NATIONAL ENERGY TECHNOLOGY LABORATORY

Natural Systems Monitoring

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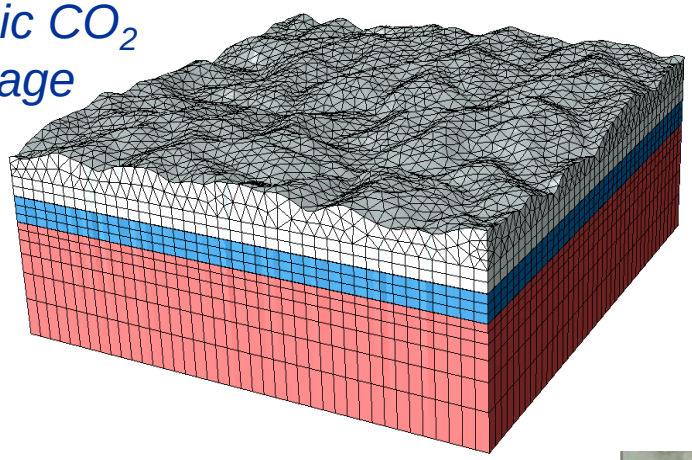
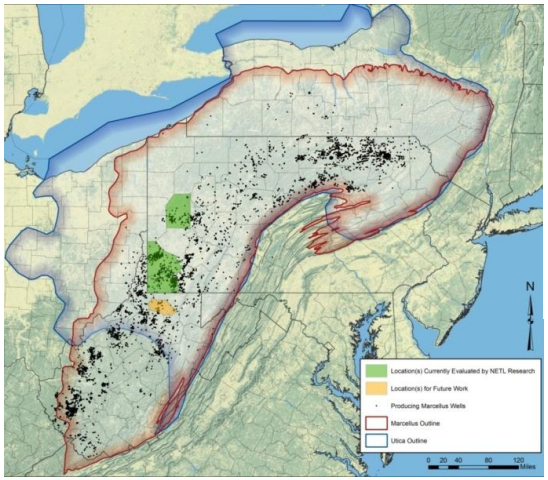
Natural Systems Monitoring
Applications Towards Engineered-Natural Systems

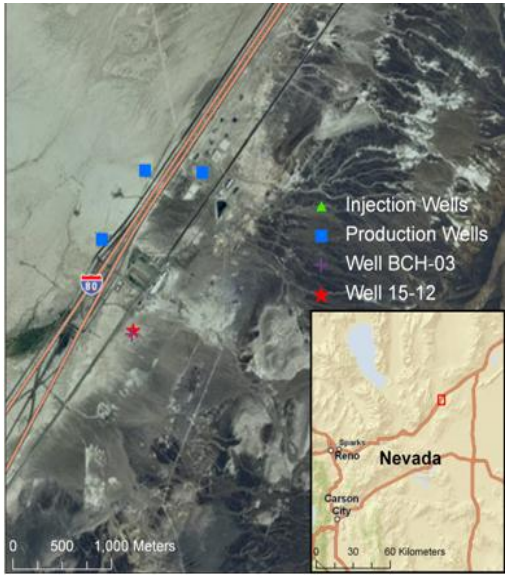
Geologic CO_2 Storage





Conventional and Unconventional Oil and Gas

Offshore Systems



Geothermal Systems

Monitoring for environmental integrity and system performance

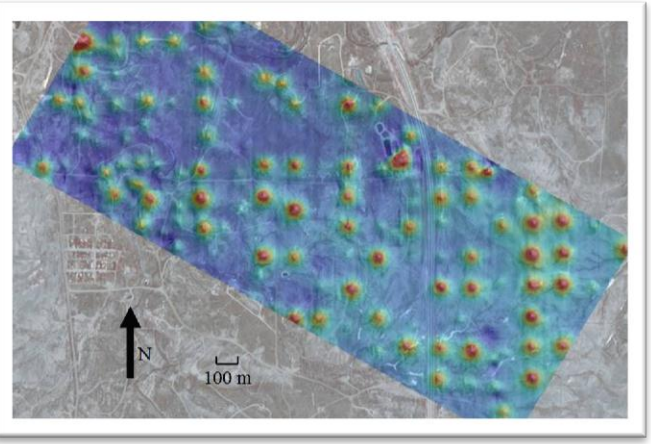
- **Monitoring to Evaluate:**
  - Air Quality
  - **Water Quality**
  - **Existing Wellbores and Wellbore Integrity**
  - **Gas and Fluid Migration**
  - **Legacy Subsurface Issues**
  - **Fracture Propagation and Ground Motion**

Developing baseline environmental datasets to aid industry and regulators with decision-making

