

Use of Geophysical Techniques to Characterize Fluid Flow in a Geothermal Reservoir

May 12, 2010

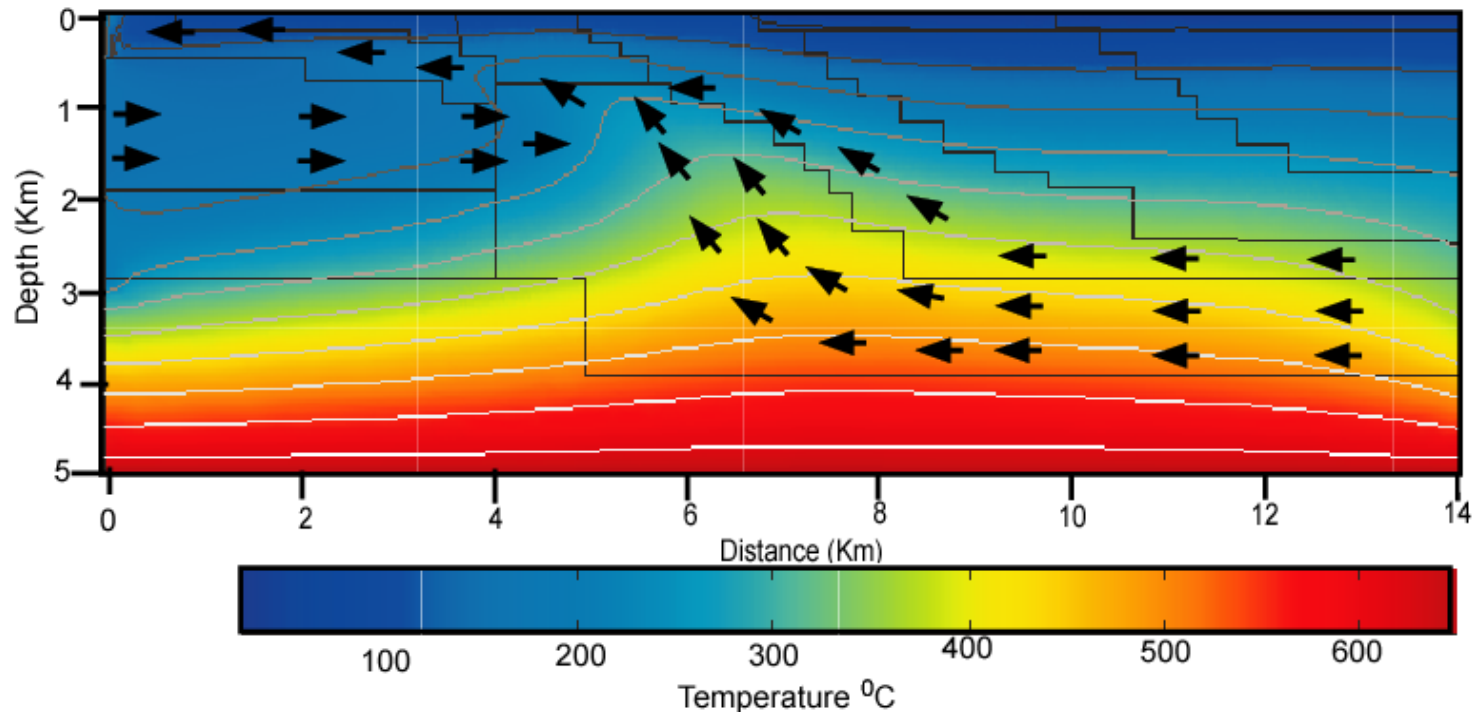
André REVIL
Colorado School of Mines

- **Use of Geophysical Techniques to Characterize Fluid Flow in a Geothermal Reservoir:**
 - Timeline: April 1st 2009-March 30th, 2012.
 - Budget
 - Total project DOE funding \$ 832,433
 - Funding received in FY09 \$ 335,339
 - Funding for FY10 \$ 255,261
 - Project total cost \$1,137,567
 - Partners

Boise University,
Flint LLC, Mt. Princeton Geothermal, LLC

Joint inversion of geophysical data for ground water flow imaging

- Reduced the cost in geothermal exploration and monitoring
- Combining geophysics with hydromechanical codes: new science



Objectives of your project

- Joint inversion of geophysical data for ground water flow imaging
 - Reduced the cost in geothermal exploration and monitoring
 - Combined passive and active geophysical methods
 - Proof-of-concept mainly at Mount Princeton geothermal field, CO
 - Methodologies can be easily transferred to other DOE test sites.
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- Numerical modeling with TOUGH and eTOUGH
 - Stochastic and deterministic joint inversion
 - Use seismic to provide the architecture of the system plus wells,
 - Use EM/resistivity, self-potential to model ground water flow
 - Technical feasibility at Mount Princeton and Poncha Springs

