Integrating Magnetotellurics, Soil Gas Geochemistry and Structural Analysis to Identify Hidden, High-Enthalpy, Extensional Geothermal Systems

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This presentation does not contain any proprietary confidential, or otherwise restricted information.
Project objectives:

- **Barriers to Geothermal**
  - Many small, low-T systems but few large magnitude producers
  - Difficulty in establishing ultimate heat source
  - Non-uniqueness in the interpretation of individual techniques

- **Cost Reduction and Applications**
  - Improved recognition of high-T heat sources
  - Reduction of false structures and anomalies
  - Economies of scale and increased resource base

- **Innovative Aspects and Strengths**
  - Exploits recently-recognized opportunities in individual techniques
  - Combines highly independent methodologies to curtail non-uniqueness
  - Brings district-scale geophysical concepts into exploration
  - Strong cooperation with geothermal industry
Scientific/Technical Approach

Defining High-T, High-Enthalpy Geothermal Systems

• 1), Select two districts in Great Basin with pronounced crustal-scale, low-resistivity upwellings (2-D) for large, high-T resource promise.

• 2), First is new development with proven resource (McGinness Hills, Ormat Inc.), favorable geophysical structure (Phase I).

• 3), Follow up with: a), 3D MT survey and inversion to pinpoint core structures, relation to production; b), detailed structural analysis with integration of industry data to resolve crustal fluid plumbing framework; c), Verify magmatic/deep metamorphic character of source using isotope geochemistry from soil gas and well surveying.

• 4), Presuming favorable confluence of geoscientific indicators, apply exploration concept to a more ‘greenfield area’: Black Rock/Kumiva Valley area (Phase II).

• 5), Strong Scientific Team: Phil Wannamaker (P.I.), Virginie Maris (post-doc) (U Utah)- Concept identification, 3D MT survey design and inversion; Jim Faulds (Co-I), Drew Siler (post-doc) (U NV Reno)- Structural controls on geothermal systems, new mapping and cross sections, 3D visualization; B. Mack Kennedy (Co-I) (LBNL), Jen Lewicki (now at USGS), Isotope techniques in geothermal systems, noble gases and radiometric dating, crustal and geothermal fluid fluxes.
Scientific/Technical Approach

Favorable structural settings and setting types for geothermal systems (Faulds et al., 2011)
Grand Canyon Hydrol. Model (Crossey et al., 2006, Geology)

Multiscale Magmatic/ Hydrothermal Connections

Scientific/ Technical
US DOE Geothermal

NW Great Basin MT Transect

W. et al, 2007,
GRC, SGW
Mantle Helium Evidence
(Kennedy and van Soest, 2007, Science)
## Accomplishments, Results and Progress

<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and execution of new 3D MT survey, incorporation of legacy Ormat MT data, creation of 3D MT inverse resistivity model, distribution to Ormat and co-investigators.</td>
<td>All completed</td>
<td>November, 2012</td>
</tr>
<tr>
<td>Correlation of structural style, MT resistivity structure, composition of soil gas anomalies to verify magmatic contribution to McGinness system.</td>
<td>In progress, awaits minor structural and MT refinement, gas/fluid geochem completion</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>
Structural Characterization (UNR)

• Geologic mapping.
  – Map compilation (B. Delwiche, Ormat) and legacy regional mapping.
  – New geologic mapping (total of 60 km²) by D. Siler (UNR).
  – Construction of preliminary cross-sections.

• Structural setting – Step-over (or relay ramp) in broad accommodation zone.
Geologic Map & Cross Sections
Univ. of Utah
U NV Reno
LBNL
Ormat Inc.

MT Survey
McGinness Hills

Results
US DOE Geothermal

NATIONAL GEOGRAPHIC
2D MT Inversions
(derived by contractor, courtesy of Ormat Corp.)

"B" is production conductor,
"A" is proj. of deep conductor
FD mesh:  
105x 107y 43z

Inv mesh:  
54x 55y 28z  
top voxel 160 m thick,  
19 km depth extent  
(memory bound at present)

Gauss-Newton parameter step (heavily) modified from Sasaki (2004)

FREQS: 10 – 0.018 Hz

nRMS: starting 23,  
ending 4.1 in 5 iters

Parallelized on 8-core  
linux w/s 32 Gb RAM: run times ~8 days
McGinness Hills, central Nevada

