Products, Geoscience Tools, and Data Integration Necessary for Successful Geothermal Development

F.C. Monastero – Magma Energy (U.S.) Corp.

Products That Are Needed to Move Geothermal Ahead with Alacrity

Establishment and/or Standardization of Databases

- Location and geochemistry of hot & cold springs
- Geochemistry of rocks
- Drill hole locations & logs
- Temperature, heat flow, and temperature gradients

Compilation, Quality Control, and Update of Data Sets

- Geologic Maps
- Geophysical Surveys
- Hydrology
- Aerial & Satellite Photos

Crustal Dynamics: Because Strain Matters

- Establishment and Maintenance of a Regional Seismic Network
- Regional GPS and INSAR Studies

Digitize Everything and Make it Available on the Web in a Timely Manner

Provide a Comprehensive Assessment of Geothermal Potential for Western Canada

- "Assessment of moderate- to high-temperature geothermal resources of the United States"
- http://www.pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf

New Technologies for Geothermal Exploration

Here's what you will hear

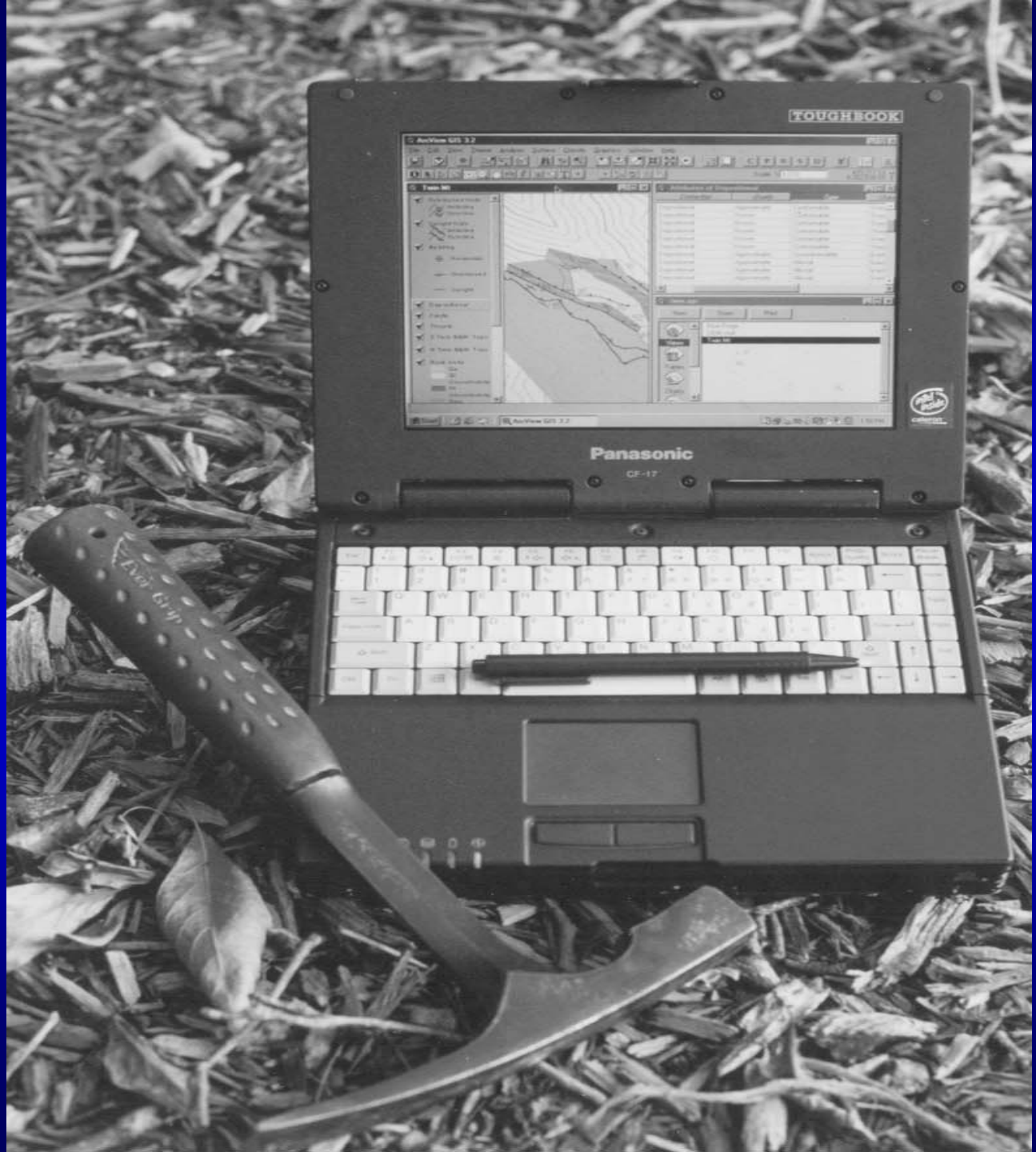
- Digital mapping is the leading edge
- Geodetic measurement & analysis is "spot-on"
- Remote sensing gives us the 40,000 ft. view
- Database mining is rich in precious morsels