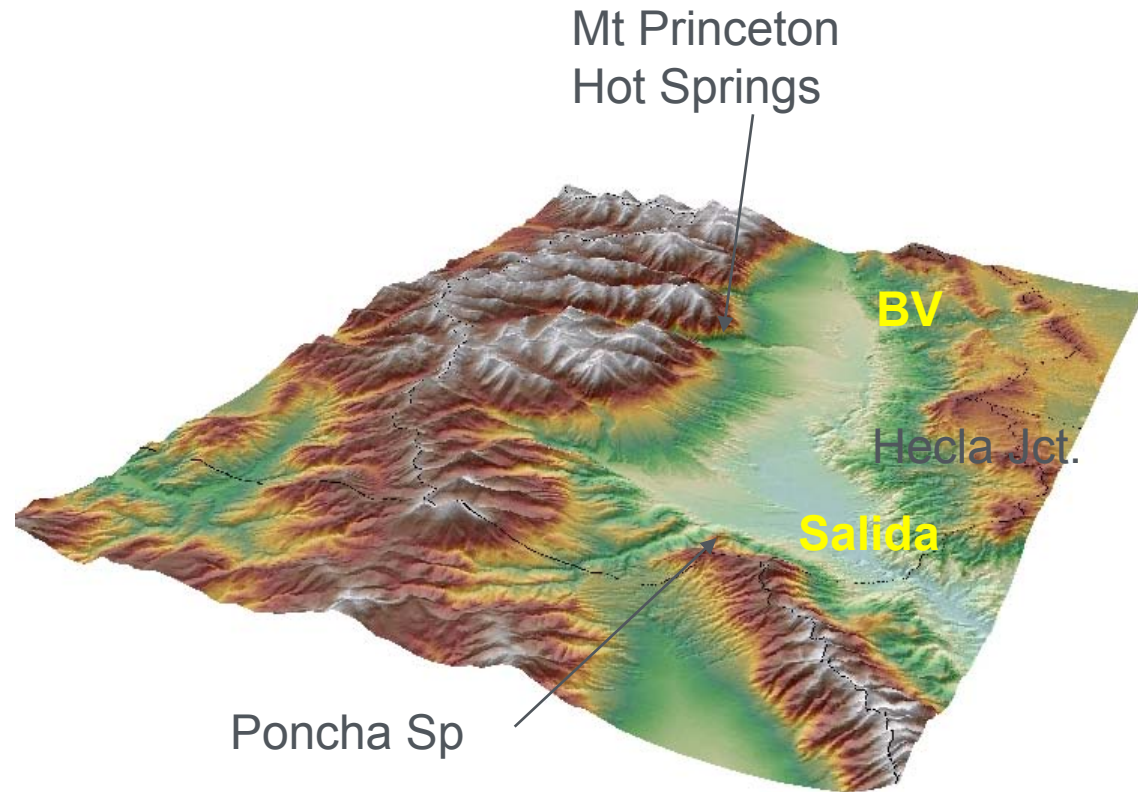
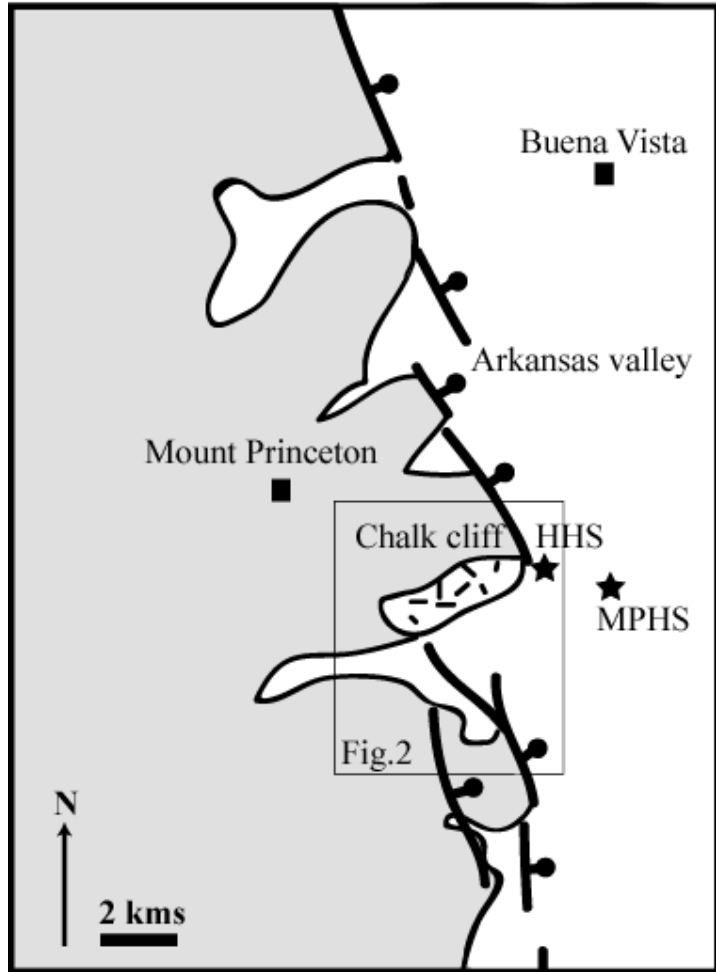
- FY09 First data set: done Joint inversion T and SP: done
- FY10 Joint inversion of seismic and SP/resistivity/temperature
- FY11 Ground Water flow model at three geothermal sites in the Upper Arkansas valley

- TEAM: CSM. André Revil (EM, SP, resistivity)
Mike Batzle (petrophysics, seismic)
Boise: Kasper vanWijk and Lee Liberty (Seismic).
- Recognition received
 - Best poster award at the 2009 SEG in Houston.