Development and application of new technologies

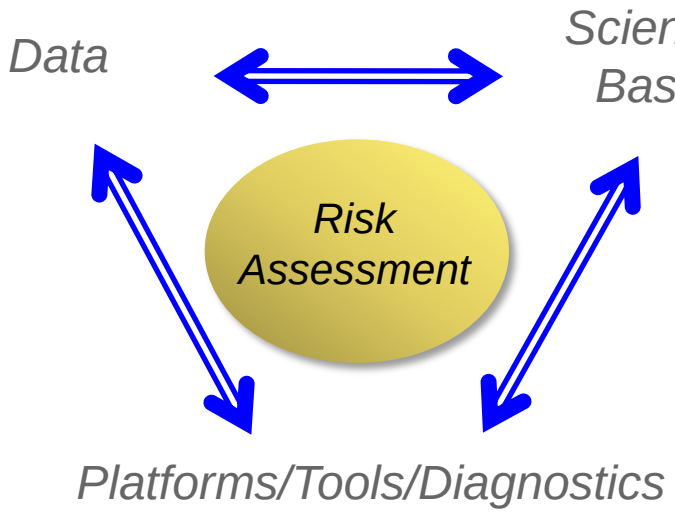
NETL Ambient Air Quality Monitoring

Produced Water Evaluation



Magnetic Well Surveys

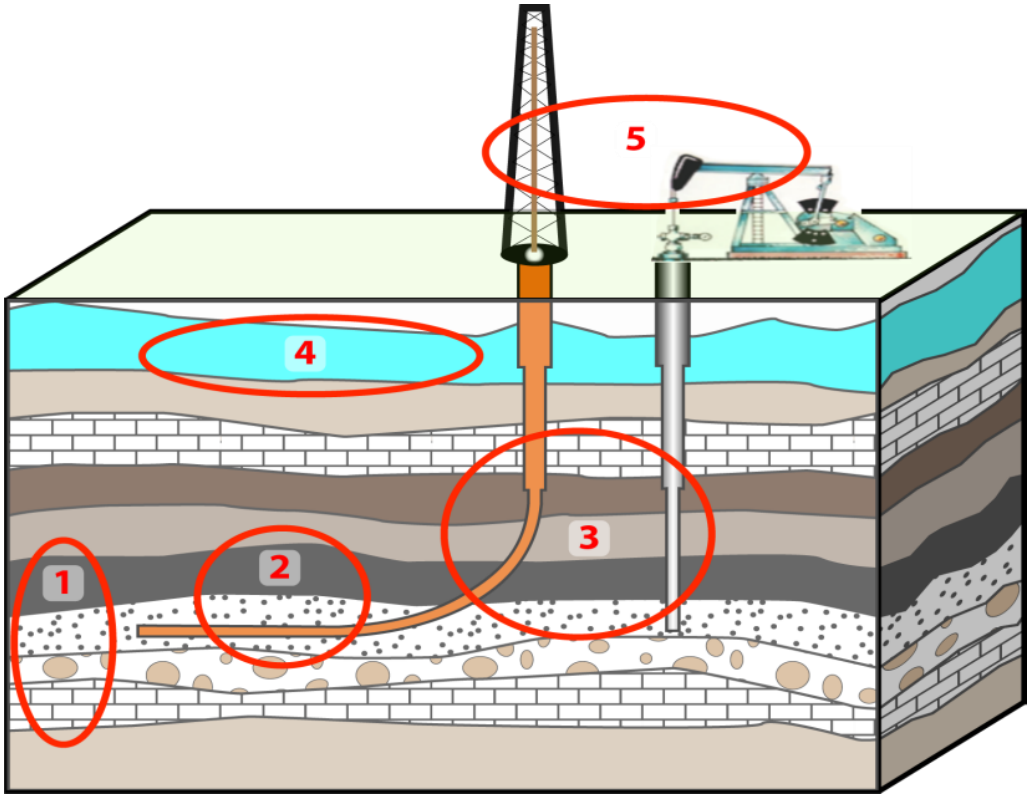
Development of natural systems monitoring technologies is integrated with laboratory and computational investigations



Risk = probability X consequence

- *site performance*
- *impact of event*

- *Field Data to establish baselines and impacts of processes*
- *Laboratory Data for simulations and confirmation of field data*
- *Computational Tools to characterize and predict system baselines and behavior*



Natural Systems Monitoring
Examples of Collaborative Opportunities

- **Perfluorocarbon tracers for subsurface gas tracking**
  - Trace quantities injected with CO_2, hydraulic fracturing fluid
  - Monitoring in shallow aquifers and at the surface; Sensitive detection limits

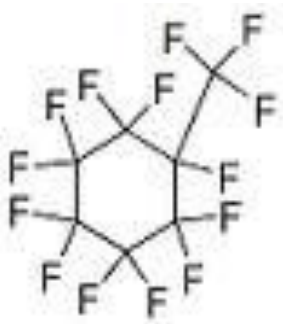
- **Natural geochemical tracers for subsurface fluid and gas monitoring**
  - No additional chemicals added to the system
  - Develop rapid-throughput analytical techniques for improved processing time; Sensitive detection limits

- **Helicopter geophysics with various applications**
  - Location of abandoned/unknown wellbores
  - Produced water management
  - Geohazards at coal waste impoundments

- **Advanced 4D geophysical techniques to monitor enhanced geothermal systems during stimulation and production**
  - Newberry EGS (AltaRock)
  - New portable radar interferometry, 4D electromagnetic imaging methods, high-resolution gravimetry

Perfluorocarbon Tracers (PFTs)

