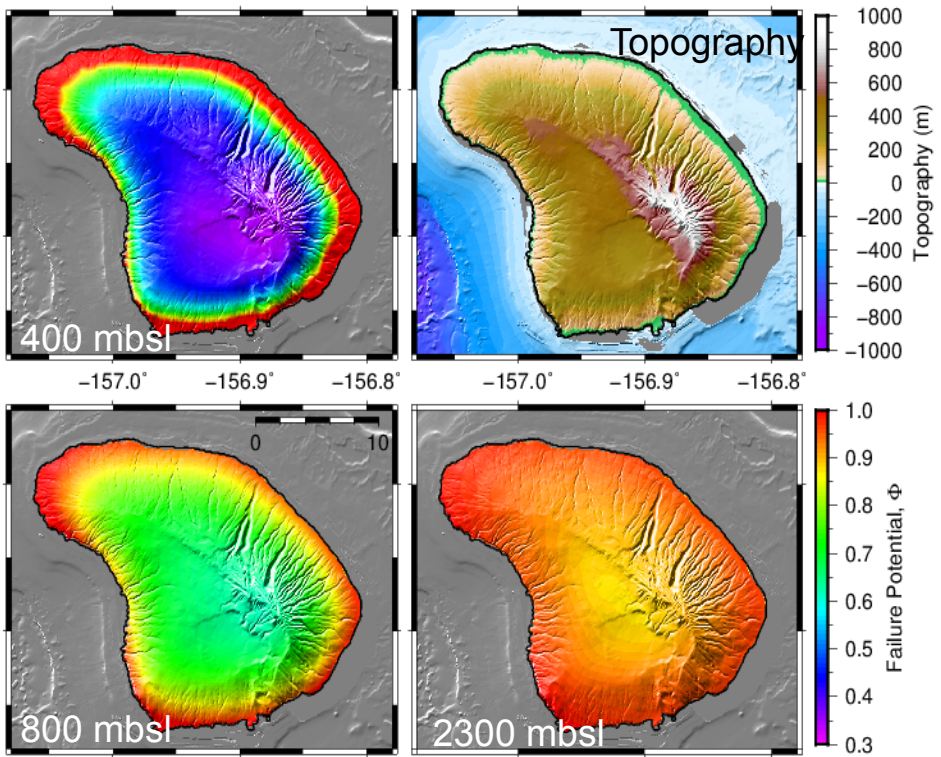| PHASE 2 TASK	OUTPUT	OUTCOME
8. Groundwater Sampling	- 62 samples collected in 10 areas - analyzed for T, major, trace elements and isotopes	*Expanded and validated Phase 1 groundwater dataset relevant to geothermal *Improved GW flow paths for Lanai
9. Topographic Stress Modeling	3D models of stresses for all target islands	Improve probability and confidence maps.
10. Geophysical Surveys	- 44 MT sites Lanai, 8 MT sites Maui - New inversions of MT lines, Mauna Kea - 140 gravity stations Lanai - 73 gravity stations Mauna Kea - Acquire and inverted a gravity survey, Haleakala SE Rift Zone	* Significantly added to geophysical data relevant to geothermal potential on Lanai, Maui, and Hawaii. * 2D/3D structural models (density & resistivity) to identify & rank drill sites.
11. Update Probability and Confidence Maps	Updated maps of probability of heat, permeability, fluid, and geothermal resources across Hawaii and in the 3 geophysical survey areas	Improved assessment of resource potential statewide.
12. Rank Drilling Plays for BP3	Qualitative and quantitative evaluations of all data in the 3 geophysical survey areas	• Priority 1: SE Mauna Kea • Priority 2: Lanai's Palawai caldera

Methods/Approach

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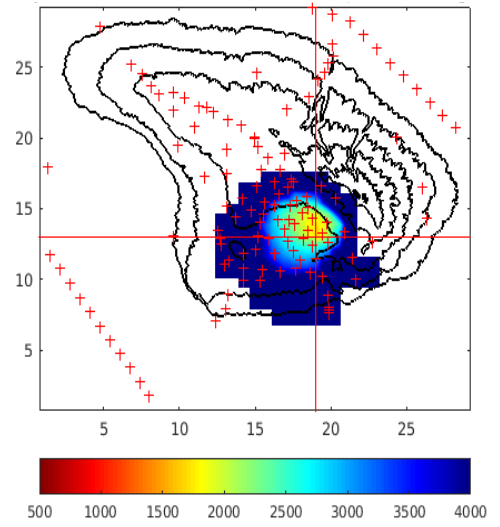| PHASE 2 TASK	OUTPUT	OUTCOME
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PHASE 2 TASK	OUTPUT	OUTCOME
9. Topographic Stress Modeling	3D models of stresses for all target islands	Improve probability and confidence maps.