- Organization :
 - Meeting once a month (skype) + field camp in May
 - Application of resources and leveraged funds/budget/spend plan
 - Connection to ORMAT, ENREL, State of Colorado
- The new methodology is applicable:
 - To other geothermal prospects
 - To monitoring (seismic and electrical monitoring of fracturing)
- Possibility to develop a geothermal program at Mines
 - Connection with ORMAT
 - Connection with ENREL

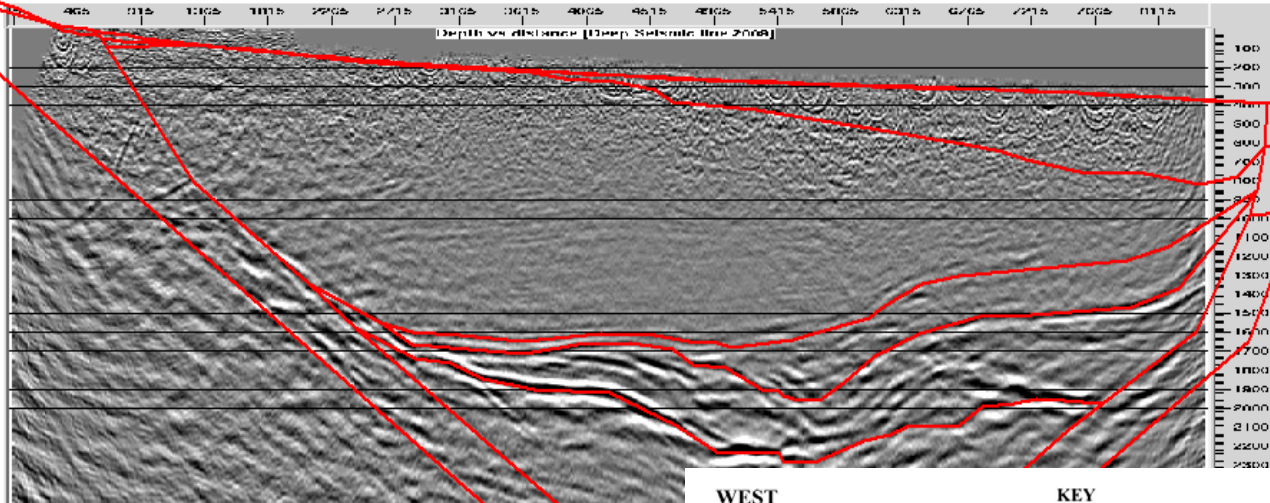
Localization and geology

Cottonwood



Deep seismic

Stacked seismic profile



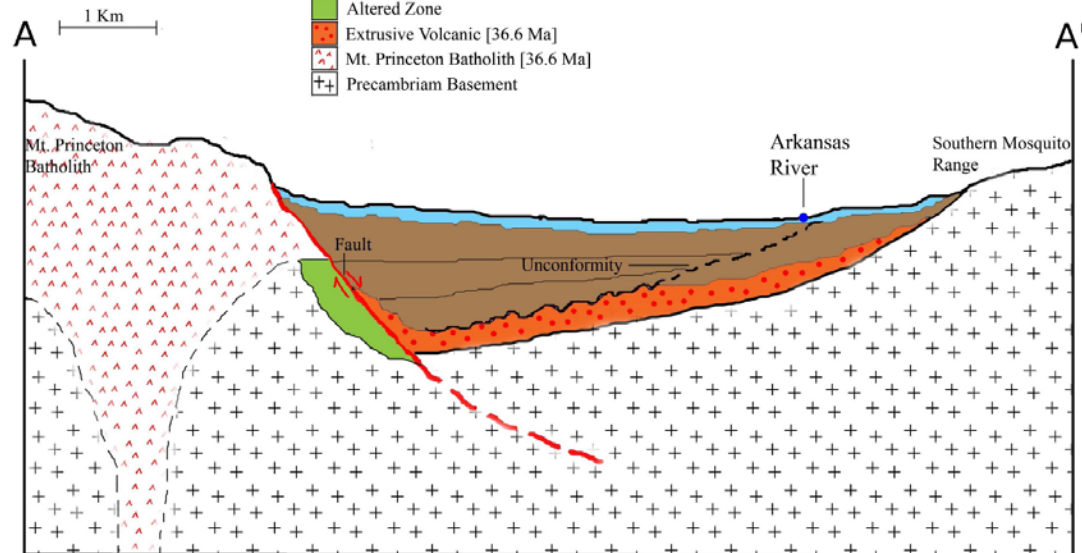
WEST

KEY

- Glacial/Alluvial
- Dry Union
- Altered Zone
- Extrusive Volcanic [36.6 Ma]
- Mt. Princeton Batholith [36.6 Ma]
- Precambrian Basement