State of Science/Technology

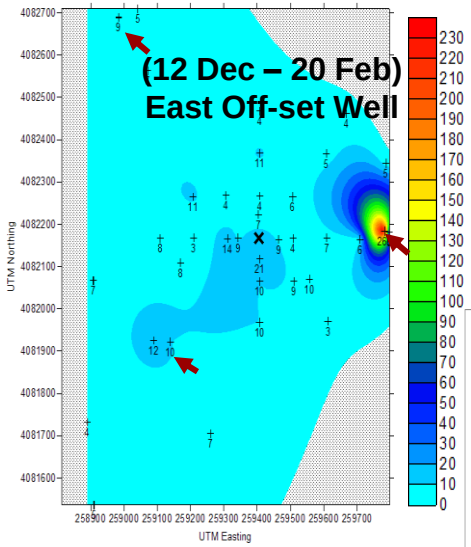


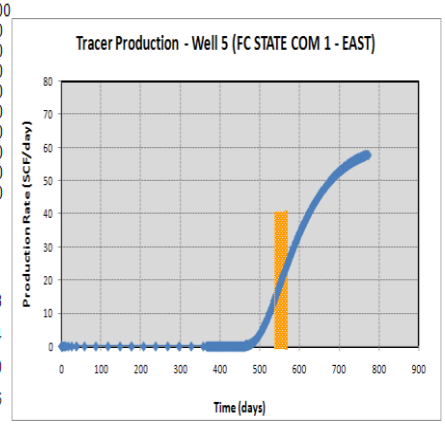
- Developed by Brookhaven National Laboratory (http://www.bnl.gov/des/ERTD/TracerTechnologies/)
- Used to study air movement and leak detection since the early 1980s
- Meteorological and environmental applications (Lagomarsino et al., 1991; Senum and Dietz, 2004)
- Subsurface applications (Senum et al., 1989)
- To evaluate water alternating gas injection in North Sea oil reservoir (Ljosland et al., 1993)
- **Demonstrated indicators of CO_2 leakage at West Pearl Queen EOR test injection site (Wells et al., 2007)**

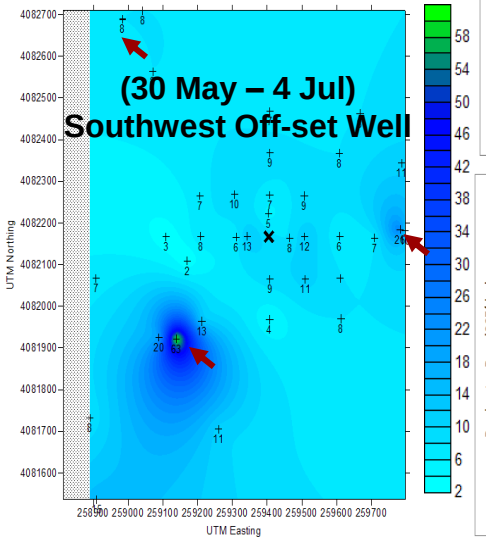
Advantages of PFTs

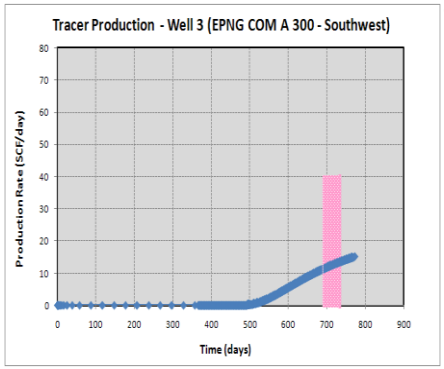
- Nontoxic, inert, stable up to 500^{o}C, and detectable down to 10^{-16} mol PFT/L
- High vapor pressure, enhanced solubility in CO_2 and low water solubility

Example: PFT Application to San Juan Basin Site









1 year post injection near-surface monitoring of PFT - semi-arid climate / sandy soil

- ***PFT tracers in production gas were monitored at vents from 3 offset producing wells (indicated by arrows).***
- ***Tracer breakthroughs at the east and southwest offset wells were used to refine reservoir simulations (blue curves).***
- ***Sensors at the wells have not detected CO_2 breakthrough (CO_2 is 20-30% of the produced gas).***
- ***Tracer results indicate a different permeability anisotropy than originally believed.***

OUTCOME: The combination of PFT tracer monitoring with reservoir simulations led to an improved model of the San Juan Basin site.

Passive Atmospheric Concentrations of PMCH

Laboratory Investigation of PFT Behavior in Dry and Saturated Geologic Media to Verify Field Behavior

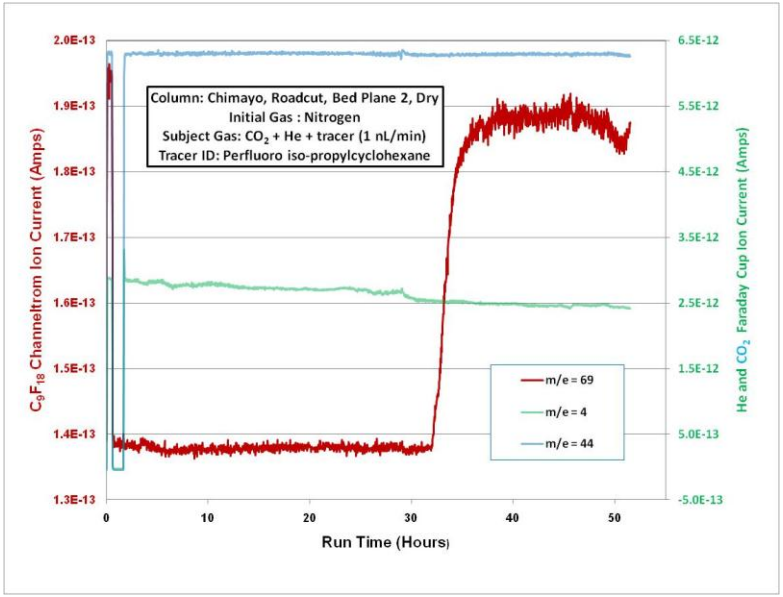
Strata Interactions Laboratory (PFTs and Carbon Dioxide)

- Provide Fundamental Parameters for Reservoir and Migration Pathway Simulations
- Evaluate the Retention of Tracers and CO_2 on Reservoir and Overlying Strata

FY 2011 Goals

- Complete interaction measurements for a series of dry media.
- Obtain data verifying the importance of moisture.