LANAI: High failure potential at reservoir depths (1-3 km) favorable for enhanced permeability

New method & code **1000x faster** than other methods

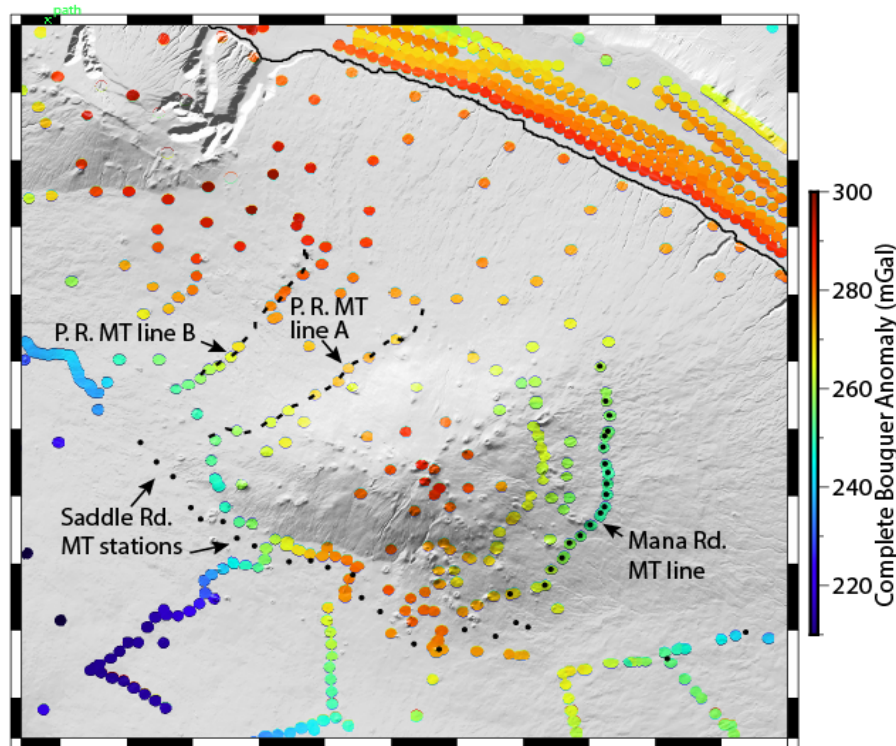Depth below surface to the 90% probability of density > 2900 kg/m

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10. Geophysical Surveys	- 44 MT sites Lanai, 8 MT sites Maui - New inversions of MT lines, Mauna Kea - 140 gravity stations Lanai - 73 gravity stations Mauna Kea - Acquire and inverted a gravity survey, Haleakala SE Rift Zone	* Significantly added to geophysical data relevant to geothermal potential on Lanai, Maui, and Hawaii. * 2D/3D structural models (density & resistivity) to identify & rank drill sites.