Interpreted profile

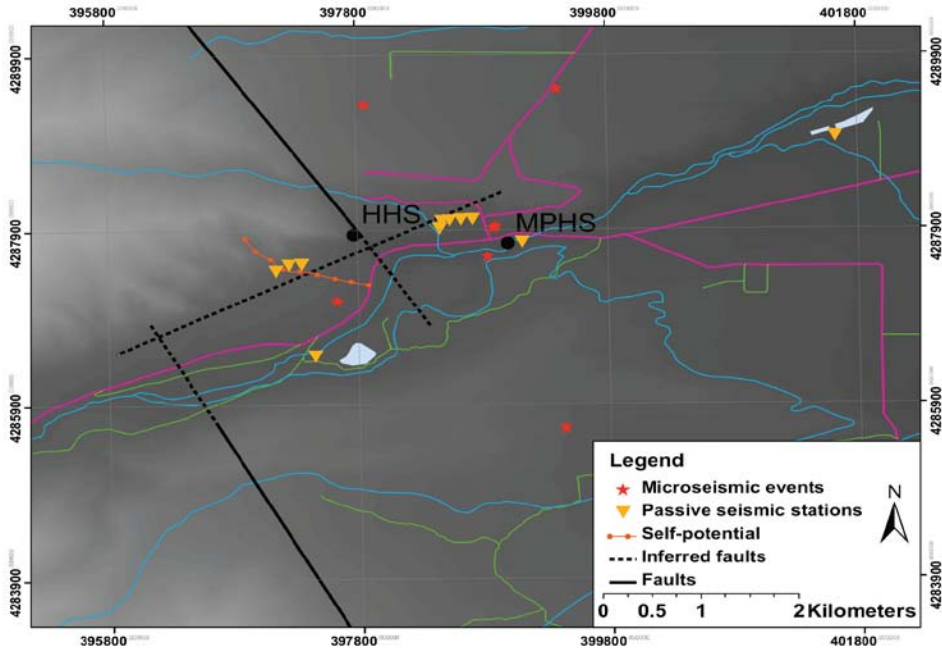
EAST



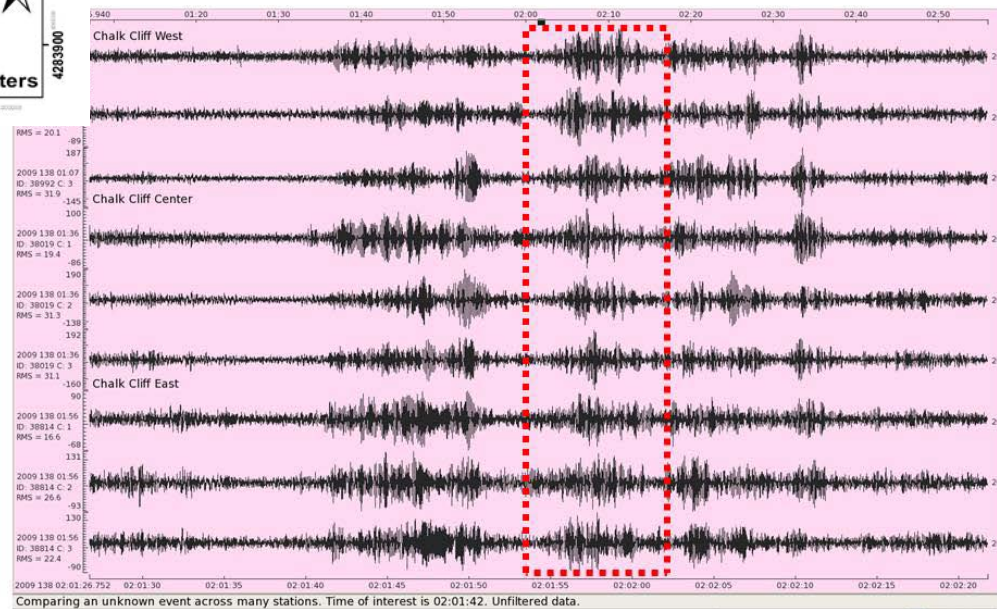
Seismic Acquisition (CGG Veritas)