- **Results so far are qualitative**
  - **On dry samples, tracer can be retained longer than CO_2**
  - **Order of increasing retention of tracer**
    - Sand (silica) — Low Retention
    - Kaolinite
    - Montmorillonite
    - Chimayo — High Retention



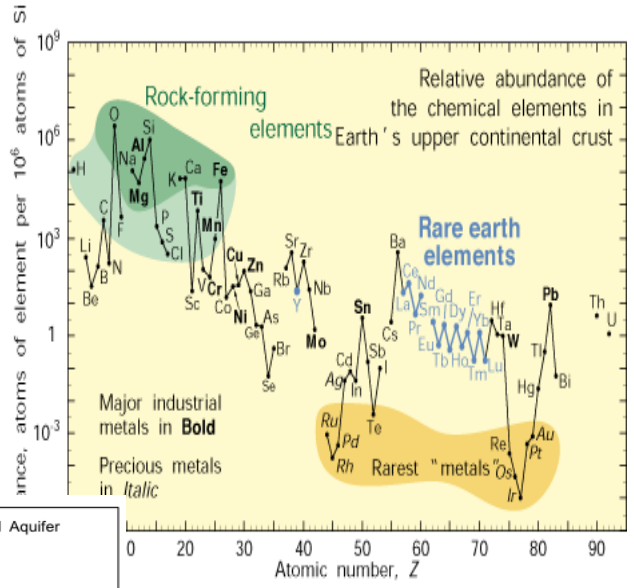
CONCLUSION: UNDER VERY DRY CONDITIONS PFT ADSORBS TO MEDIA (Adds to uncertainty of monitoring)

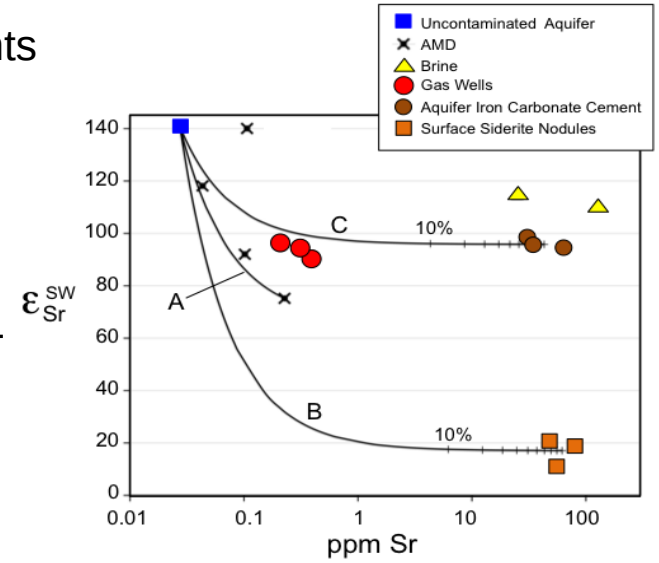
Geochemical Signals: Isotopes and REEs

Use a combination of naturally occurring trace elements and elemental isotopes as indicators of subsurface geochemical reactions and fluid migration

- Sensitive indicators of changes in water-rock interaction, including unplanned release of metals
- Mineral dissolution and precipitation of secondary mineral cements (Sr, Si, Cu, Fe, Zn)
- Tracking subsurface fluid flow (Sr, Nd, B, Fe)
- Geochemistry of aqueous systems—redox active elements (Fe, Mo, Cu); pH-affected elements (B)
- Indicators of microbiological activity (Zn, Ca, Fe)
- Combined field and laboratory-scale experiments