Here’s what you won’t hear

- Much ado about electrical methods
- Better exploration is achieved through geochemistry
- Potential fields geophysics has a lot of potential
- Tried-and-true is “true blue”

Digital Mapping

- Real-time mapmaking in the field
- Powerful tool because of the power of the computer
- Multi-layered information mechanism
- Integrated geodetic, geologic, and geophysical data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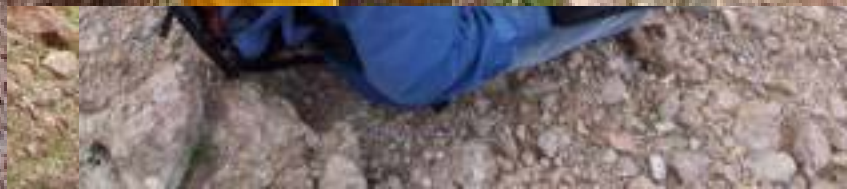
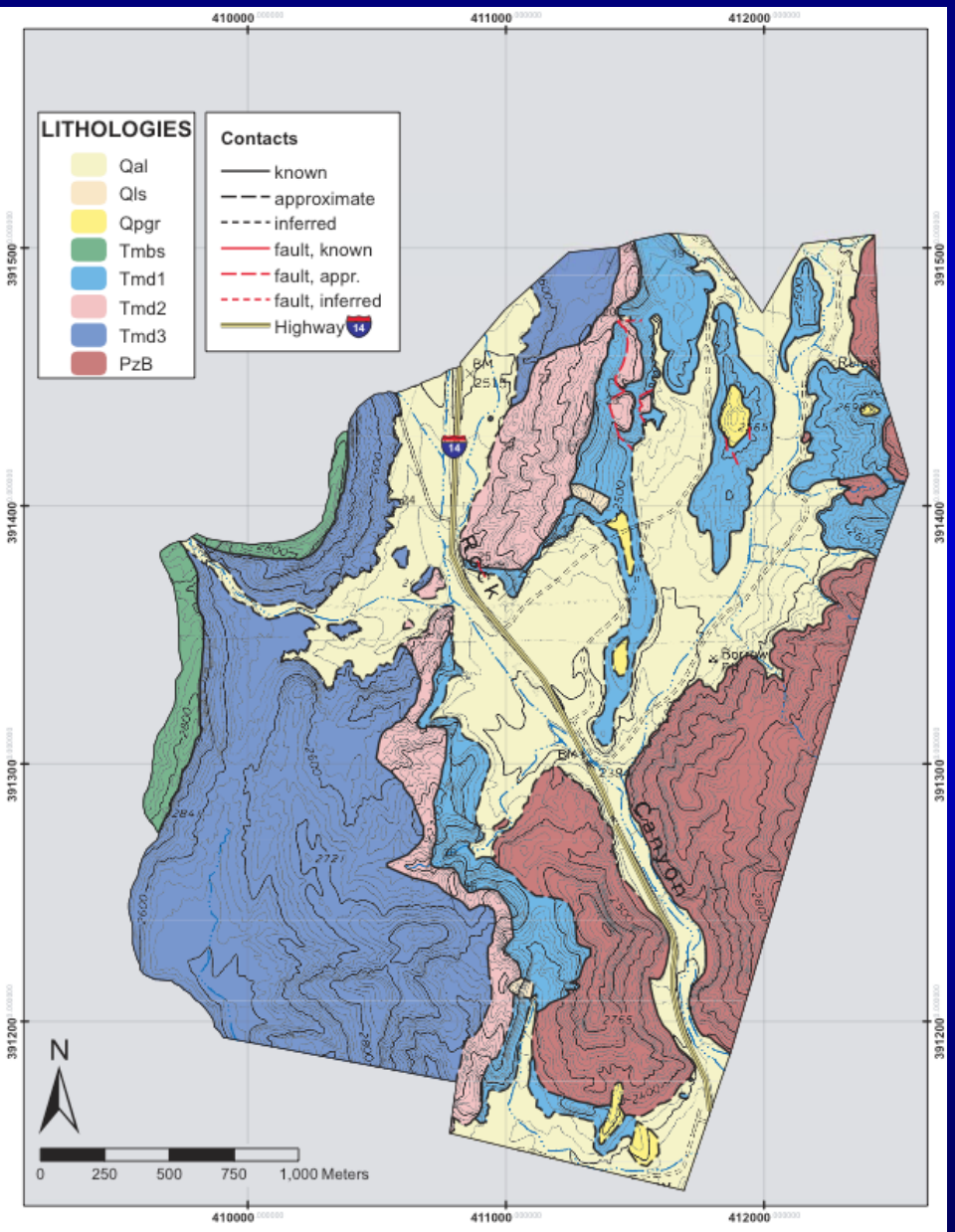
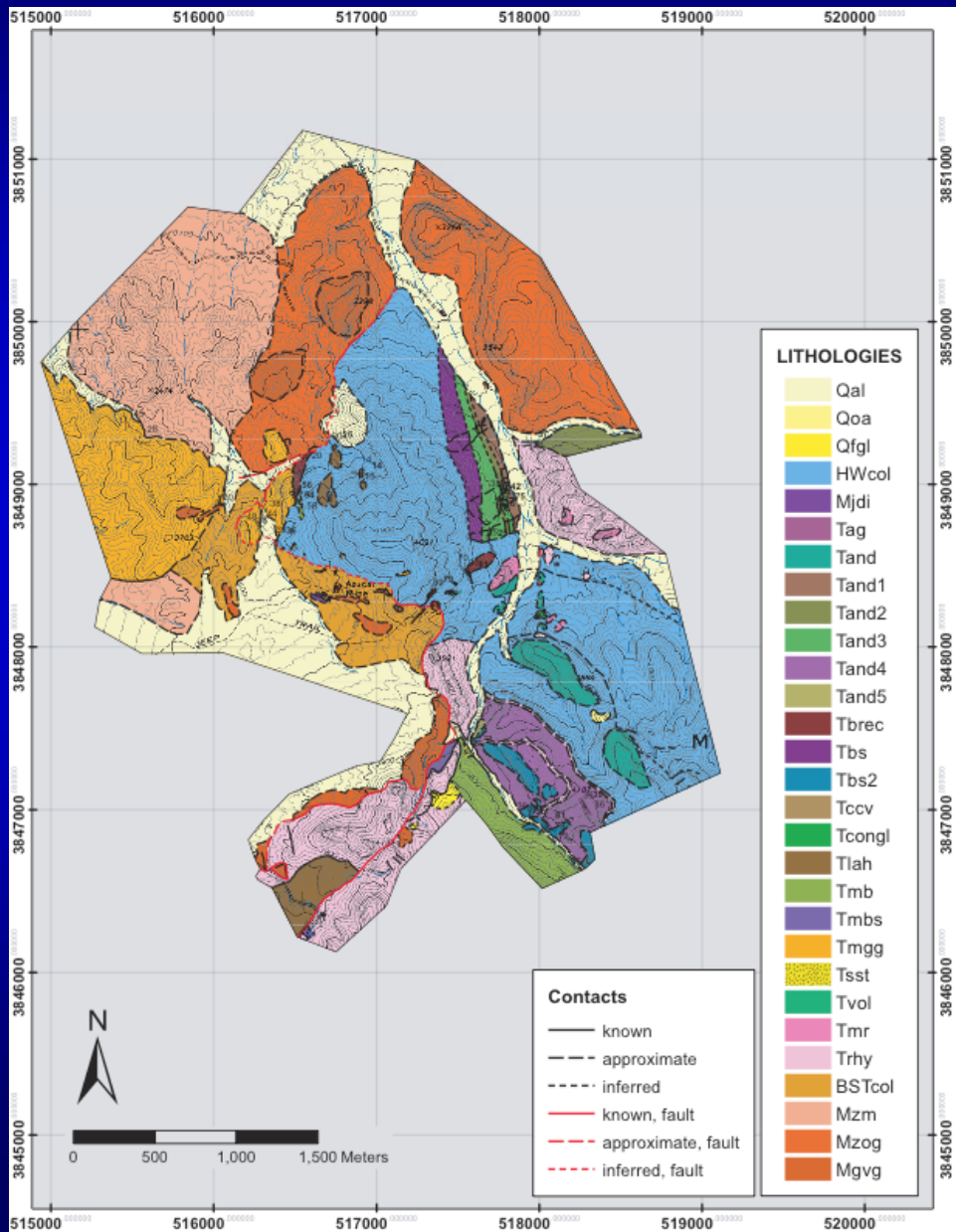