Lāna'i:
44 MT
144 Gravity
**Sites**

Mauna Kea MT & Gravity *(PF Bonus!)*

## Maui MT & Gravity (ORMAT)

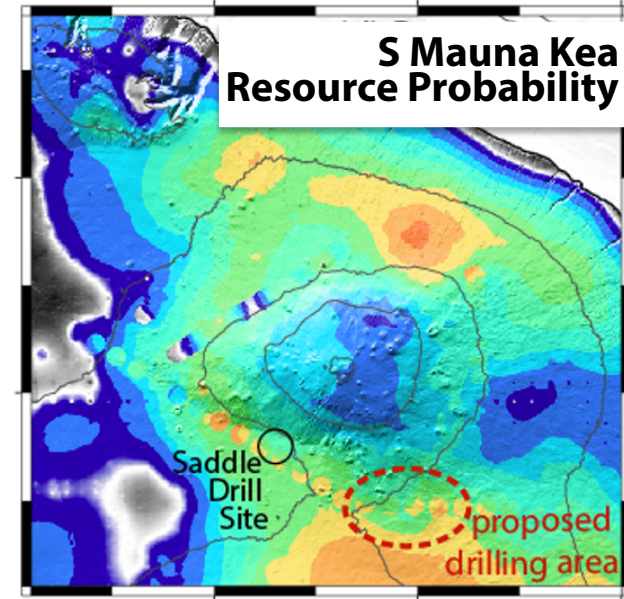| PHASE 2 TASK	OUTPUT	OUTCOME
10. Geophysical Surveys	- 14 MT sites Lanai, 8 MT sites Maui - New inversions of MT lines, Mauna Kea - 140 gravity stations Lanai - 73 gravity stations Mauna Kea - Acquire and inverted a gravity survey, Haleakala SE Rift Zone	* Significantly added to geophysical data relevant to geothermal potential on Lanai, Maui, and Hawaii. * 2D/3D structural models (density & resistivity) to identify & rank drill sites.
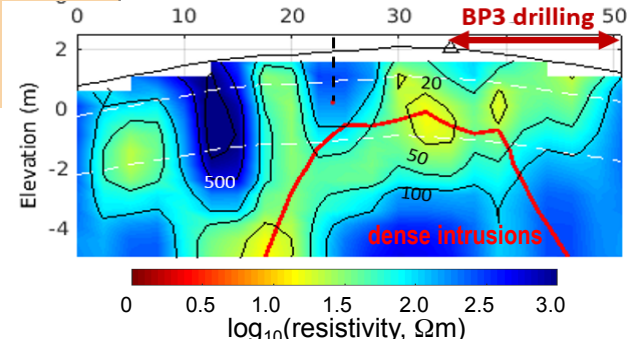
LĀNA'I 3D MT Inversions
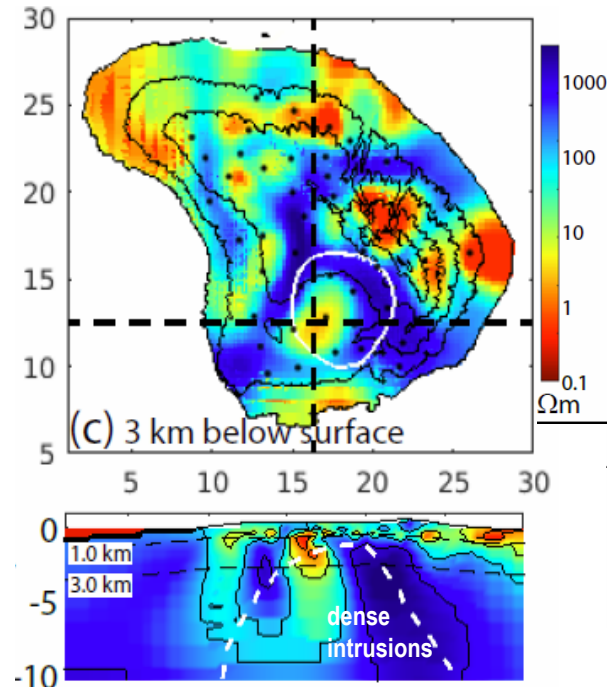
**S. Mauna Kea MT Inversions**

LĀNA'I Resource Probability
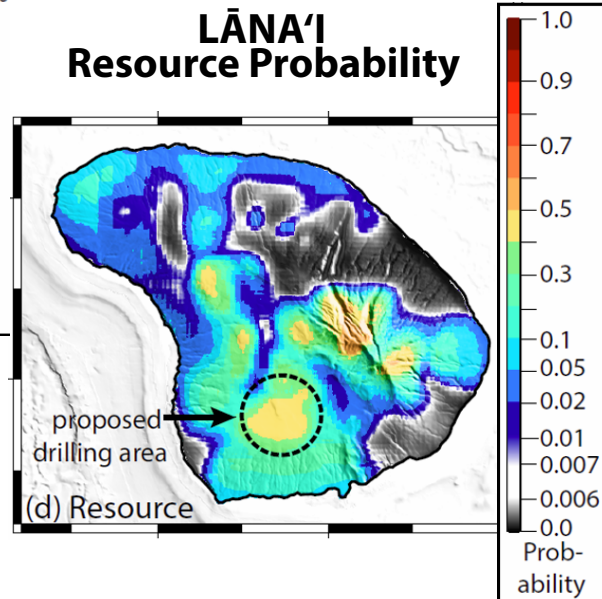
S Mauna Kea Resource Probability

PHASE 2 TASK	OUTPUT	OUTCOME
11. Update Probability and Confidence Maps	Updated maps of probability of heat, permeability, fluid, and geothermal resources across Hawaii and in the 3 geophysical survey areas	Improved assessment of resource potential statewide.