USGS Abundance Chart: http://pubs.usgs.gov/fs/2002/fs087-02/



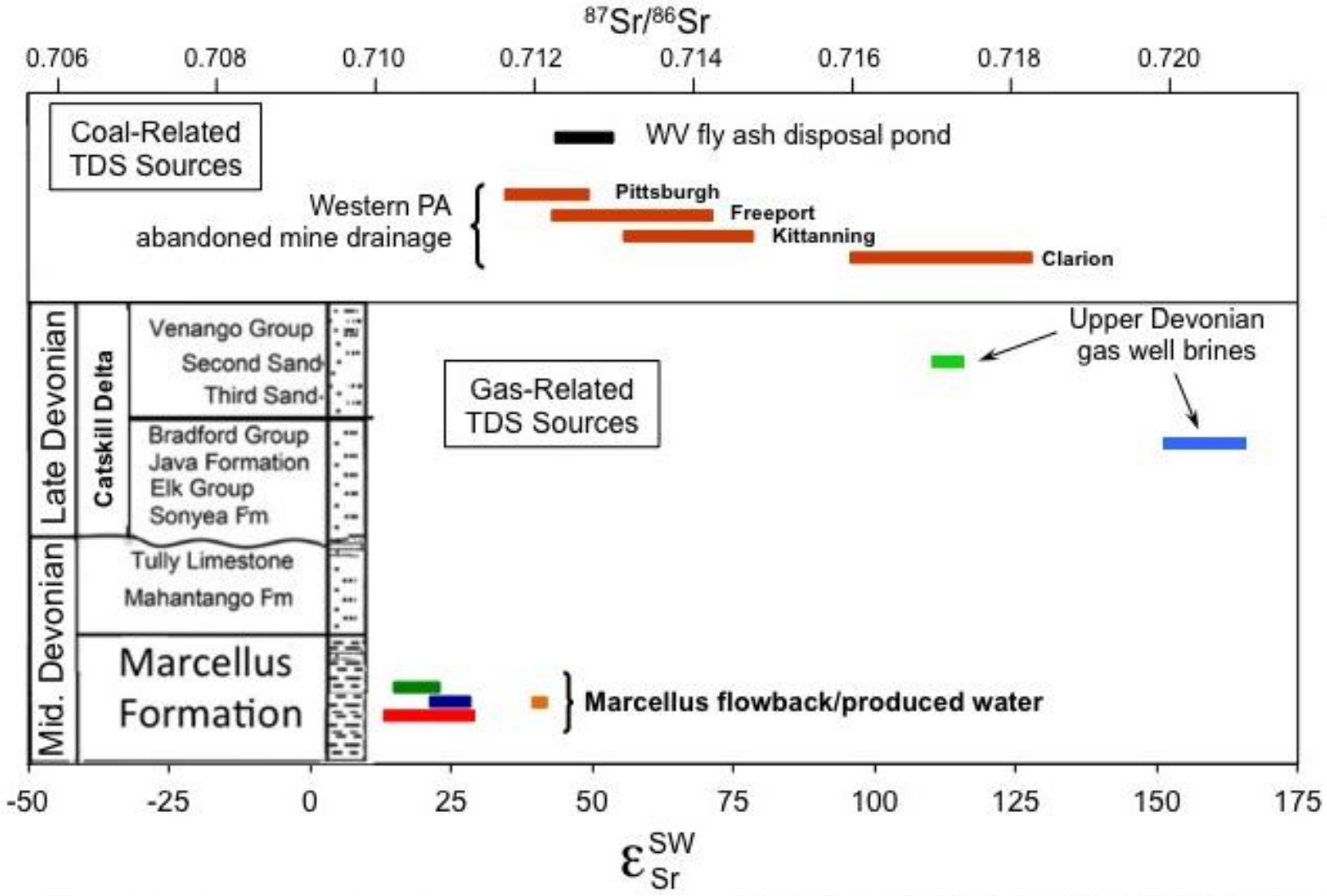


Brine Mixing vs. Water-Rock Interaction

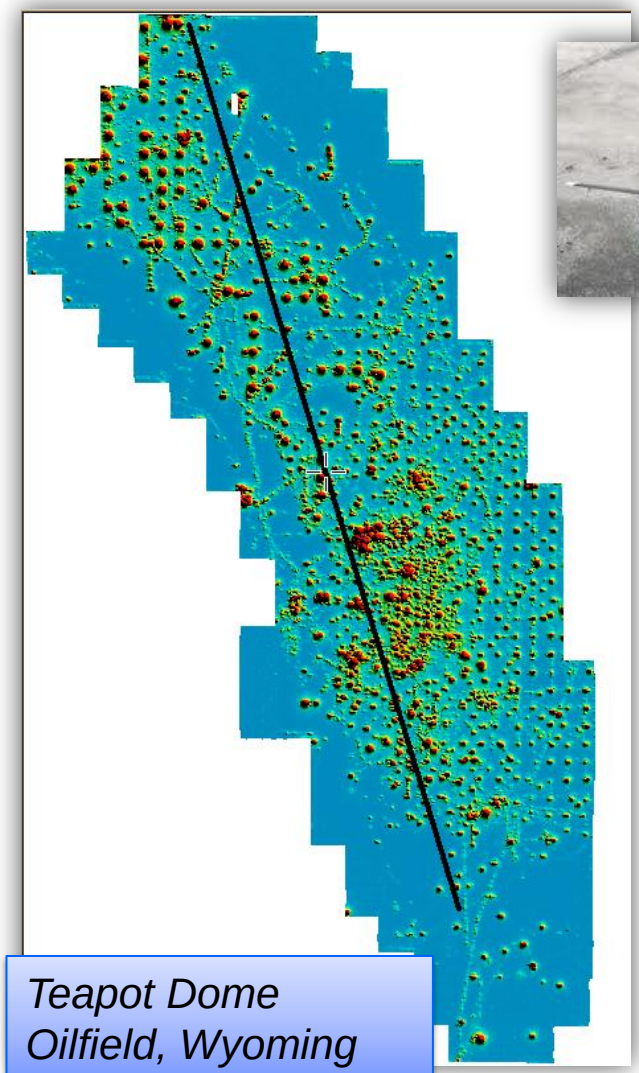
Geochemical Signals: Development of Isotope Capabilities

- Development of NETL-RUA multicollector ICP-MS shared facilities (NETL-Pitt-Penn State)
- C, O, S isotopes (WVU) ; Cu and Fe isotopes

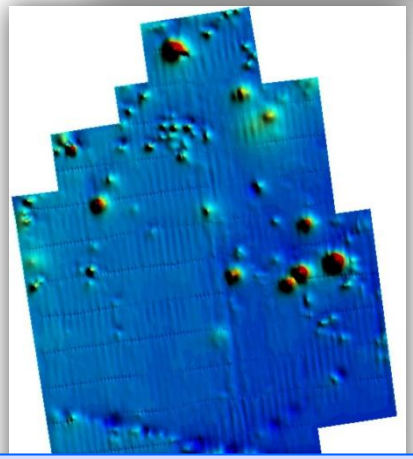
Rapid-throughput Sr isotope methods using column chemistry and multicollector ICP-MS applied to Appalachian Basin monitoring