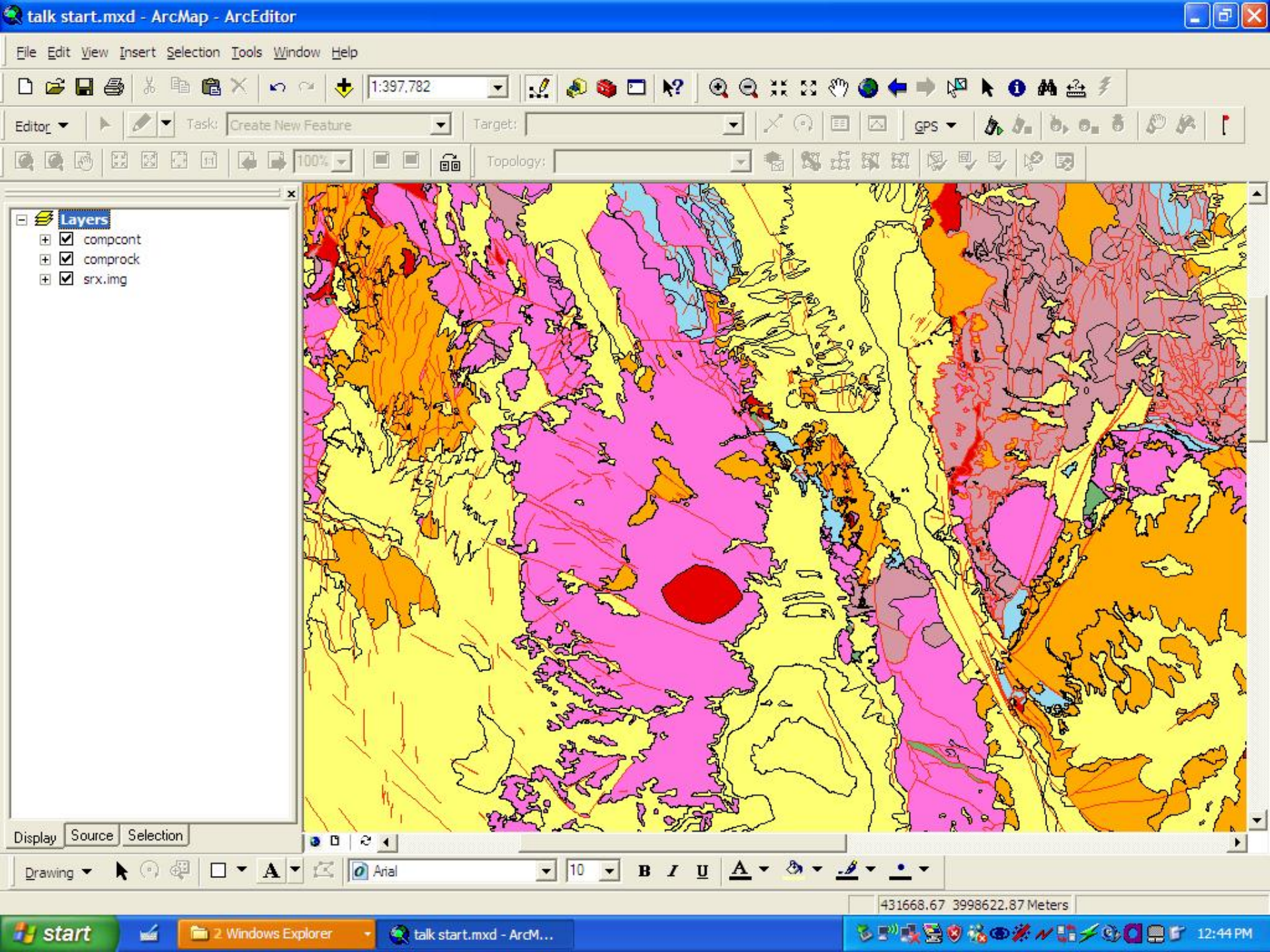
Field Course Maps





Integration of Other Data and On-The-Fly Hypothesis Testing

- Integration with other datasets and layers gives a lot more power for mapping
- Remotely sensed data are critical
- All existing mapping and interpretations