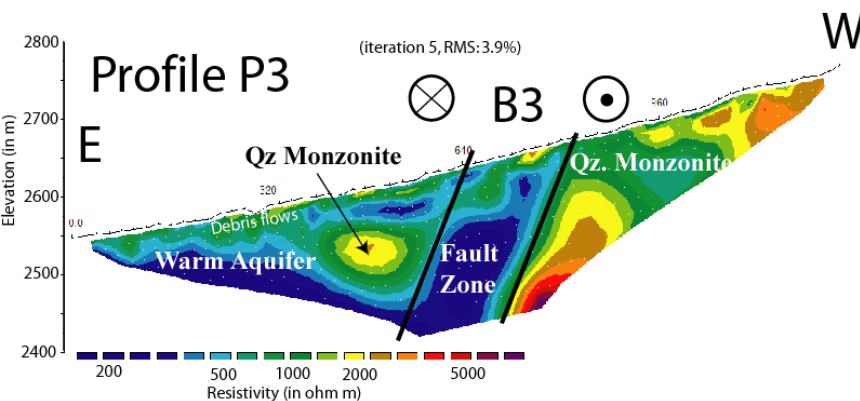
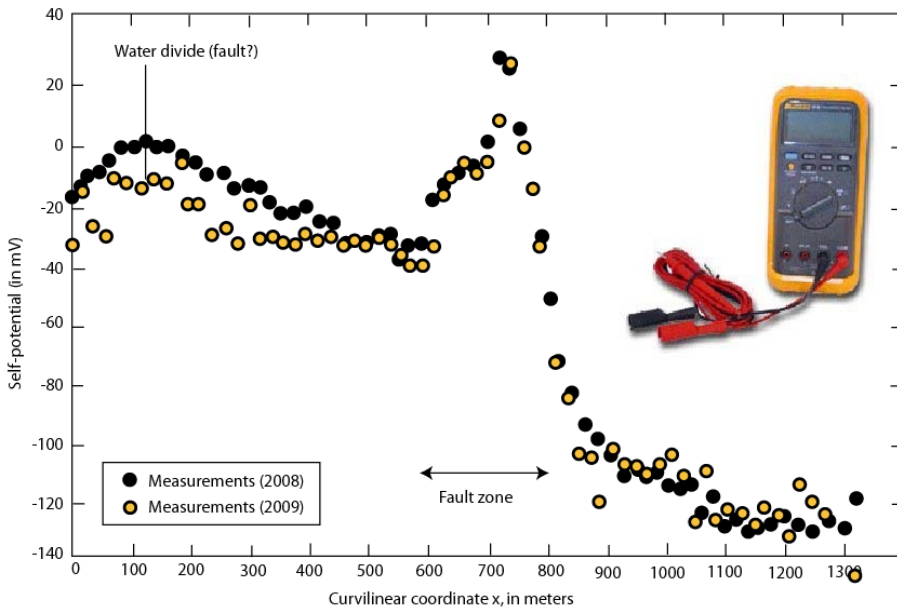
Passive seismic



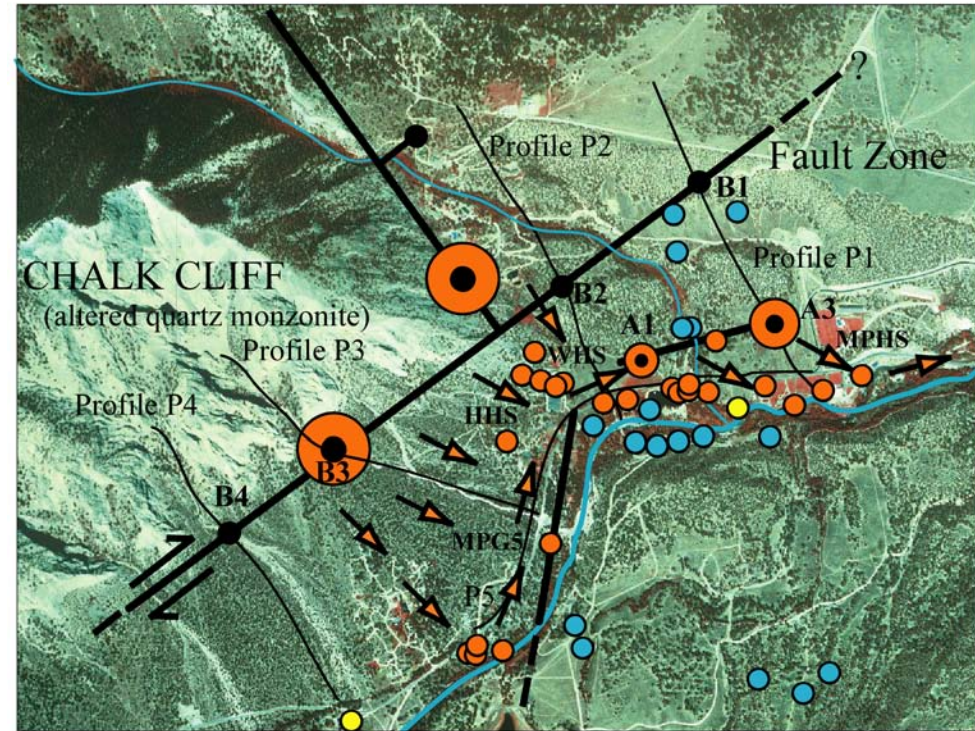
Chalk Cliff Stations (night)