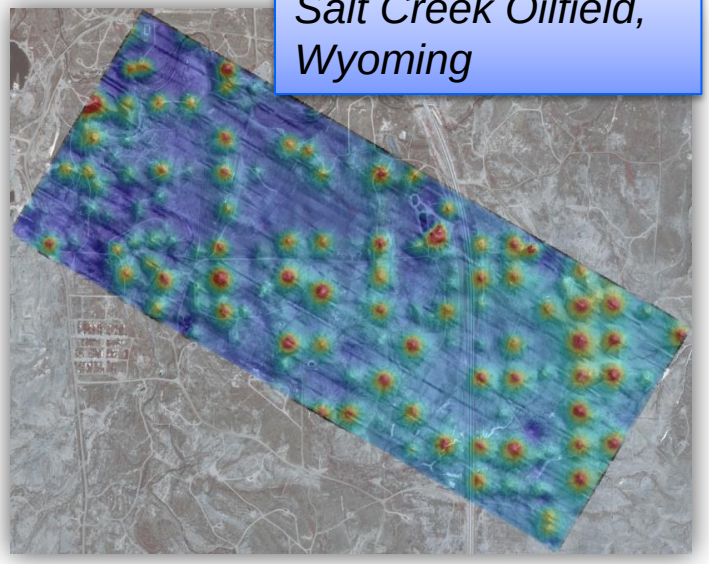
Helicopter Geophysics Applied to Upstream Oil and Gas Operations-
Location of Legacy Wells



