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

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Track1: Geophysics

Relevance/Impact of Research

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

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

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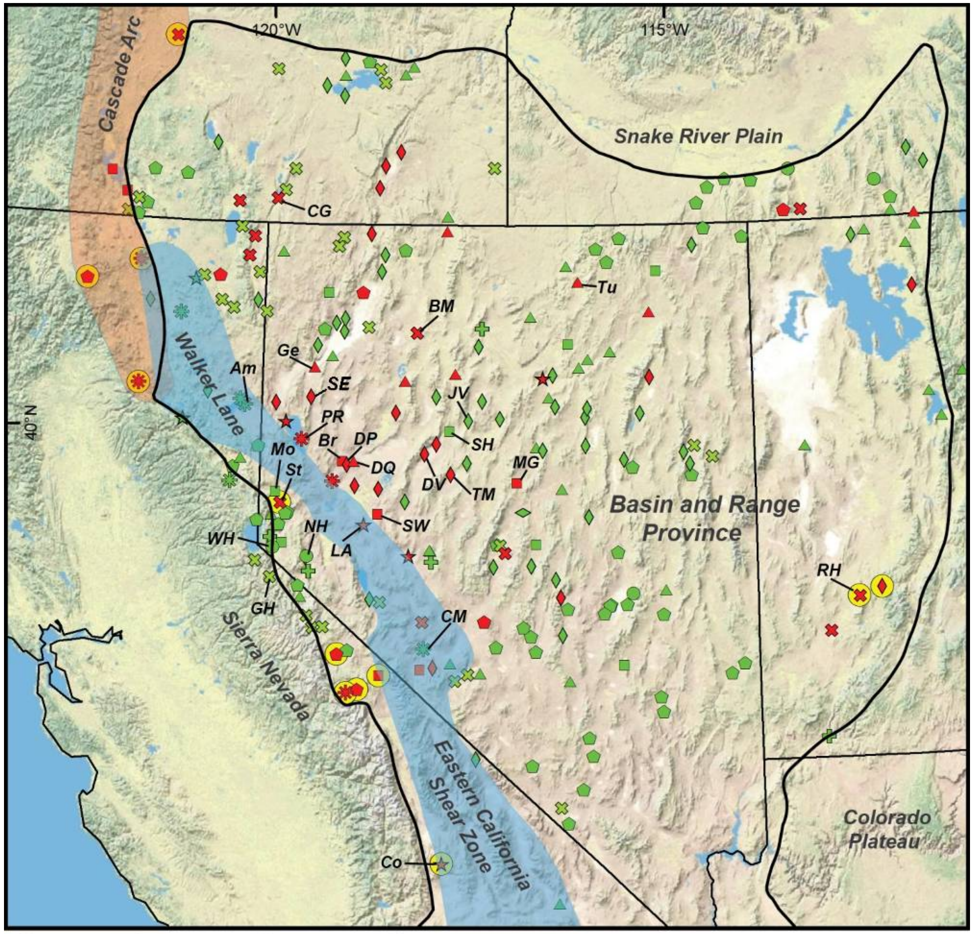
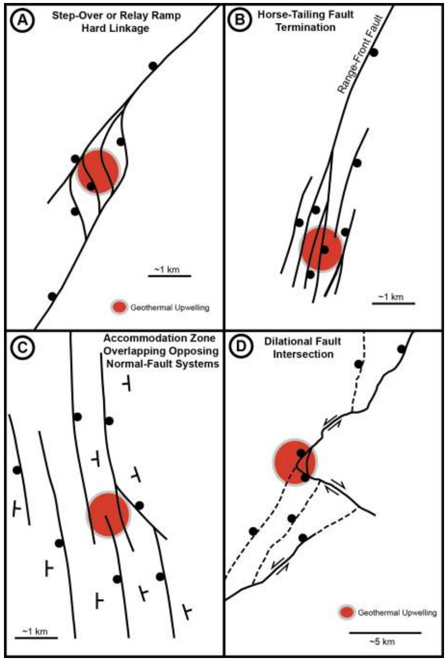
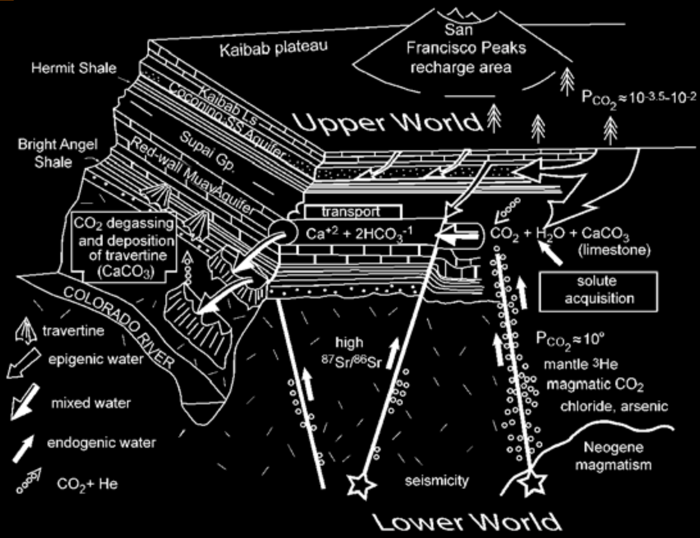


Structural Settings of Geothermal Systems: Red symbols ≥150°C, Green symbols <150°C

- ▲ Termination of a major normal fault
- ♦ Stepover or relay ramp in normal fault zones
- ■ Accommodation zone
- ✚ Major normal fault
- ● Apex or salient of normal fault
- ◆ Antithetic normal fault to major range-front fault
- ✖ Fault intersection
- ✱ Displacement transfer zone
- ★ Pull apart in strike-slip fault zone
- ⬟ Analyzed system, but structural setting not yet defined
- ○ Known or inferred magmatic system

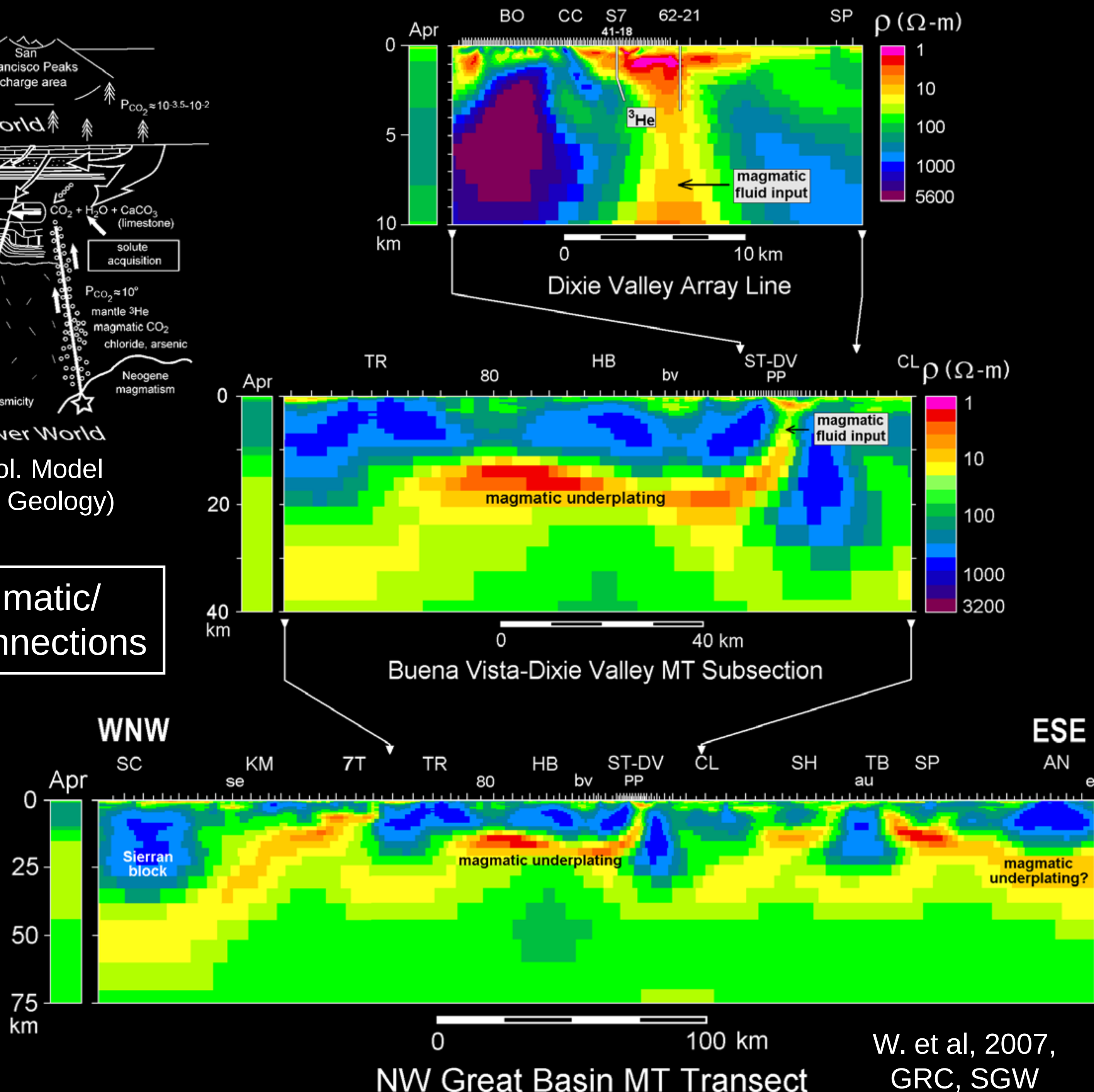


Favorable structural settings and setting types for geothermal systems (Faulds et al., 2011)