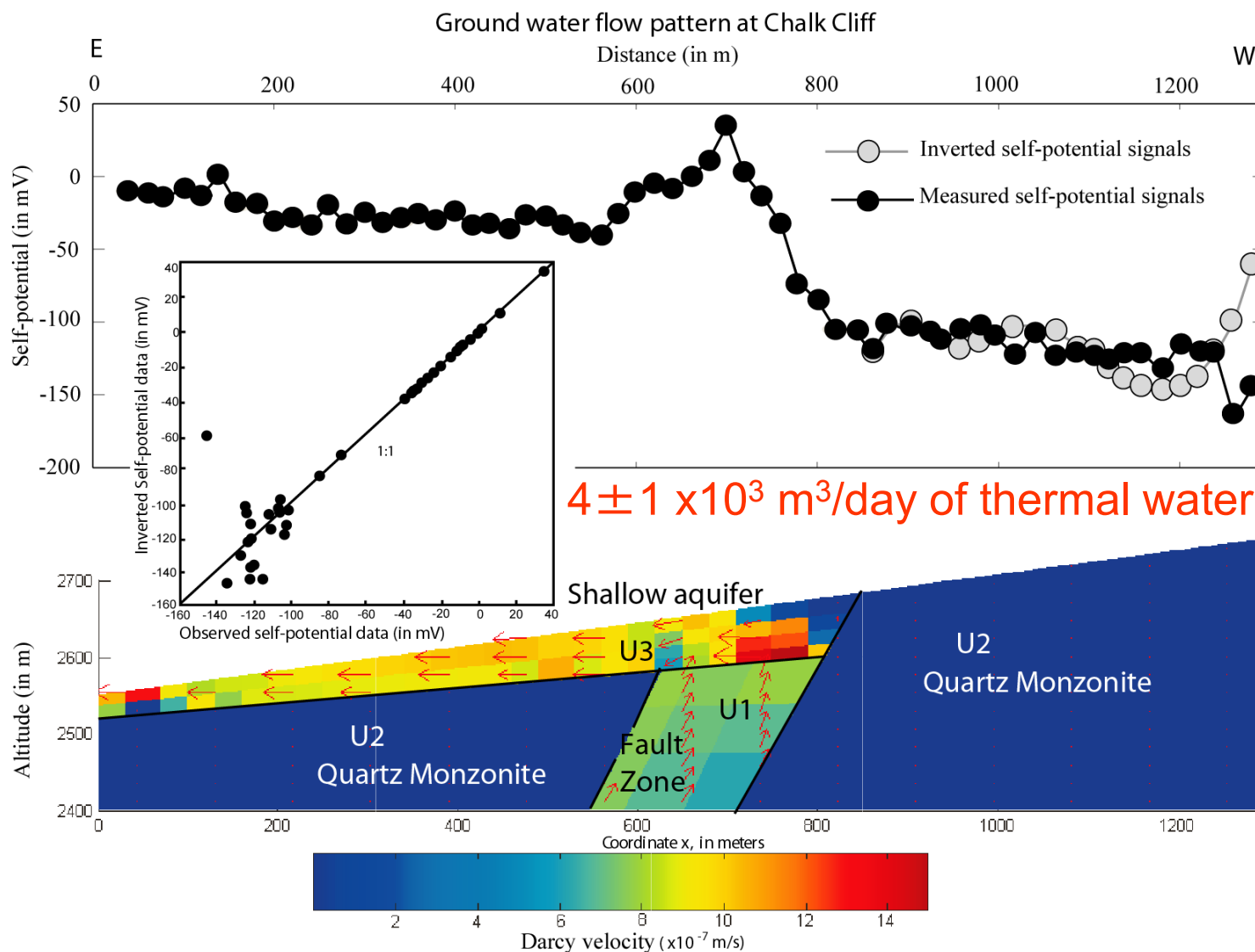
DC resistivity and self-potential



Sawatch fault Mount Princeton Hot Spring area