Resource Probability
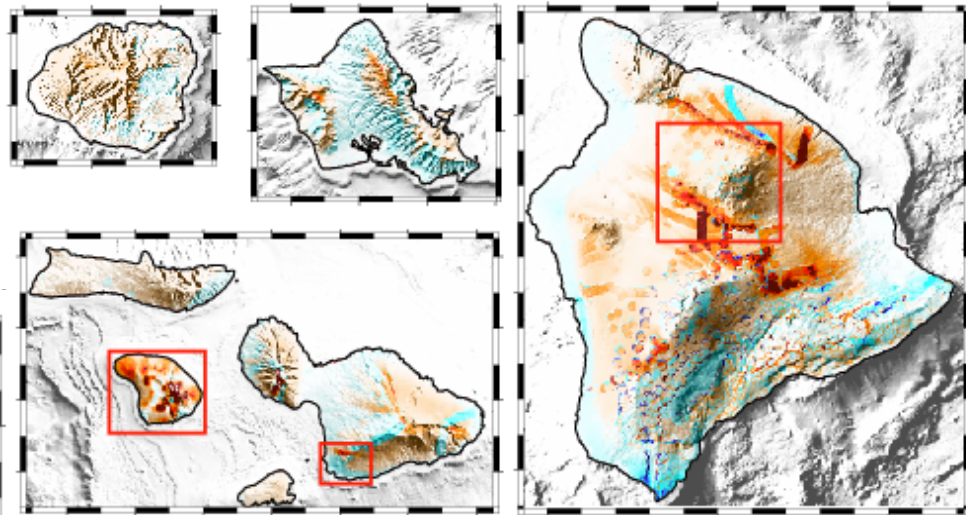
Confidence in Probability

% Change from BP1 Estimate
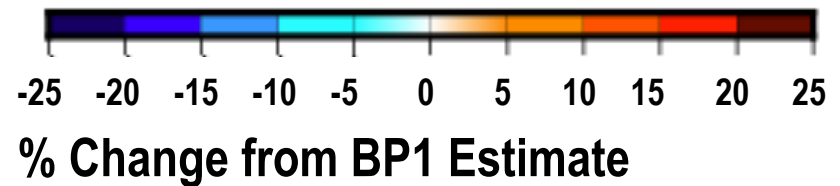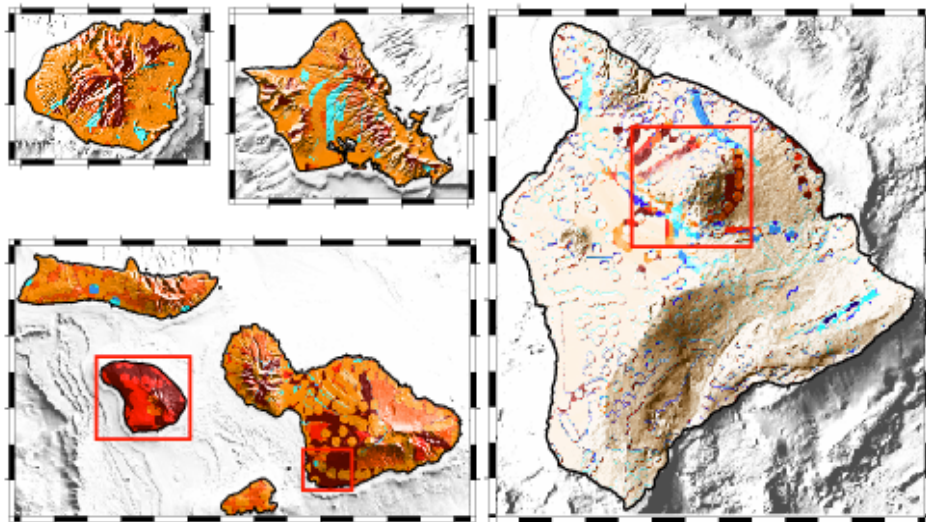
PHASE 2 TASK	OUTPUT	OUTCOME
12. Rank Drilling Plays for BP3	Qualitative and quantitative evaluations of all data in the 3 geophysical survey areas	Priority 1: SE Mauna Kea Priority 2: Lanai's Palawai caldera