Grand Canyon Hydrol. Model
(Crossey et al., 2006, Geology)

Multiscale Magmatic/ Hydrothermal Connections



W. et al, 2007,
GRC, SGW

Scientific/ Technical
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Scientific/
Technical
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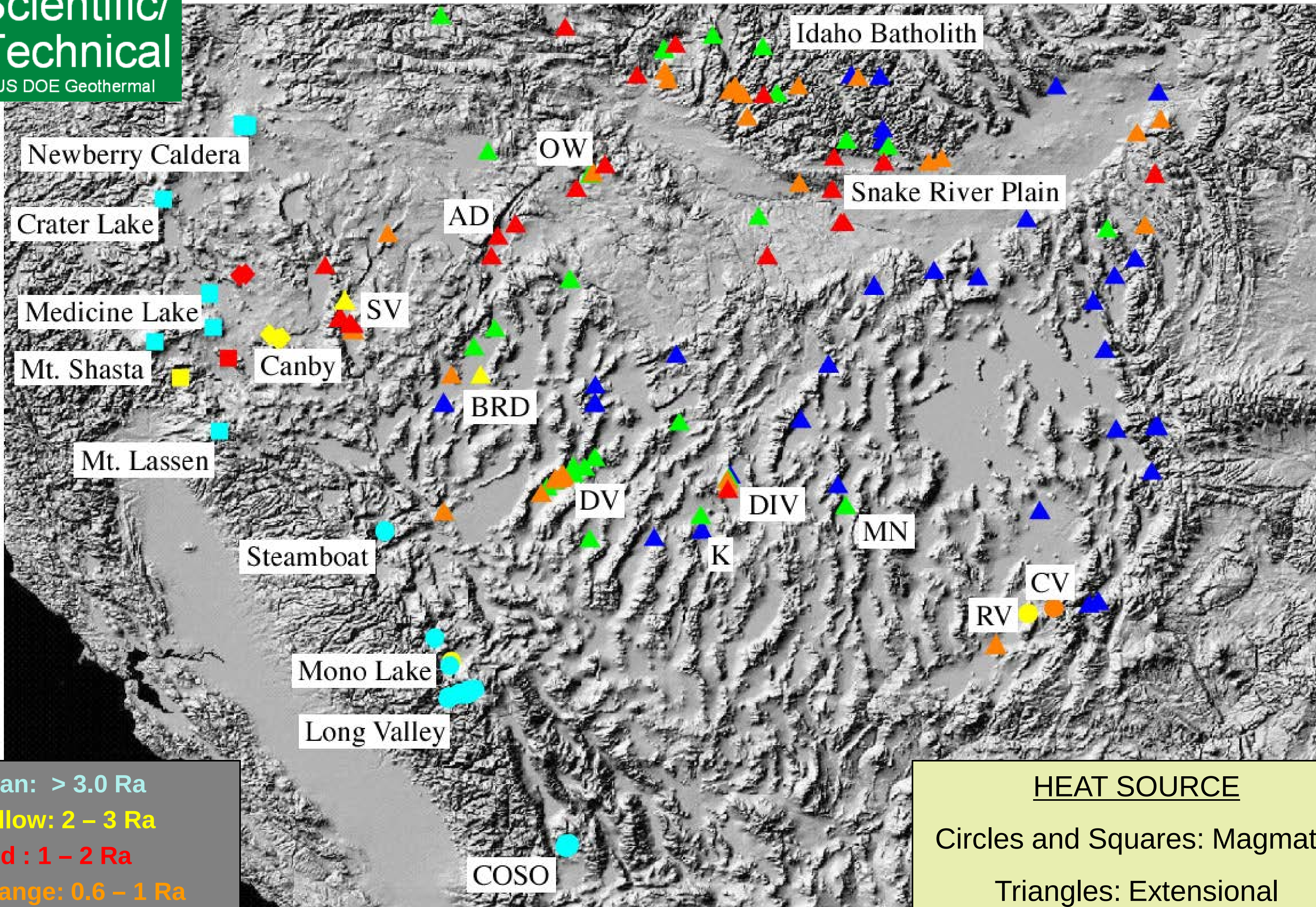

Cyan: > 3.0 Ra
Yellow: 2 – 3 Ra
Red : 1 – 2 Ra
Orange: 0.6 – 1 Ra
Green: 0. 3 – 0. 6 Ra
Blue: < 0.3 Ra

HEAT SOURCE

Circles and Squares: Magmatic

Triangles: Extensional

Diamonds: not sure

Mantle Helium Evidence

(Kennedy and van Soest, 2007, Science)

Accomplishments, Results and Progress

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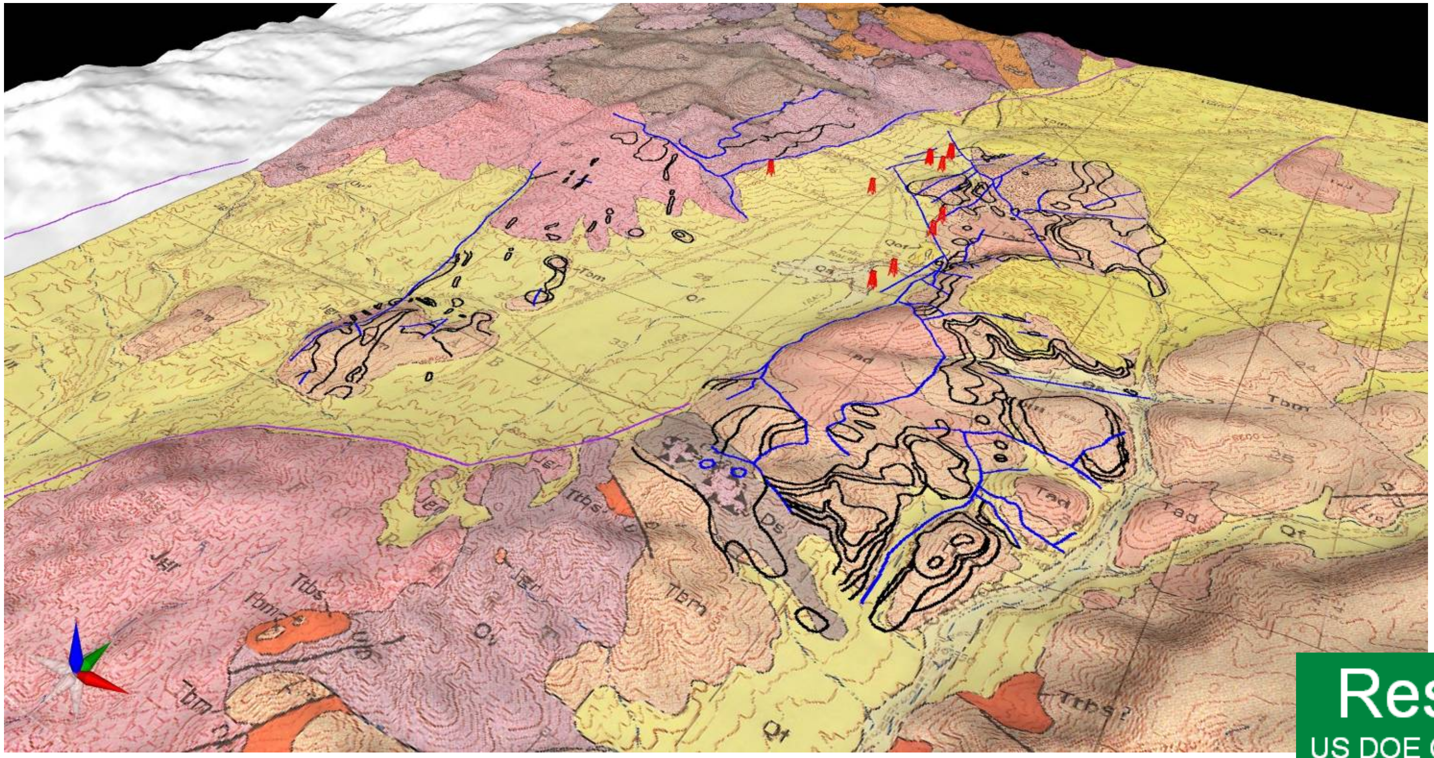
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Design and execution of new 3D MT survey, incorporation of legacy Ormat MT data, creation of 3D MT inverse resistivity model, distribution to Ormat and to co-investigators.	All completed	November, 2012
Reconnaissance and detailed geological/structural mapping, integration of legacy Ormat structural data, distribution of models to Co-I's.	Nearly completed. Possibly some limited mapping followup and model refinement.	January, 2013
Surveying for soil gas flux anomalies, follow-up soil gas isotope collection at anomalies, analysis of well fluids for magmatic/metamorphic comp's.	Initial soil gas flux surveying done, well fluids sampled. Funding to LBNL arrived August, 2012. Cannot operate in wet or snowy conditions.	October, 2012; March, 2013
Correlation of structural style, MT resistivity structure, composition of soil gas anomalies to verify magmatic contribution to McGinness system.	In progress, awaits minor structural and MT refinement, gas/fluid geochem completion	Ongoing

Structural Characterization (UNR)

- Geologic mapping.
  - Map compilation (B. Delwiche, Ormat) and legacy regional mapping.
  - New geologic mapping (total of 60 km^2) by D. Siler (UNR).
  - Construction of preliminary cross-sections.
- Structural setting – Step-over (or relay ramp) in broad accommodation zone.