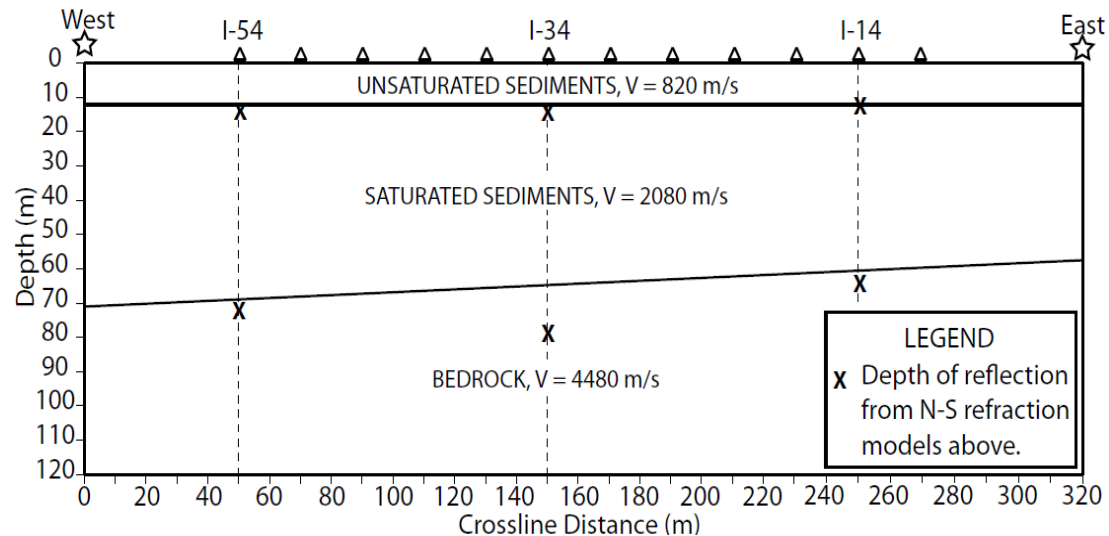
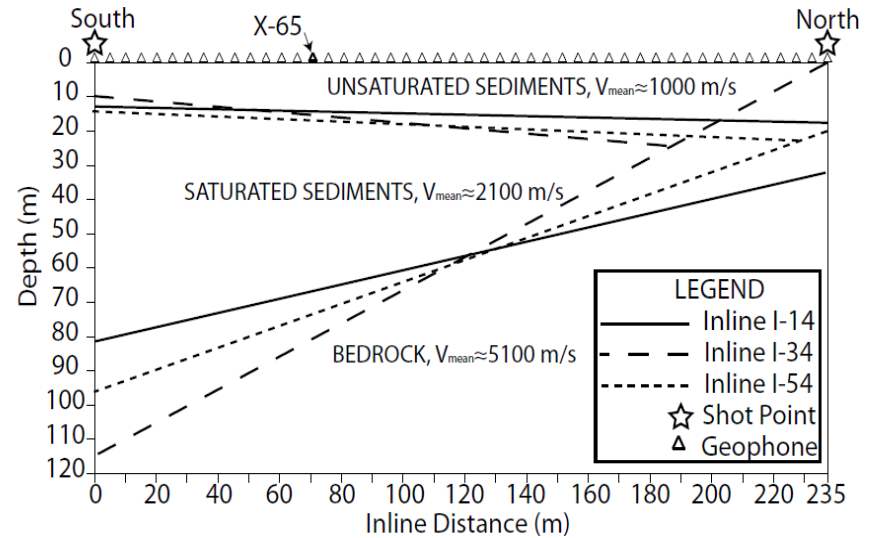
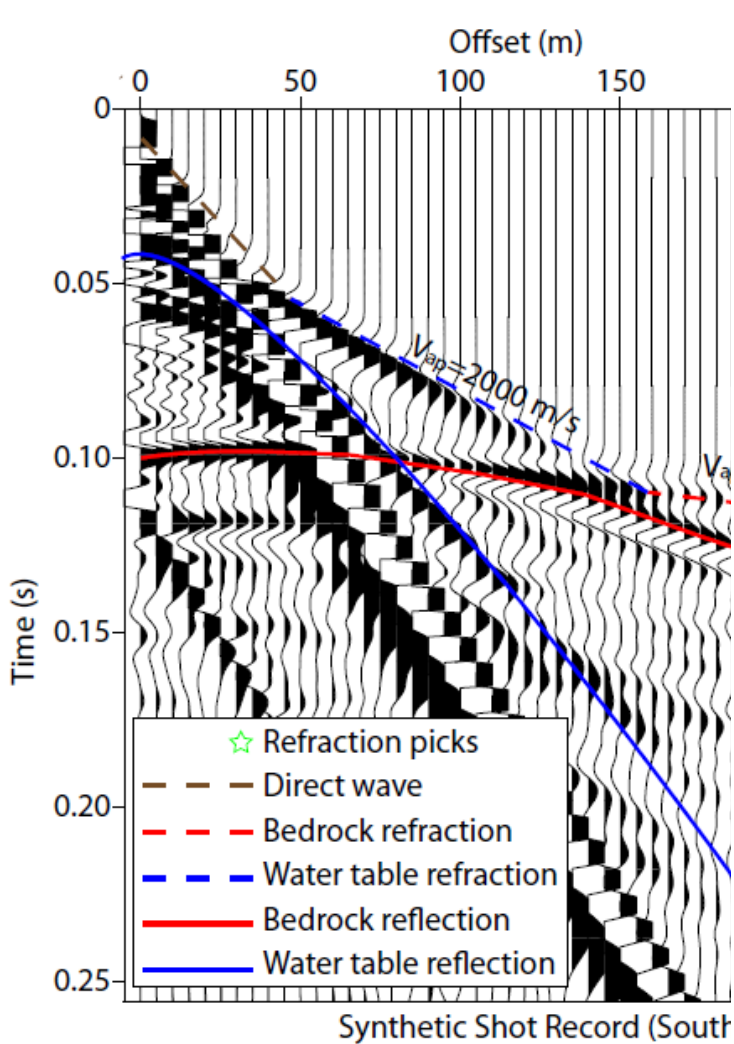