Plan Views, 3D MT Inversion Model

Plan View: Top=-160 m; Bottom=-330 m

Plan View: Top=-715 m; Bottom=-935 m

Results
US DOE Geothermal
McGinness Hills, central Nevada

Plan Views, 3D MT Inversion Model

Plan View: Top=-1435 m; Bottom=-1715 m

Plan View: Top=-2675 m; Bottom=-3035 m
McGinness Hills, central Nevada

Plan Views, 3D MT Inversion Model

Plan View: Top=-4235 m; Bottom=-4675 m

Plan View: Top=-6205 m; Bottom=-6805 m

Results
US DOE Geothermal
Soil Gases as Surface Manifestations of “Hidden” Systems In the Basin and Range

McGinness Valley, Nevada

Hi-Resolution 2D MT Transect

Ormat Corp., P. Wannamaker
Univ. of Utah

Favorable structure

J. Faulds
Nevada Bureau of Mines

Results
US DOE Geothermal
Integration of Data Sets

Preliminary fault model of McGinness Hills using geologic map, cross-sections, and mud log data (courtesy of Ormat). Wide areas along well paths correspond to loss circulation zones and are used to constrain fault locations in the subsurface.

Correlation of preliminary fault model of McGinness Hills with MT survey.
## Future Directions

<table>
<thead>
<tr>
<th>Milestone or Go/No-Go</th>
<th>Status &amp; Expected Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1: 3D MT resistivity model.</td>
<td>Essentially done, may increase discretization, June/13.</td>
</tr>
<tr>
<td>P1: Soil gas geochem surveying.</td>
<td>Promising recon, more to come, July/13.</td>
</tr>
<tr>
<td>P1: Go/NoGo- Concept evaluation (magmatically connected structures can be ID’d geophys, geochem, structurally).</td>
<td>Close to complete, August/13.</td>
</tr>
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</table>
• Motivated to focus on high-enthalpy systems.
• Recognition of indicators of magmatic input.
• Fully 3-D approach to proving/pinpointing resources.
• Integration of highly independent resource indicators.

<table>
<thead>
<tr>
<th>Target/Milestone</th>
<th>FY2013</th>
<th>FY2014</th>
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</thead>
<tbody>
<tr>
<td>Target/Milestone</td>
<td>McGinness Hills MT survey, initial inversion, structural study, soil gas survey, Phase I decision</td>
<td>McGinness analysis completion and write-up; Phase II plan/ permit; MT/structure/geochem at Black Rock-Kumiva</td>
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<tr>
<td>Results</td>
<td>MT survey acquired; new mapping, integr of legacy Ormat structure, geophys; new gas geochemistry</td>
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### Timeline:

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<thead>
<tr>
<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Current End Date</th>
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<tbody>
<tr>
<td>October 1, 2011</td>
<td>December 31, 2012</td>
<td>February, 2012 (August,</td>
<td>December 31, 2013, for Phs I</td>
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<tr>
<td></td>
<td></td>
<td>2012 for LBNL)</td>
<td>December 31, 2014, for Phs II</td>
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### Budget:

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<tr>
<th>Project</th>
<th>Federal Share</th>
<th>Cost Share</th>
<th>Planned Expenses to Date</th>
<th>Actual Expenses to Date</th>
<th>Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
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<td>$110,552**</td>
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<td>$----</td>
<td>$----</td>
<td>**assumes 25% compl. to date</td>
<td>**funding straight from DOE to LBNL</td>
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### Summary:

- Strong coordination with Ormat, provided much data, feedback and access to field, undertook well sampling for project.
- Type of project may benefit down the road from other GTO research in geophysical imaging, geothermometers, structural categorization.
Supplemental Slides:

- The following two slides depict the latest MT site span and 2D inversion of the regional MT transect wherein the crustal scale magmatic-geothermal connections were first identified.
- First slide shows transect distribution of 393 wideband sites (dark blue dots) now extending from Pacific coast south of Eureka CA eastward across the Great Basin to east of Green River UT. Sites across McGinness Hills (au-TB) include new project densification. Also plotted are locations of long-period (upper mantle level) MT recordings, complete but not yet inverted. GPS vectors after Thatcher et al (2005).
- Second slide shows two 2D models, the upper derived from TM mode only data (most robust to finite strike effects) and the lower from TM+tipper data (some along-strike info included). Compatibility of sections suggests 3D effects not fundamental. Note the strong shallow low resistivity under Black Rock-Kumiva area (kv), subject of Phase II.
S Klamath Mtns – Great Basin – Colorado Plateau MT
Approx. coincident with COCORP, PASSCAL seismic profiling