- Plotting/compiling in the field.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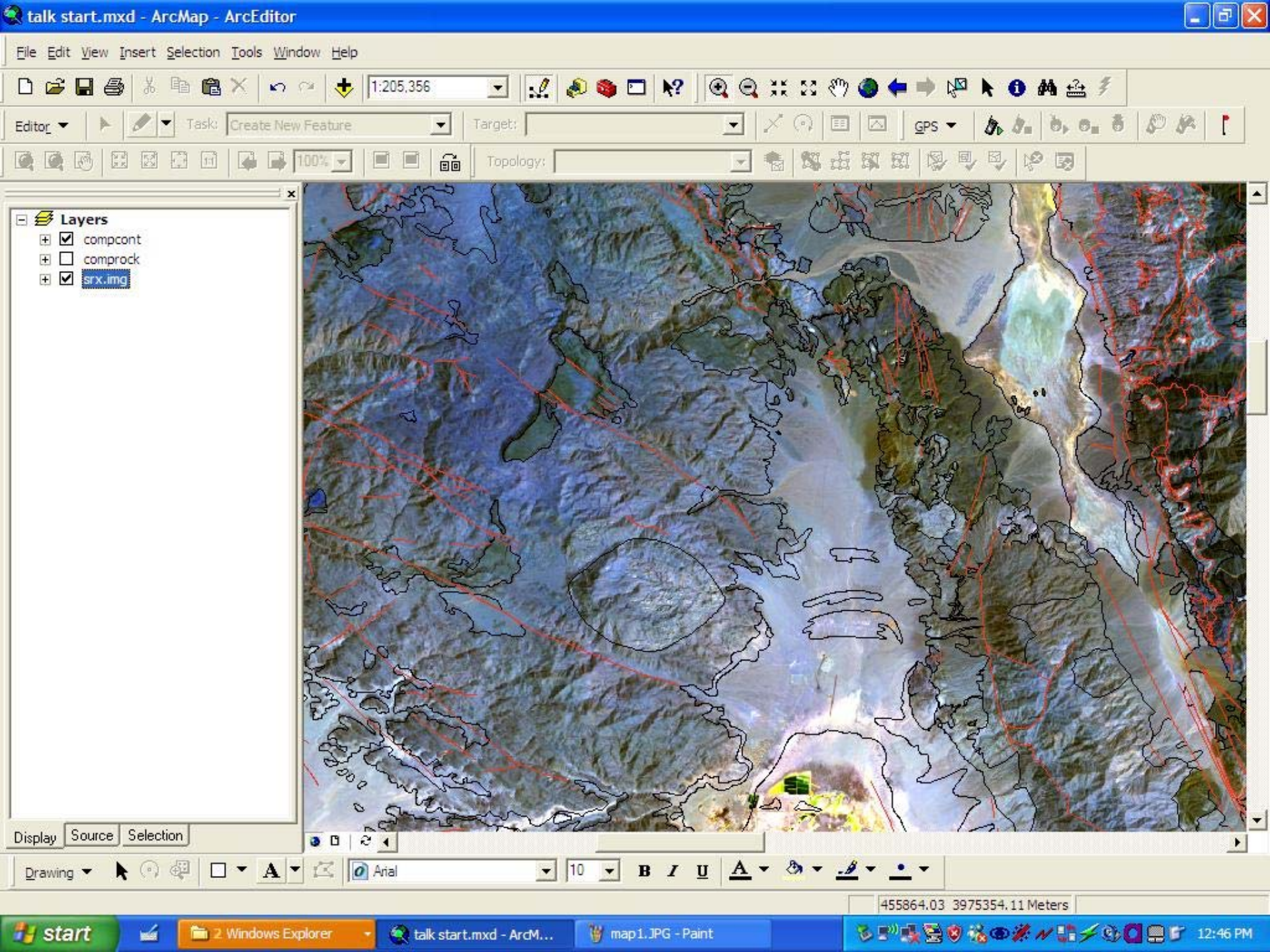
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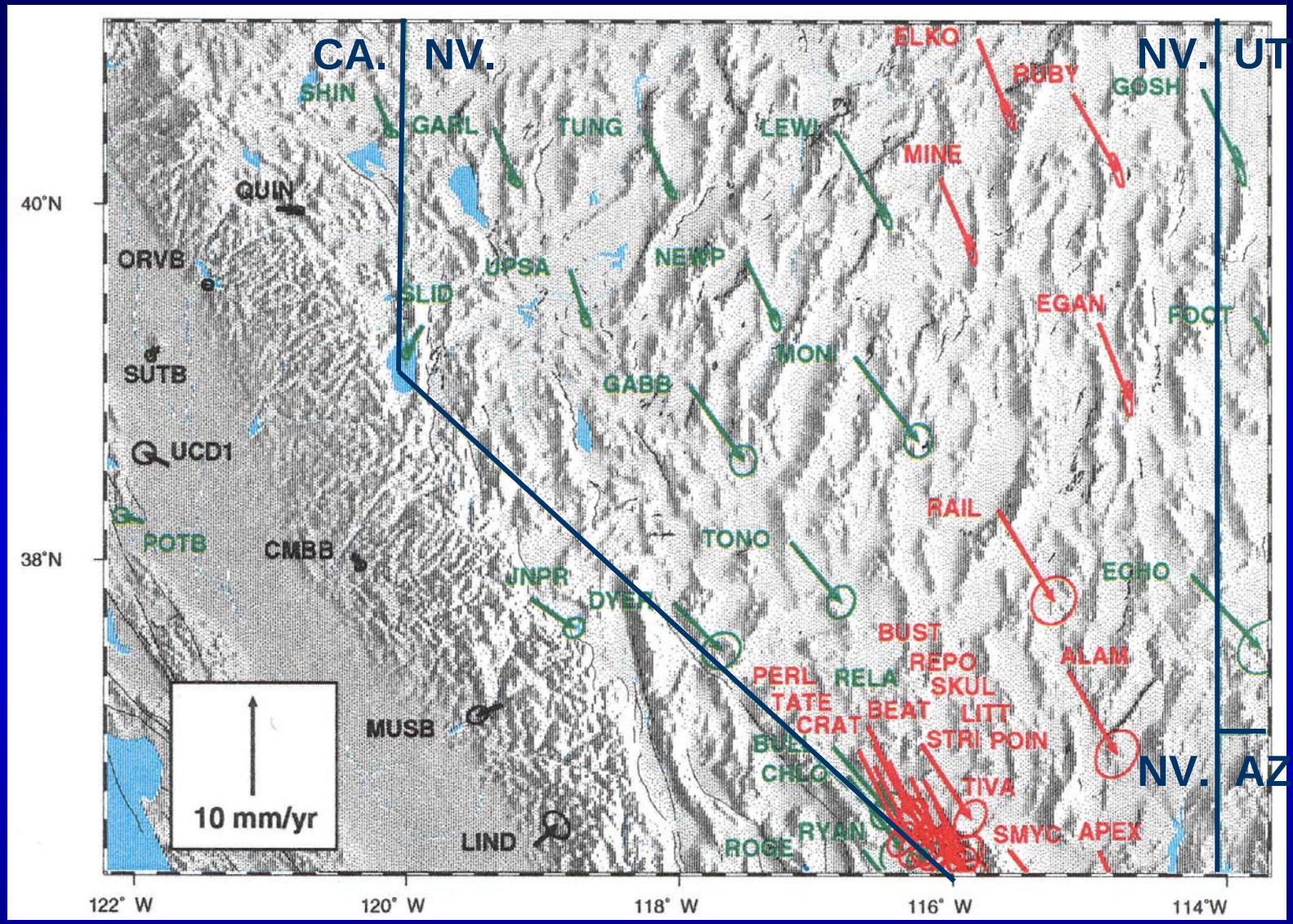
Geodesy – Where am I?