Teapot Dome Oilfield, Wyoming

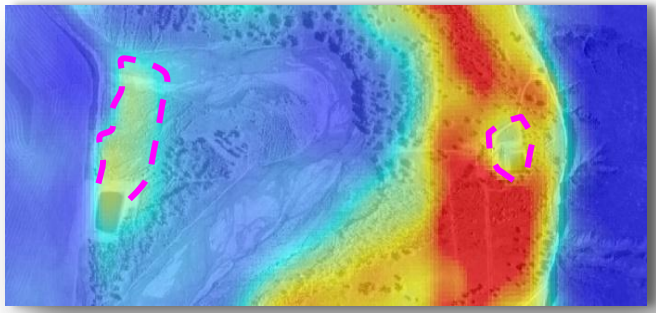


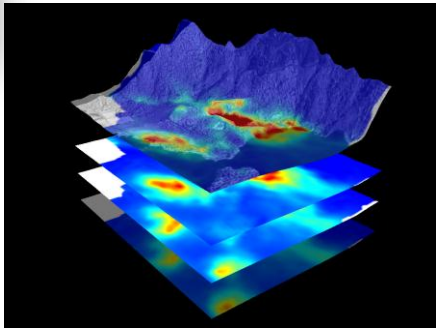
Marcellus Shale Gas, SW Pennsylvania

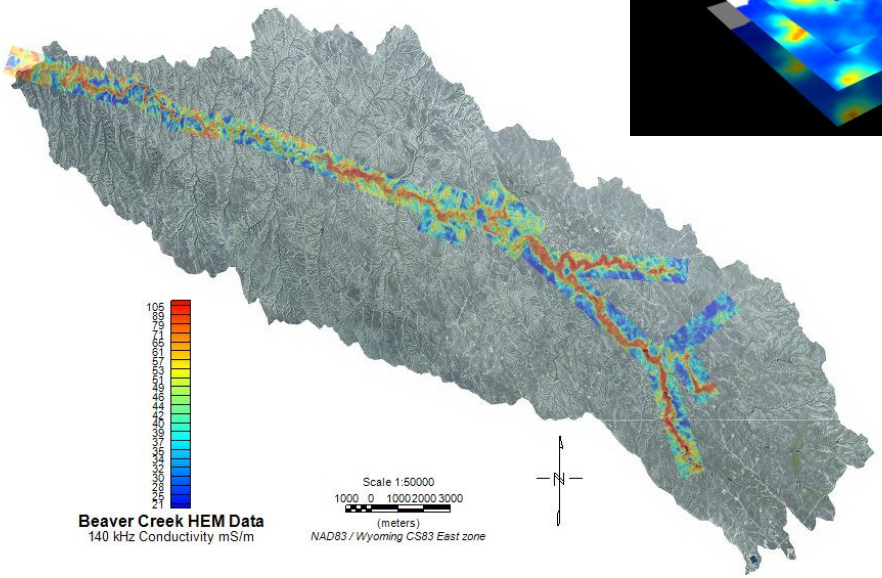


Salt Creek Oilfield, Wyoming

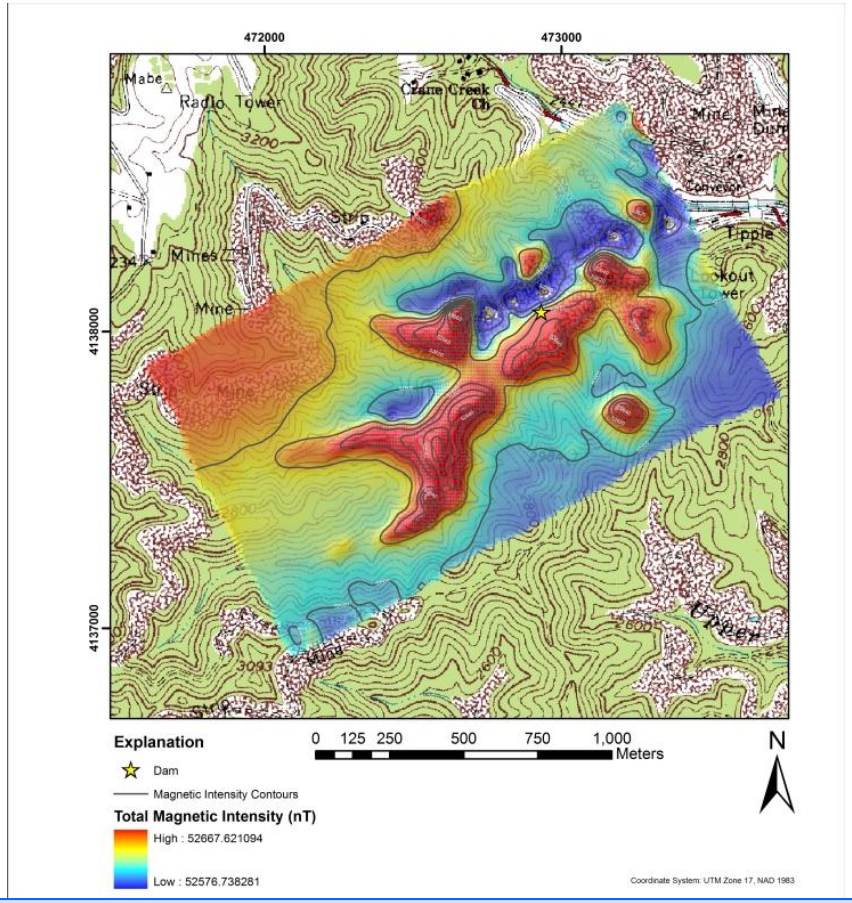
Helicopter Geophysics Applied to Upstream Oil and Gas Operations-
Electromagnetic Mapping of Produced Water Plumes





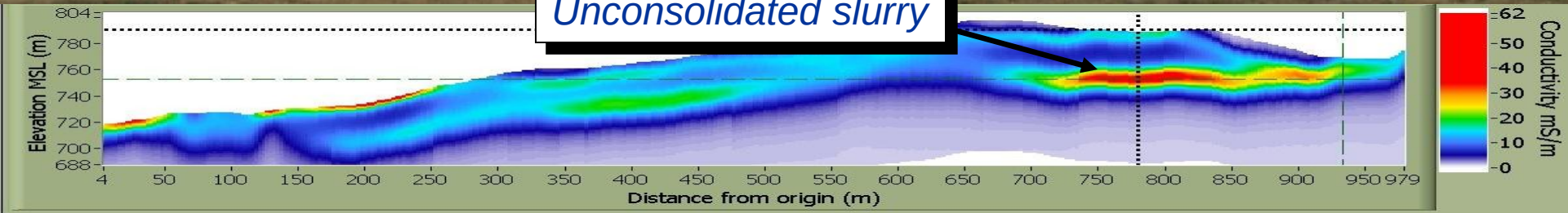


Helicopter Mapping of Geohazards at Coal Waste Impoundments

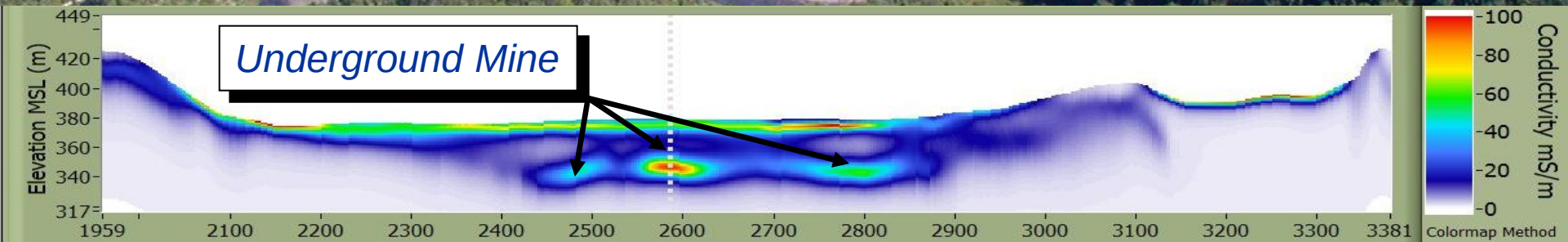


Magnetic Map of Coal Waste That Contains Small Amounts of Magnetite

Helicopter Electromagnetic Surveys Identify Potential Hazards at Coal Waste Impoundments

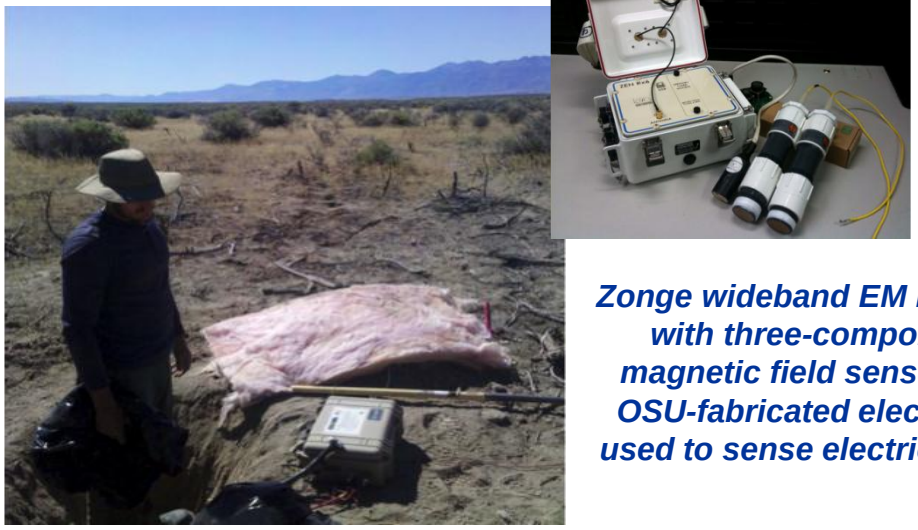


Helicopter Electromagnetic Surveys Locate Flooded Mines Beneath Coal Waste Impoundments