Results
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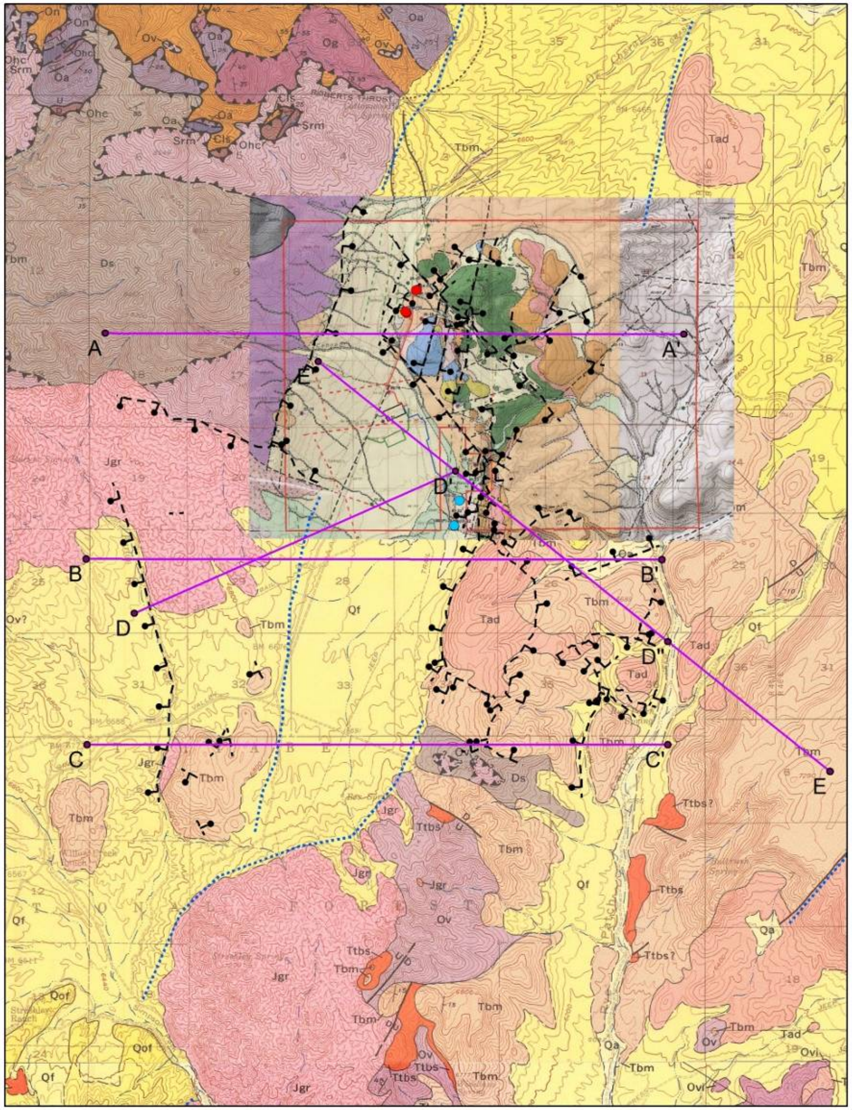
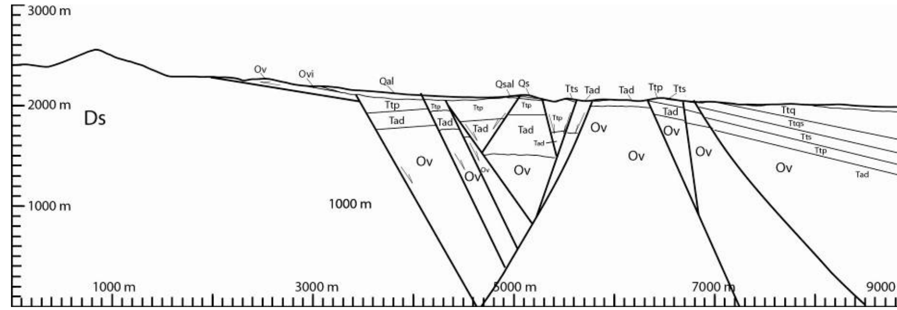
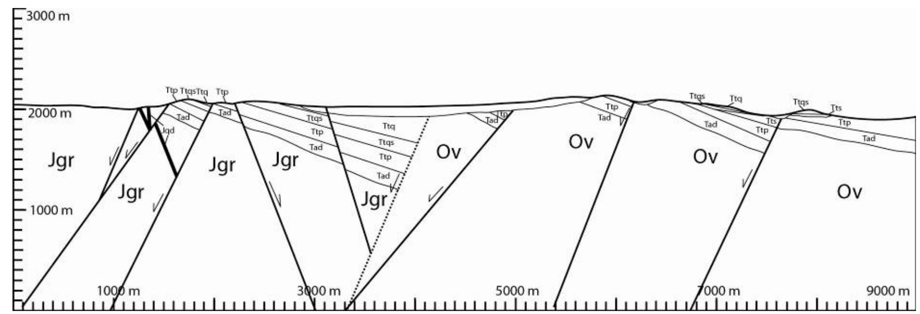
Geologic Map & Cross Sections





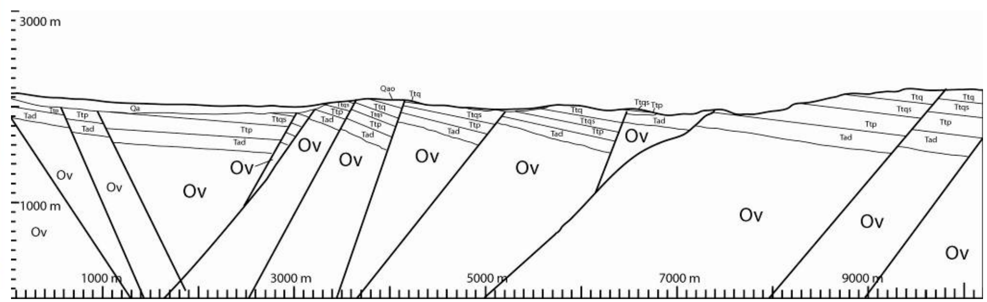
A

A'



C

C'



E

E'