Five Locations Considered, Two Selected

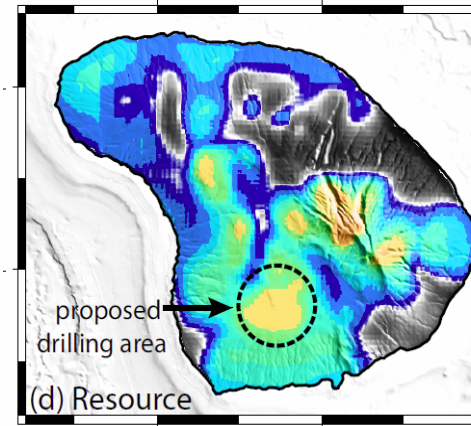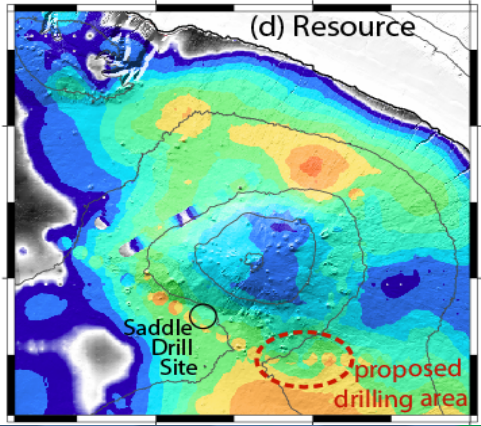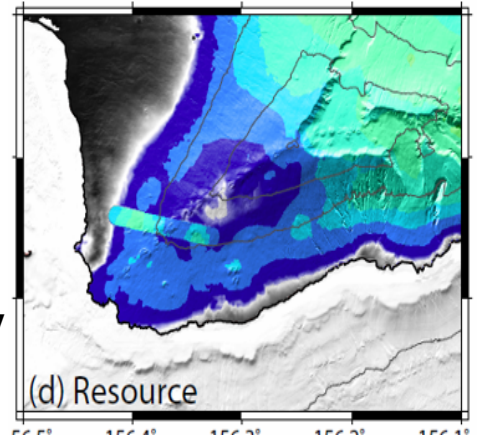### *Haleakalā SW rift (Maui); N & E Mauna Kea:*

Lower Probability Targets

- Geophysics indicates that resource is deep (3 to >4 km)
- On SW Haleakalā and N and E Mauna Kea, resistivity and gravity 'inconsistent'

(d) Resource

SSE Mauna Kea and Lāna'i: Go's

Elevated Probability and Confidence
due to 4 Phase 2 datasets…
**MT, Gravity, Groundwater, Stress**
= *Validation of PF methodology!*

(d) Resource

Saddle Drill Site

proposed drilling area

proposed drilling area

(d) Resource

Technical Accomplishments and Progress

Phase 2: Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
7. Groundwater Sampling	Samples Collected & Analyzed	4-15-17 ✔
8. Geophysics – Lanai, Maui	Data Collected and Processed	4-15-17 ✔
9. Crustal Stress Modeling	Statewide Modeling Complete	4-20-17 ✔
10. Improved Pr, C Maps	Data Integrated into New Maps	5-1-17 ✔
11. Rank Plays for Phase 3	Plays Ranked & Proposal Written	5-5-17 ✔

Special recognition

- C3E Women in Clean Energy award in Education (Lautze)

- Promotion to Associate Tenure-Track position (Lautze)

- 5 peer-reviewed publications

- 10 conference proceedings

- 9 media appearances and 10+ news articles

- Trained 6 undergraduate and 3 graduate students

- All data uploaded to GDR

- Local outreach (e.g. Science Café hosted by Hawaiian Studies Dept.)