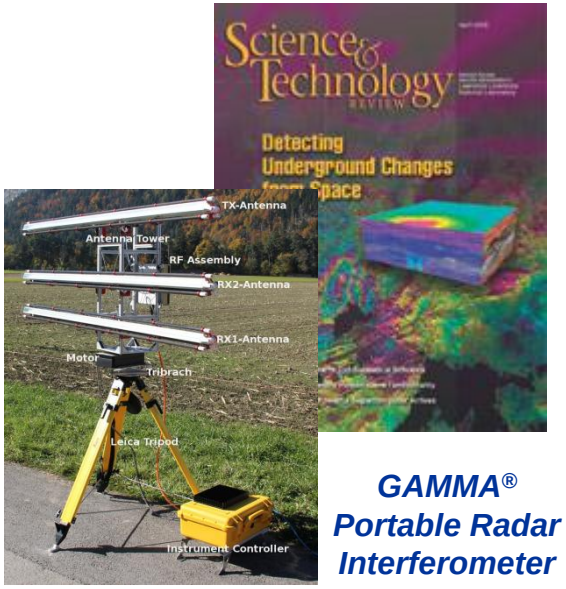


Novel use of 4D Monitoring Techniques to Improve Reservoir Longevity and Productivity in Enhanced Geothermal Systems

- **Selected for award, fall 2011, by DOE's Office of Energy Efficiency and Renewable Energy**
  - Phase 1 $770,000
  - Phase 2 $1,375,225 (contingent on Budget Phase approval)
- **Goal: Develop a new method for assessing and monitoring EGS stimulation and reservoir perturbations during production**
  - Through the application of advanced geophysical techniques with geologic and geochemical analyses
  - Utilizes new portable radar interferometry, 4D electromagnetic imaging methods, and high resolution gravimetry,



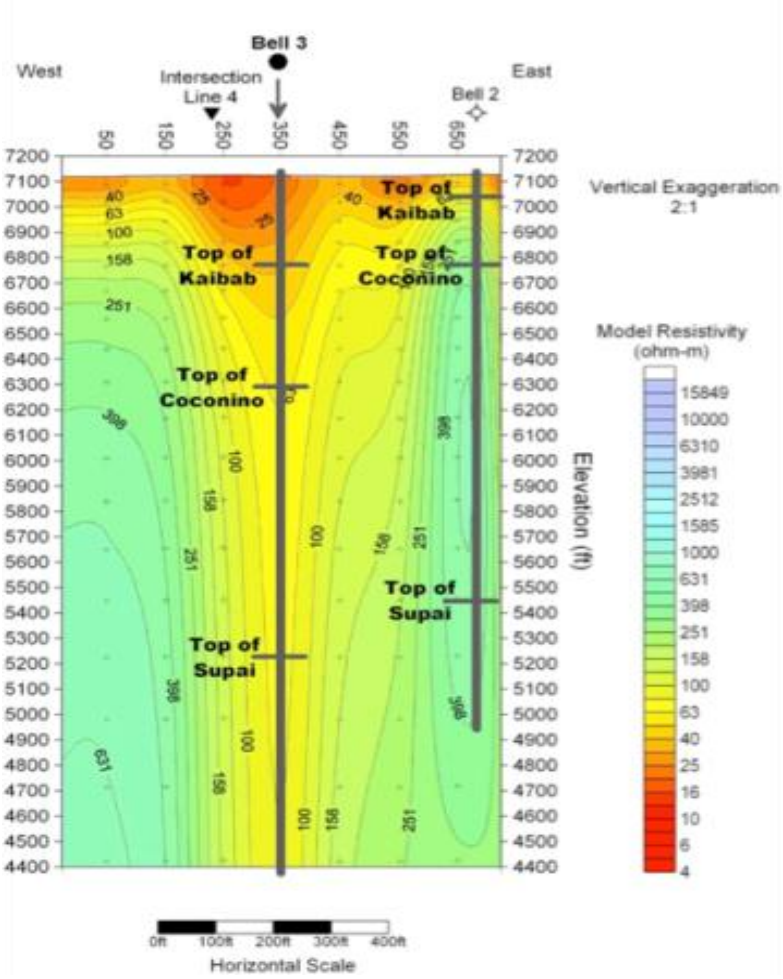
Zonge wideband EM receiver with three-component magnetic field sensor and OSU-fabricated electrodes used to sense electric fields.



GAMMA® Portable Radar Interferometer

4D Monitoring for EGS: Project Team

- **Performers:**
  - NETL-ORD (Kelly Rose, PI)
  - Oregon State University
    - Adam Schultz, Paul Vincent
  - Zonge International
- **External Collaborators:**
  - AltaRock Energy Inc.
    - Providing access and collaboration for field demonstration phase at their Newberry, Oregon EGS test site.
  - Davenport Newberry Geothermal



Example Zonge MT resistivity section from Northern Arizona

Questions?

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