Results
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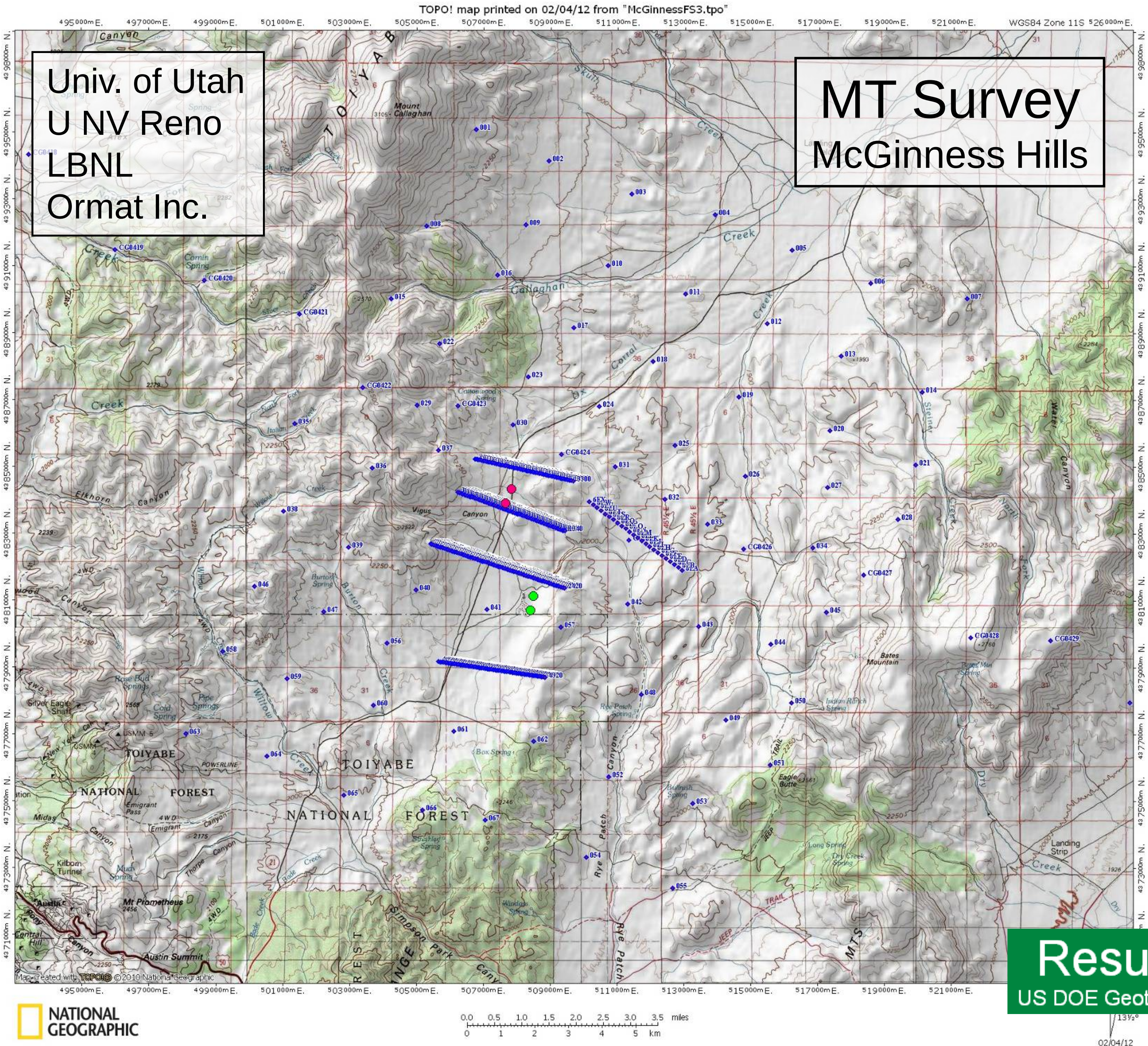
MT Survey
McGinness Hills

Univ. of Utah
U NV Reno
LBNL
Ormat Inc.



Results
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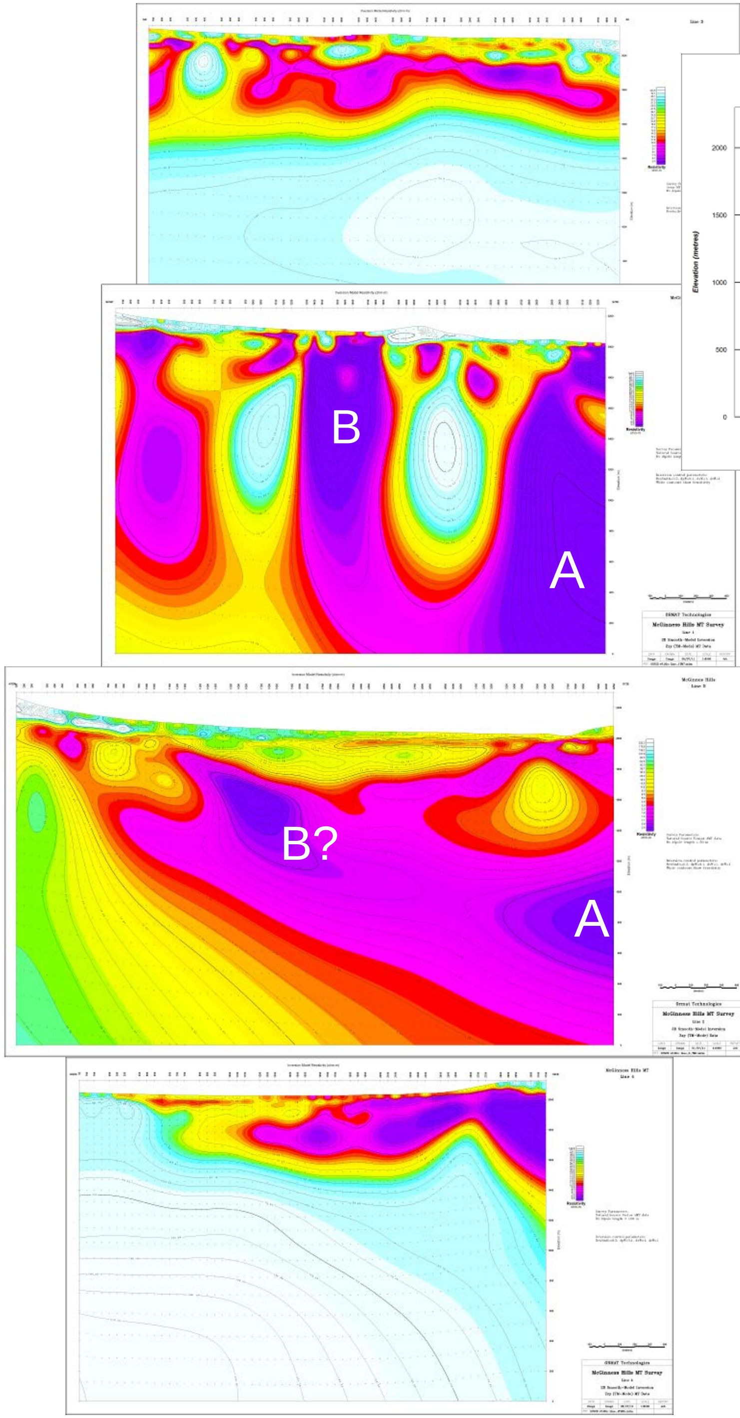
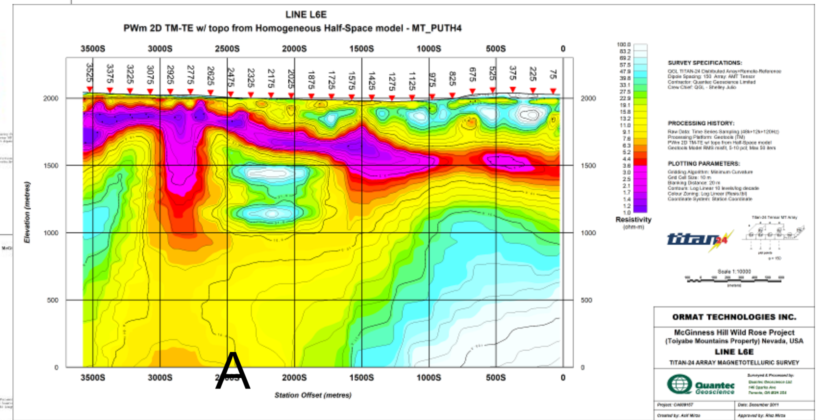




2D MT Inversions

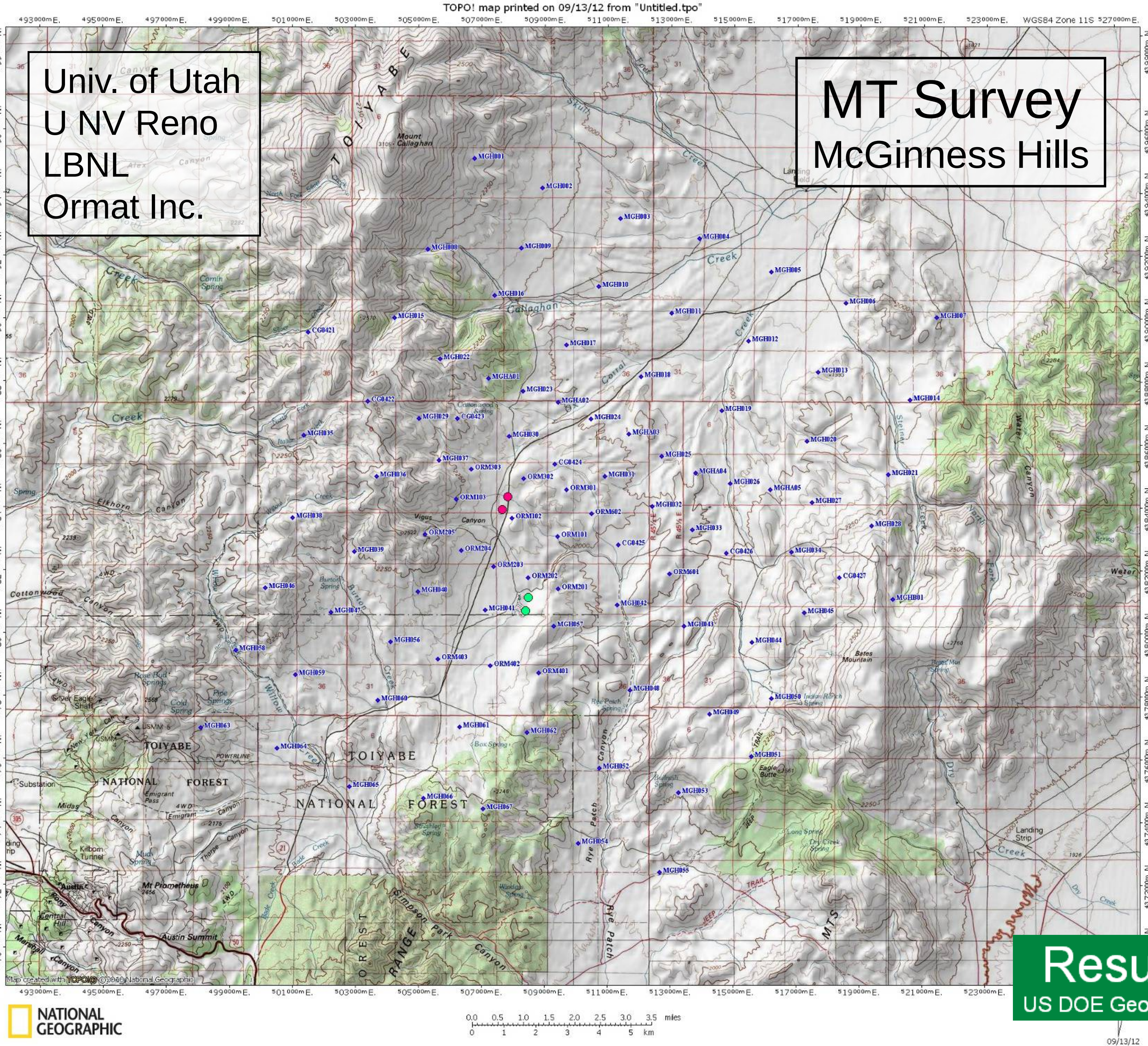
(derived by contractor, courtesy of Ormat Corp.