- Pūlama Lānaʻi
- Dept of Hawaiian Home Lands
- Parker Ranch (Big Island)
- Ulupalakua Ranch (Maui)

- Departments of Water Supply
- U.S. Navy, U.S. Army

- Hawaiian Electric Company
- DBEDT, Dept of Health

- University of Nevada – Reno
- University of Utah

SSE M. Kea **Lānaʻi**
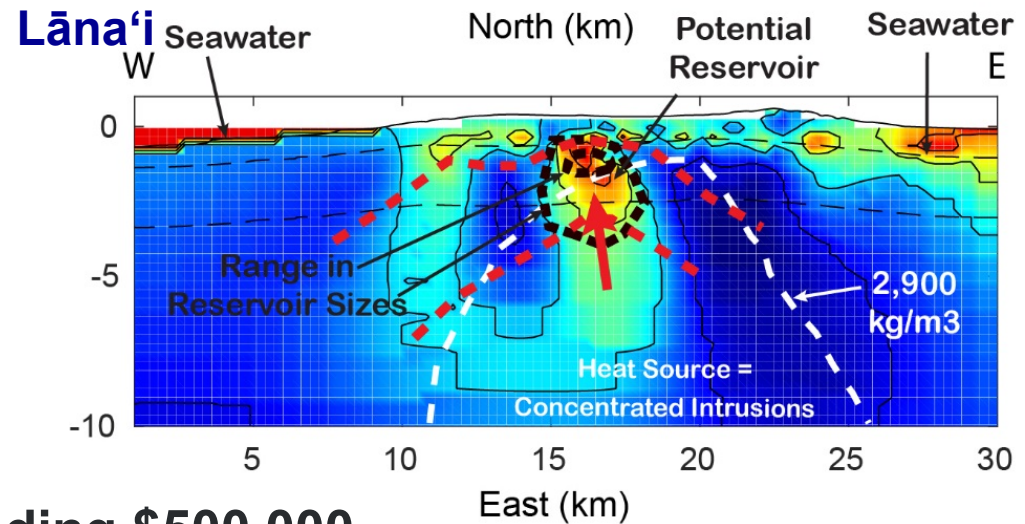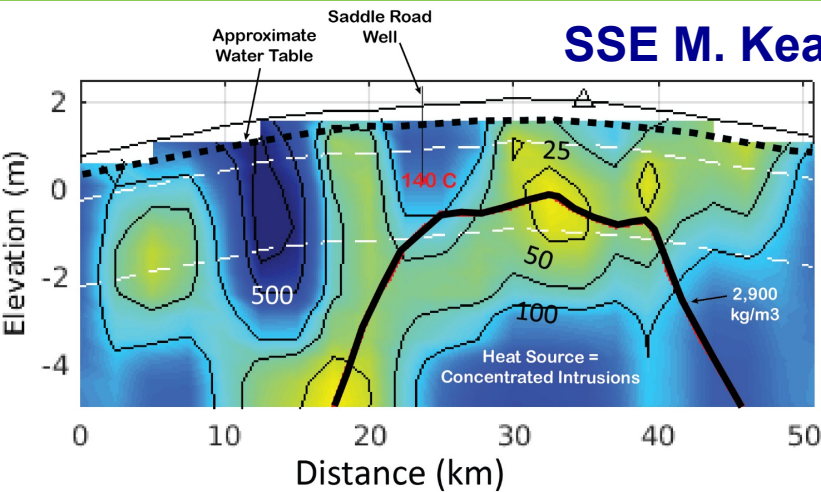
Phase 3 funding $500,000

Partner to collect scientific data from planned test well on Lanai

Milestone or Go/No-Go	Status & Expected Completion Date
14. Collection & Analysis of Core	2018
15. Collection & Analysis of Fluids	2018
16. Downhole Geophysics	2018
17. Injection/Flow Testing	2018
18. Improved Pr, C maps	2019

✓ ***Phase 1 and 2 very successful – all project objectives met***

- Encouraging results for Lānaʻi, SSE Mauna Kea. Drilling next step.
- Question: conductive zones near expected reservoir depth not associated with gravity high (SW rift Haleakalā Maui, N and E Mauna Kea)

✓ ***Development of methodology to prospect for deep (1-3 km), blind targets***

✓ Hawaii Play Fairway – ***major step forward for state***

- updated statewide resource assessment
- data aggregation
- universally-applicable methodology
- roadmap for additional prospecting
- ID of key sites for drilling

✓ Project meets GTO's goals to:
  - ⬦ lower cost of exploration and development **by identifying highest probability resource areas;**
  - ⬦ lower the cost of electricity **in the state that pays the most for it;**
  - ⬦ accelerate development of undiscovered, blind resources **as recent findings suggest resources may exist in previously unrecognized area(s).**

Thank you!