- Hot wells
- Cold wells
- Warm wells
- Area of upwelling of thermal water from positive self-potential anomaly
- Direction of shallow thermal groundwater flow



$4 \pm 1 \times 10^3$ m³/day of thermal water upwelling

3D seismic: preliminary results



Educational component

Field camp - Colorado School of Mines

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

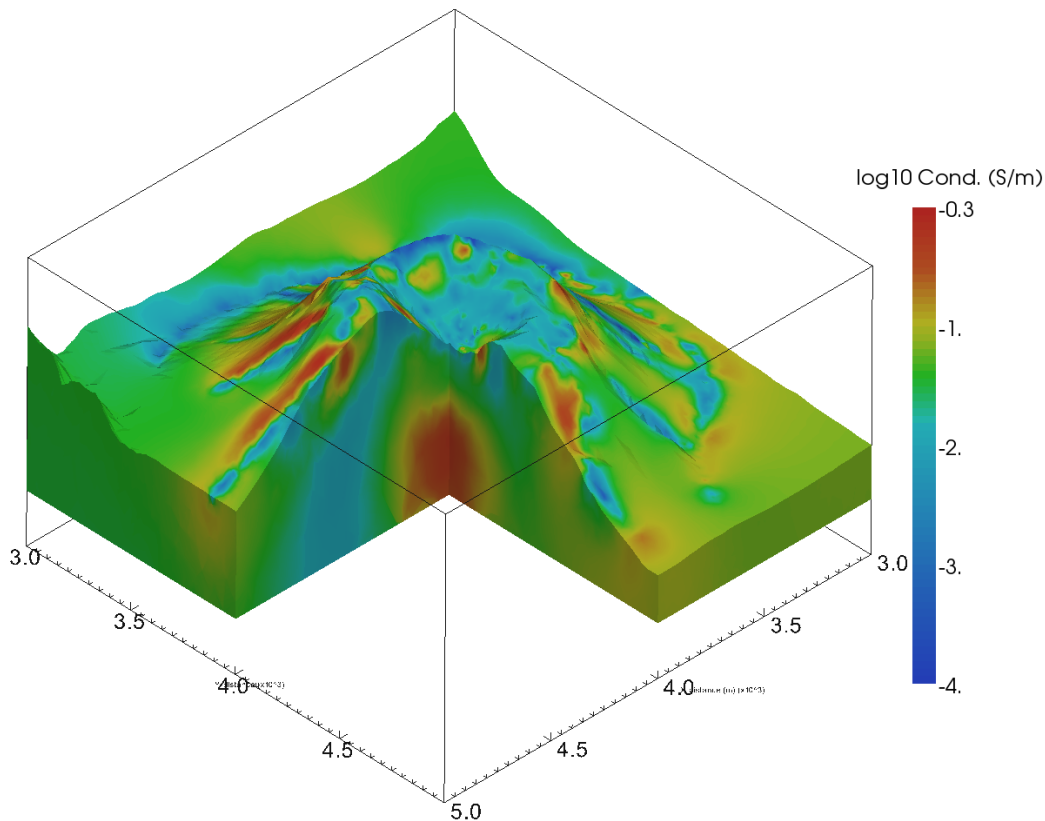
BOISE STATE
UNIVERSITY



Imperial College
London



2011. Joint inversion of seismic and electrical tomographies



- Passive seismic
- Temperature
- self-potential
- DC resistivity
- EM methods
- Active seismic



- Reactive transport code modeling
- Hydromechanical behavior

- 3D DC resistivity tomography of a volcano (Revil, Johnson and Finizola, in preparation)

- Joint inversion/integration of geophysics, geology, geochemistry
- Joint inversion temperature / self-potential / resistivity: done
- Joint inversion with seismic: in progress (2010)
- Application at Mount Princeton: shallow part done (2009)
- Application to Poncha Springs (target summer 2010)
- Development of a ground water flow model (2011-2012)

Mount Princeton

Poncha Springs

The Upper Arkansas valley

List any publications and presentations

3 papers

A. Jardani, and A. Revil, "Stochastic joint inversion of temperature and self-potential data", *Geophysical Journal International*, 179(1), 640-654, (2009).

E. Slob, R. Snieder, and A. Revil, "Retrieving electric resistivity data from self-potential measurements by cross-correlation," *Geophysical Research Lett.*, 37, L04308, (2010).

K. Richards, A. Revil, M. Batzle, A. Jardani, and A. Haas, "A quantitative estimate of the upflow of thermal waters at a dextral strike slip zone at Mount Princeton Hot Springs, Colorado, using geoelectrical methods," submitted to *Journal of Volcanology and Geothermal Research* (2010).

7 Presentations.

The following presentation got the best poster award at SEG: T. Blum, K. van Wijk, and L. Liberty, M. Batzle, R. Krahenbuhl, and A. Revil, "Characterization of a geothermal system in the Upper Arkansas Valley, Colorado," Session MIN P1 Case Histories and Technology, Wednesday, 28 October 2009, SEG Meeting, Poster, 26-30 October 2009, Houston, USA (2009).