"B" is production conductor,
"A" is proj. of deep conductor

Results
US DOE Geothermal

Univ. of Utah
U NV Reno
LBNL
Ormat Inc.

MT Survey
McGinness Hills



Results
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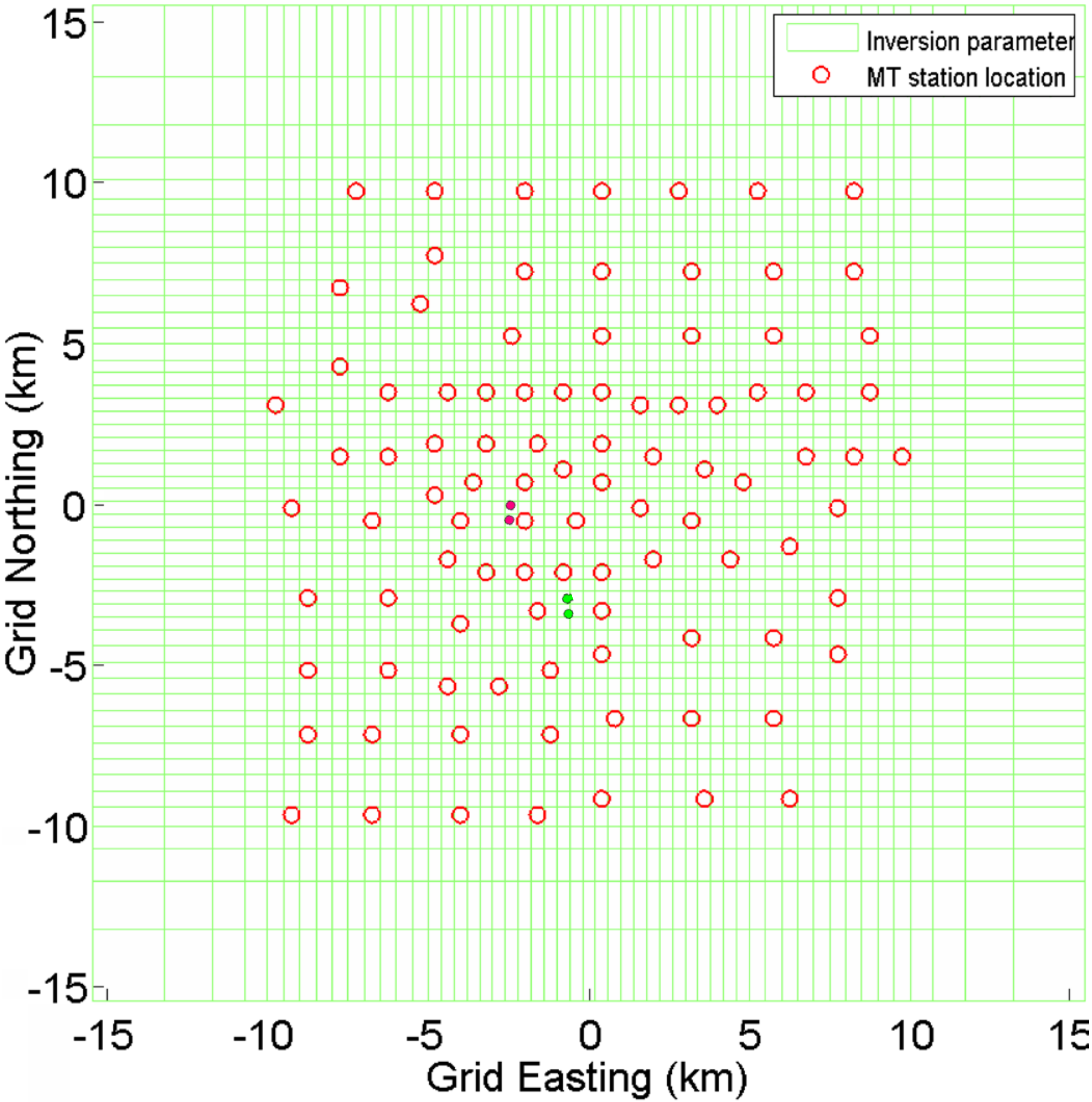

FD mesh:
105x 107y 43z

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

Results

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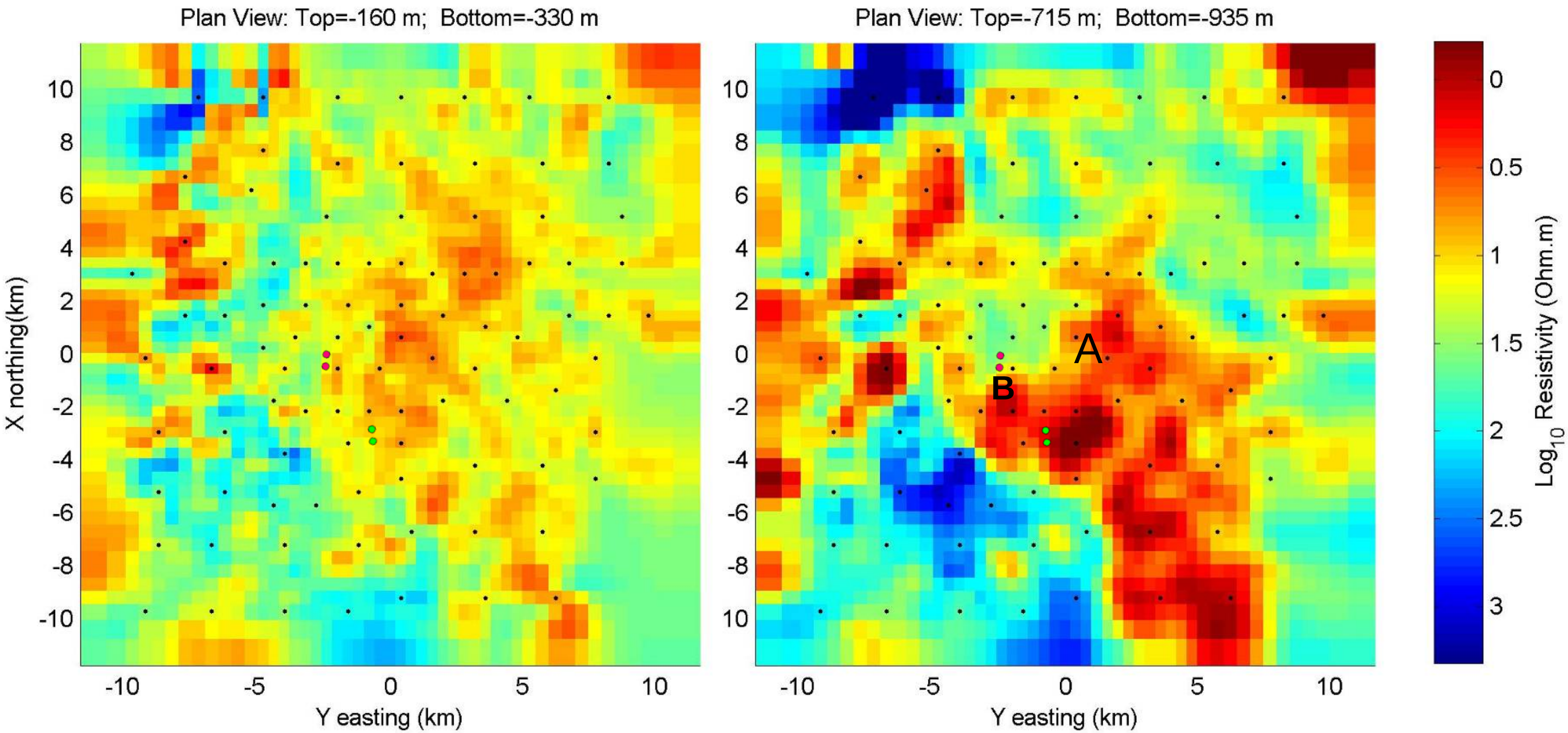
McGinness Hills, central Nevada



Plan Views, 3D MT Inversion Model

Results
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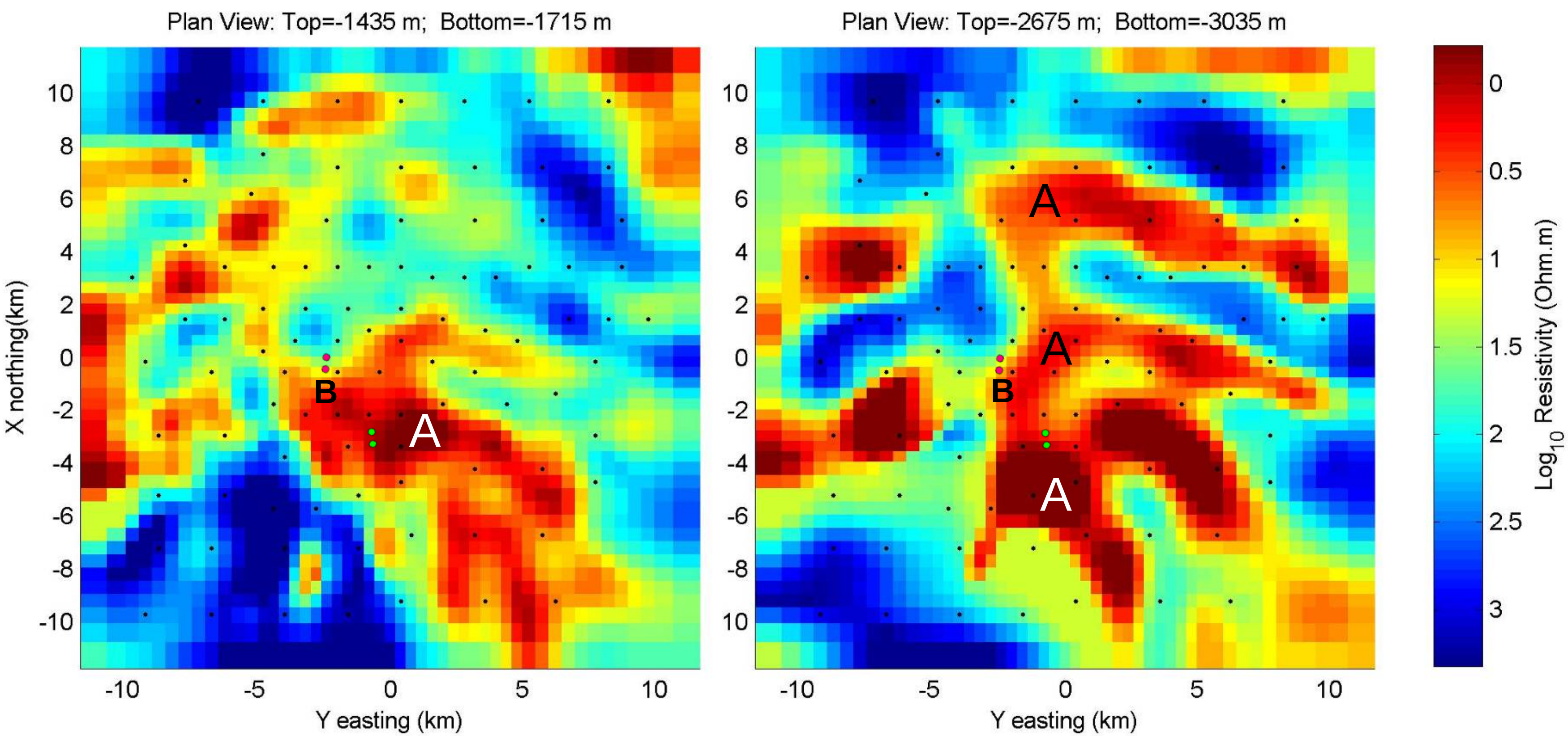
McGinness Hills, central Nevada



Plan Views, 3D MT Inversion Model

Results
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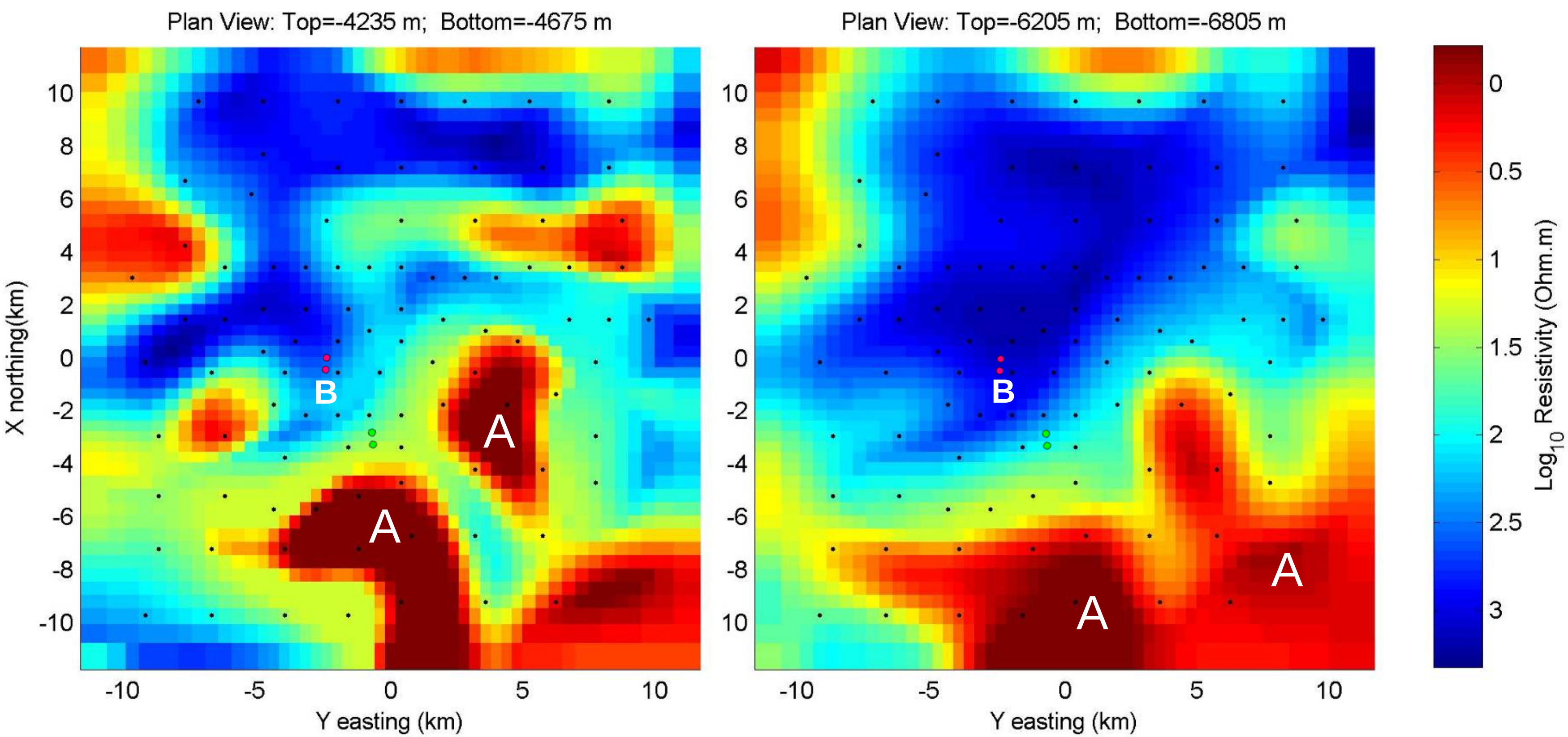
McGinness Hills, central Nevada



Plan Views, 3D MT Inversion Model

Results
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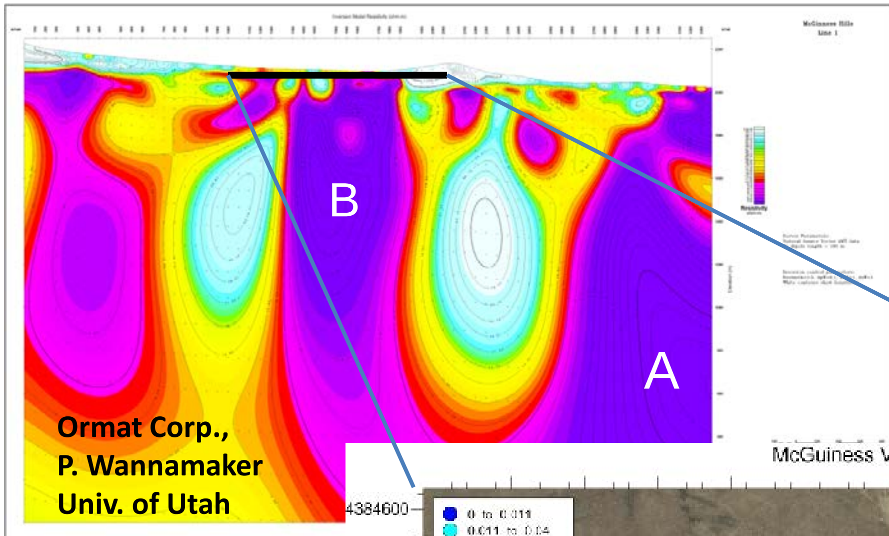
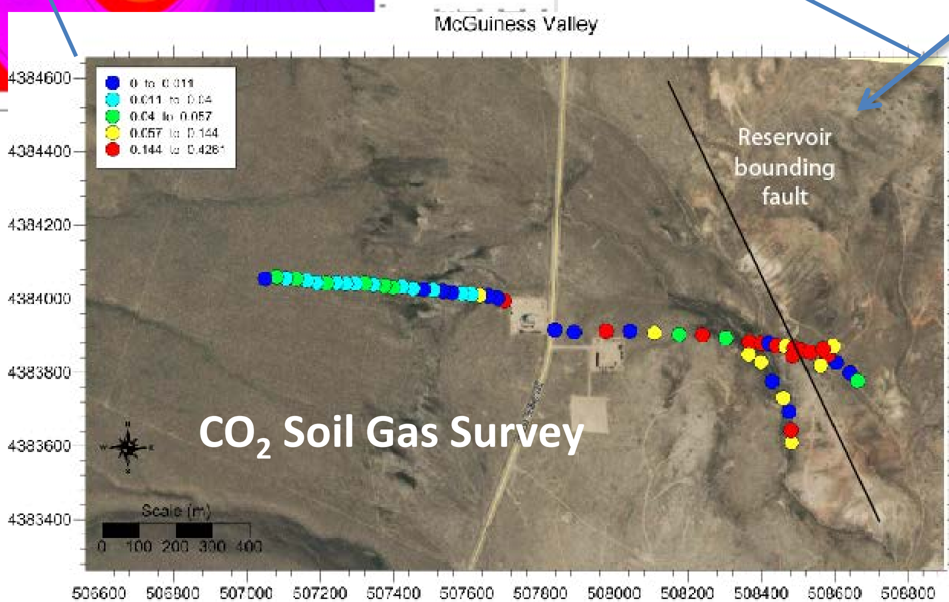
Soil Gases as Surface Manifestations of "Hidden" Systems In the Basin and Range

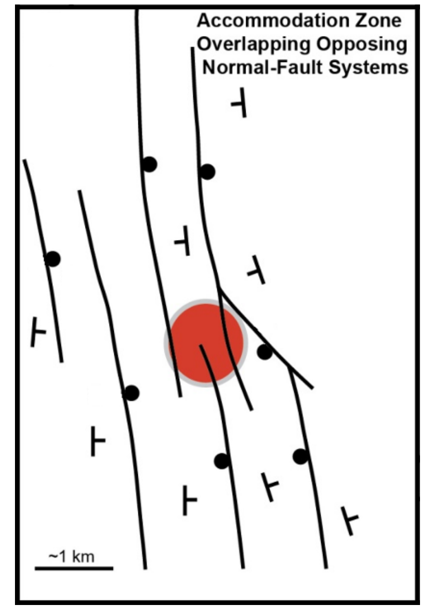
McGinness Valley, Nevada

Hi-Resolution 2D MT Transect





Favorable structure



J. Faulds
Nevada Bureau of Mines

Results
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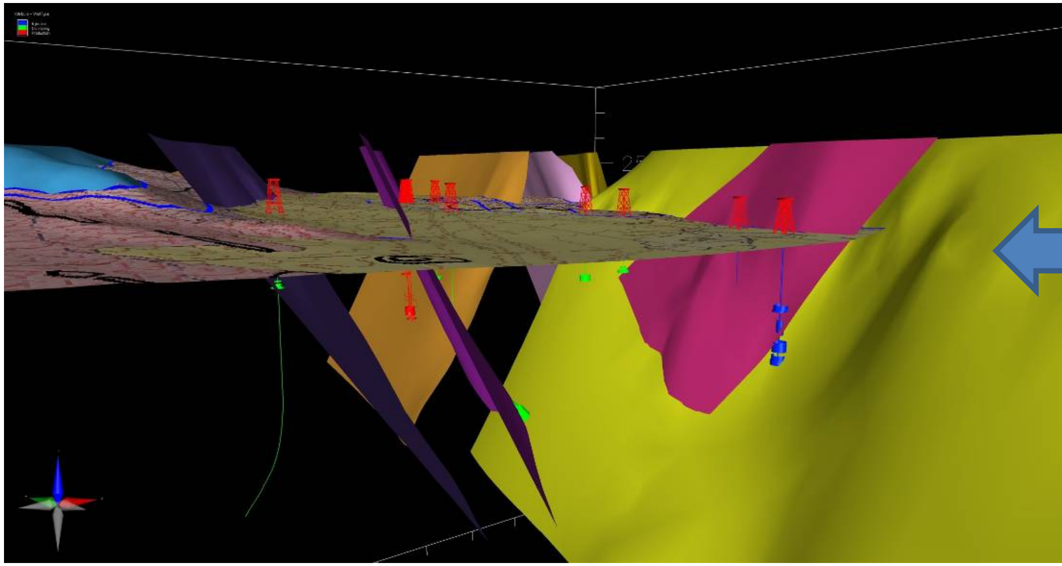
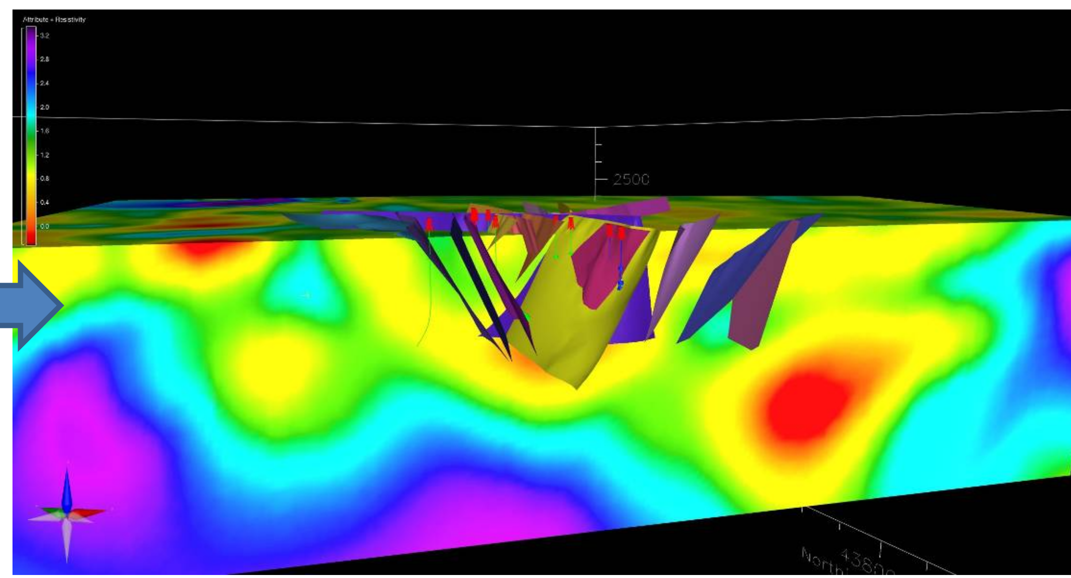
Integration of Data Sets



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.



Results
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Future Directions

Milestone or Go/No-Go	Status & Expected Completion Date
P1: 3D MT resistivity model.	Essentially done, may increase discretization, June/13.
P1: Detailed structural model.	Well advanced, some integration of drill lithology, full digital representation, June/13.
P1: Soil gas geochem surveying.	Promising recon, more to come, July/13.
P1: Go/NoGo- Concept evaluation (magmatically connected structures can be ID'd geophys, geochem, structurally).	Close to complete, August/13.
P2: Black Rock-Kumiva proceeds: structural recon, 3D MT surveying.	Start Date: September/13.

Summary Slide

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- 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.

	FY2013	FY2014
Target/Milestone	McGinness Hills MT survey, initial inversion, structural study, soil gas survey, Phase I decision	McGinness analysis comple-tion and write-up; Phase II plan/ permit; MT/structure/ geochem at Black Rock-Kumiva
Results	MT survey acquired; new mapping, integr of legacy Ormat structure, geophys; new gas geochemistry	

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
October 1, 2011	December 31, 2012	February, 2012 (August, 2012 for LBNL)	December 31, 2013, for Phs 1 December 31, 2014, for Phs II

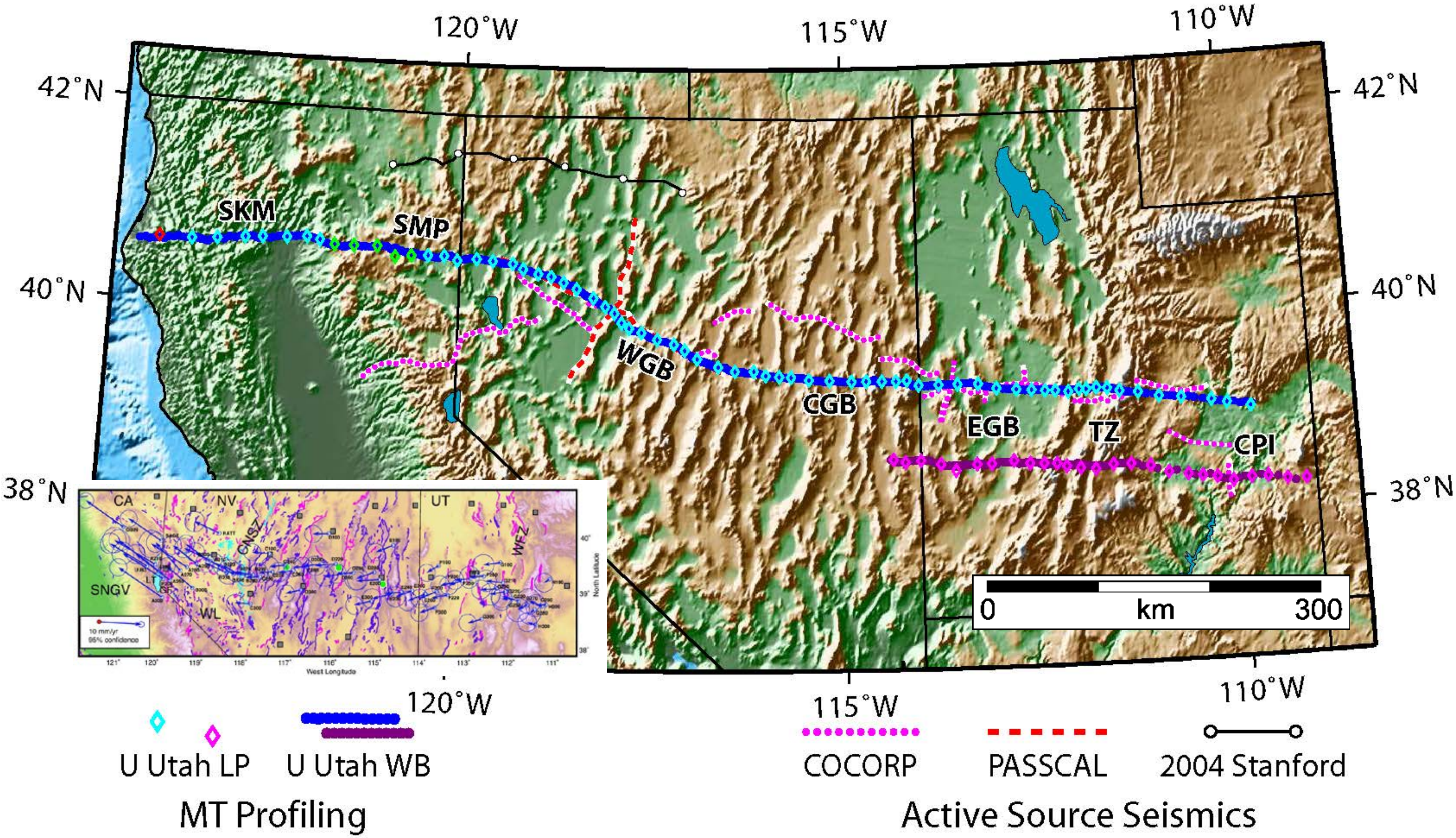
Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
P1: $418,214 -UU $ 90,947 -QTG $127,000 -UNR $ 89,715 -LBL $110,552**	P1: $0	P1: $256,717 -UU $ 37,339 -QTG $ 96,921 -UNR $ 11,905 -LBL $ ----	P1: $256,717 -UU $ 37,339 -QTG $ 96,921 -UNR $ 11,905* -LBL $ ---- *some function of invoicing	P1: $256,717 -UU $ 37,339 -QTG $ 96,921 -UNR $ 11,905* -LBL $ 27,638** **assumes 25% compl. to date	P1: $161,497* -UU $ 53,608 -QTG $ 33,069 -UNR $ 77,810 -LBL $110,552** **funding straight from DOE to LBNL
P2: $574,061 -UU $ 90,947 -QTG $114,500 -UNR $ 89,715 -LBL $110,552**	P1: $185,531 -UU $ 90,947 -QTG $127,000 -UNR $ 89,715 -LBL $110,552**	P1: $0	P1: $0	$0	P1: $759,572

- 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.

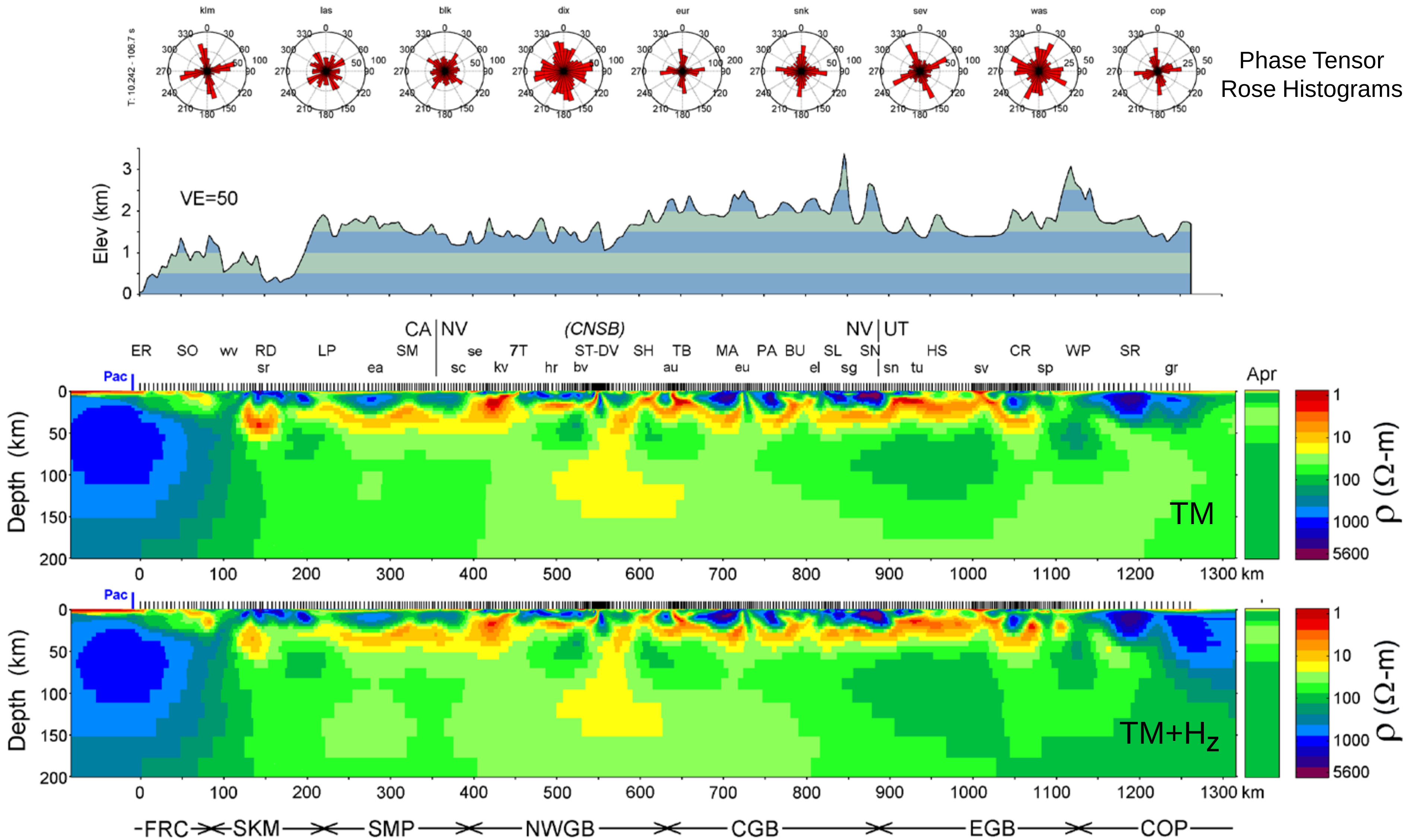
Supplemental Slides:

- The following two slides depict the latest MT site spand 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



Klamath - S Modoc - Great Basin - Colorado Plateau

MT Transect