- Advances in GPS Technology – mm accuracy in the horizontal at very reasonable prices per unit
- Continuously-recording units
- INSAR – multiple scenes available at low cost, mm resolution in the vertical



Continuous GPS velocities, eastern CA, western NV, with respect to the Sierra Nevada-Great Valley microplate. From Bennett et. al. flyer, 2000.

Holt, Kreemer, Stony Brook; Davis, Bennett, Harvard

Strain Rate Tensor estimated from GPS Velocities

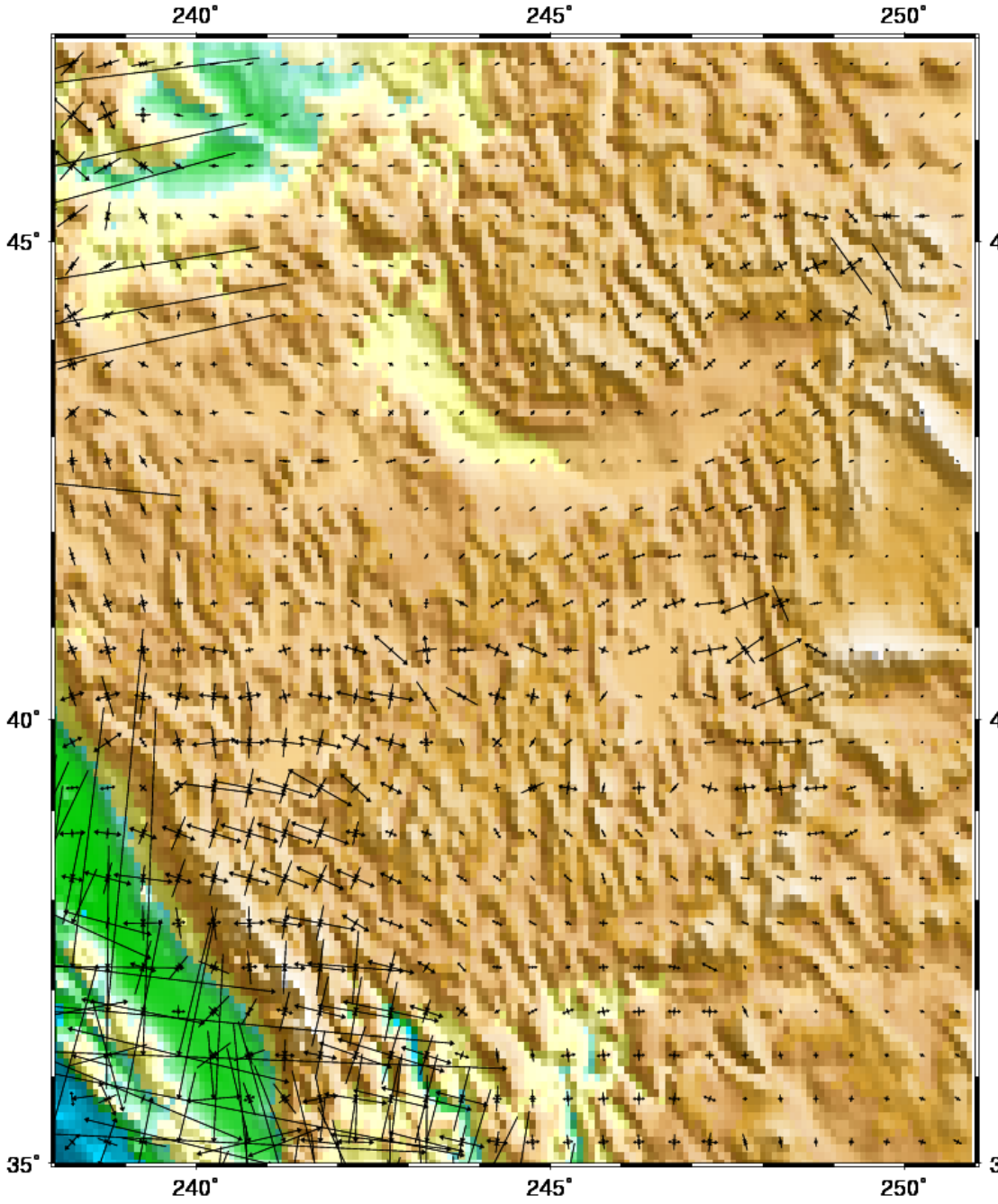
Strain Rate field characterized by four independent variables:

1) Dilatation

2) Rotation

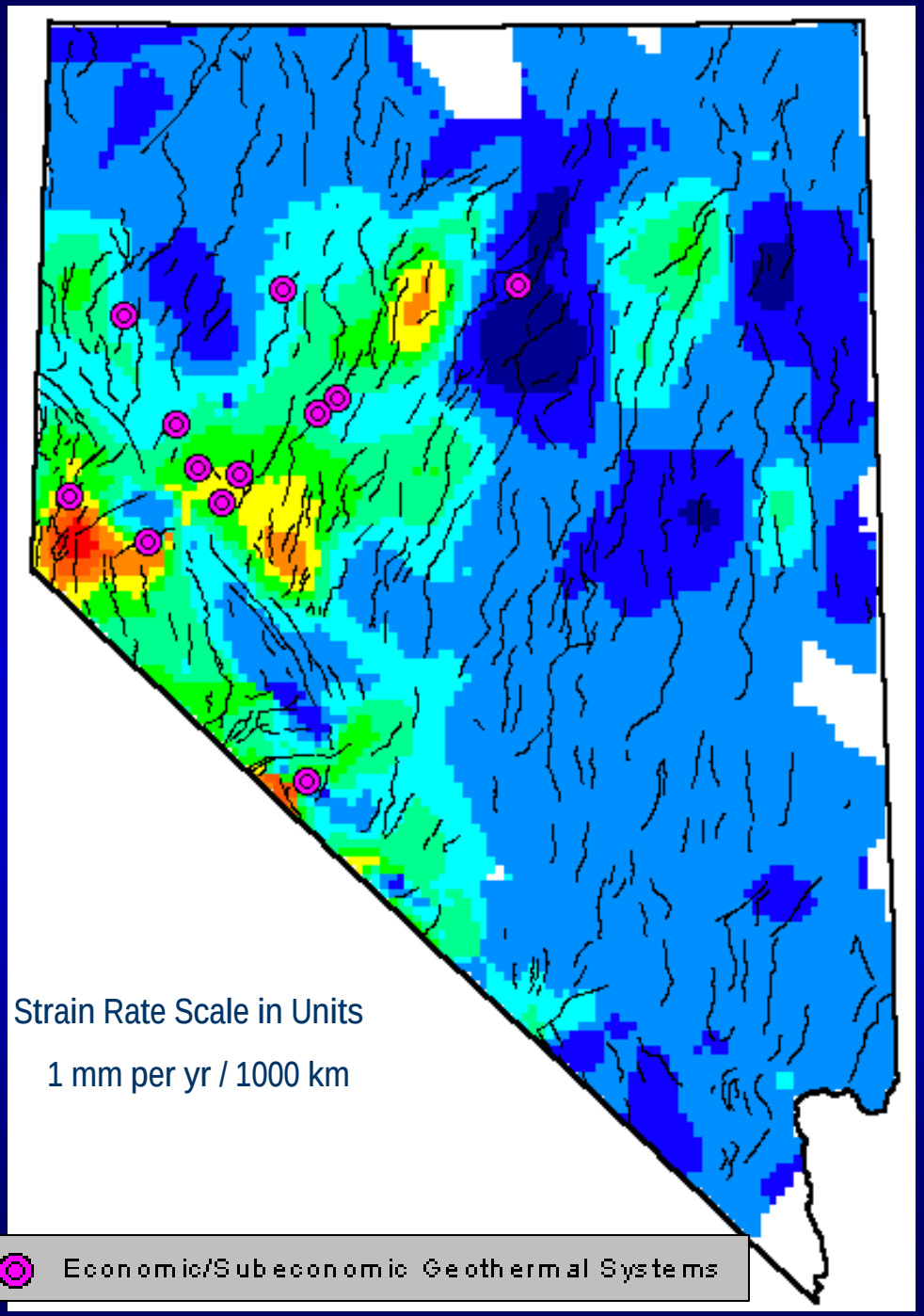
3) Shear 1

4) Shear 2

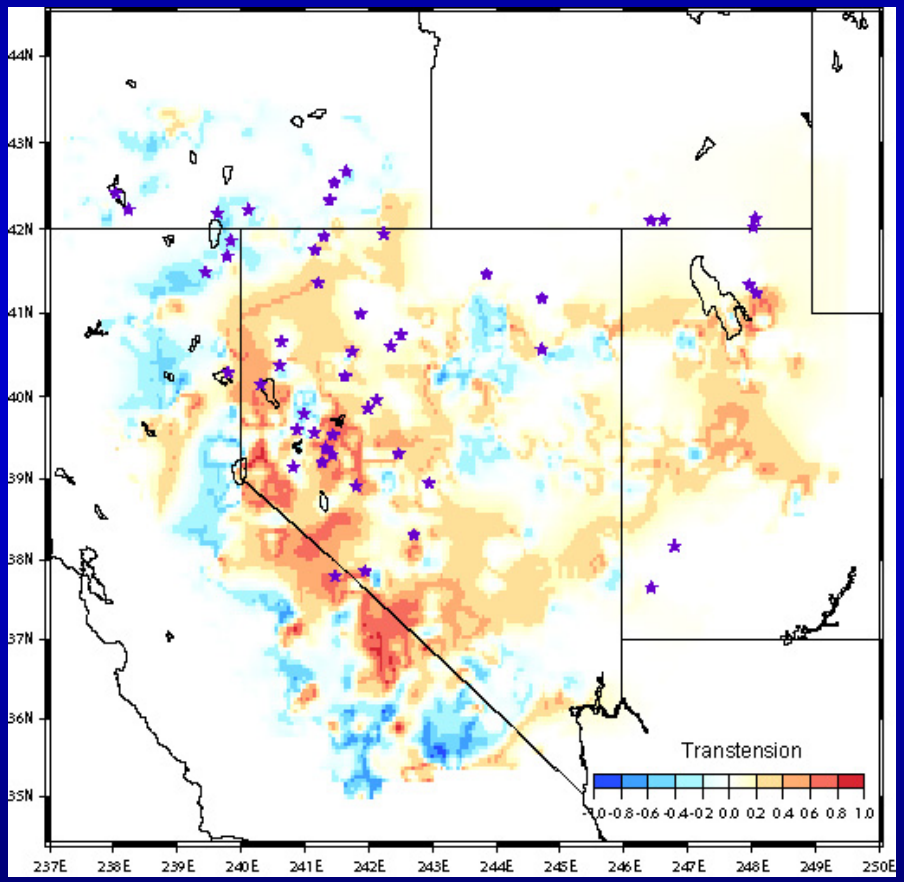


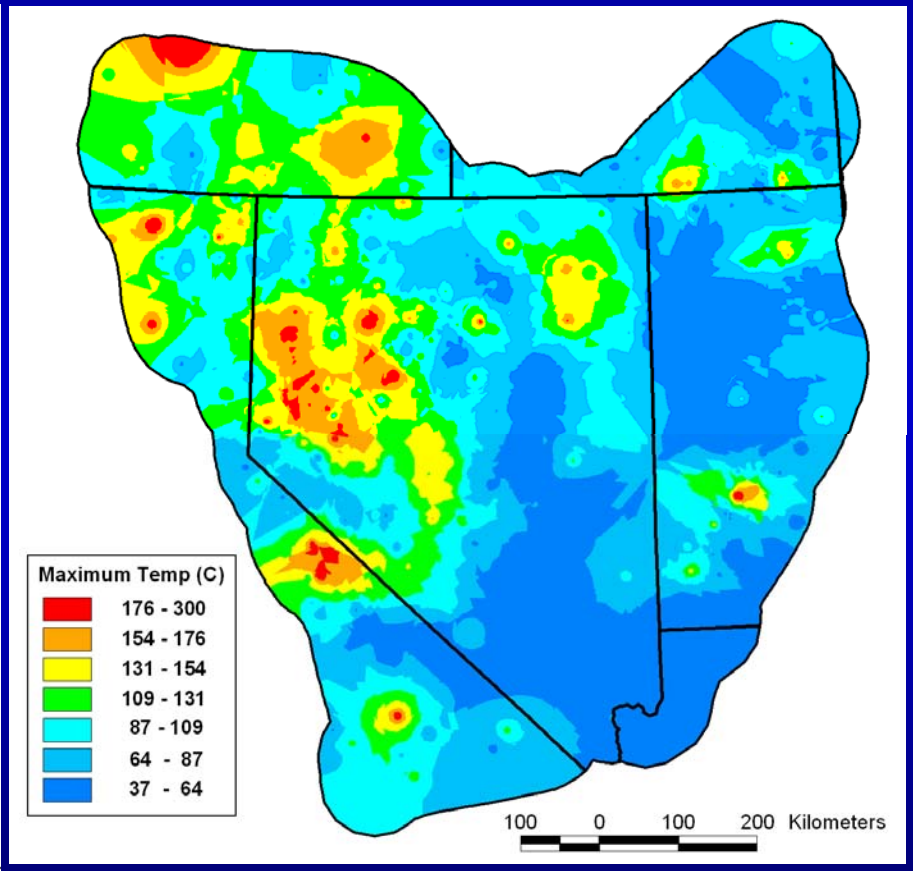
Rate of Extension Normal to Dominant Azimuth of Faults

$$s_{\perp}(\theta) = E_{xx}\cos^2\theta - 2E_{xy}\sin\theta\cos\theta + E_{yy}\sin^2\theta$$
$$= \tfrac{1}{2}\left(D + \dot{\gamma}_1\cos 2\theta - \dot{\gamma}_2\sin 2\theta\right)$$



RESULTS: Transtensional Strain vs. Maximum Known Temperatures





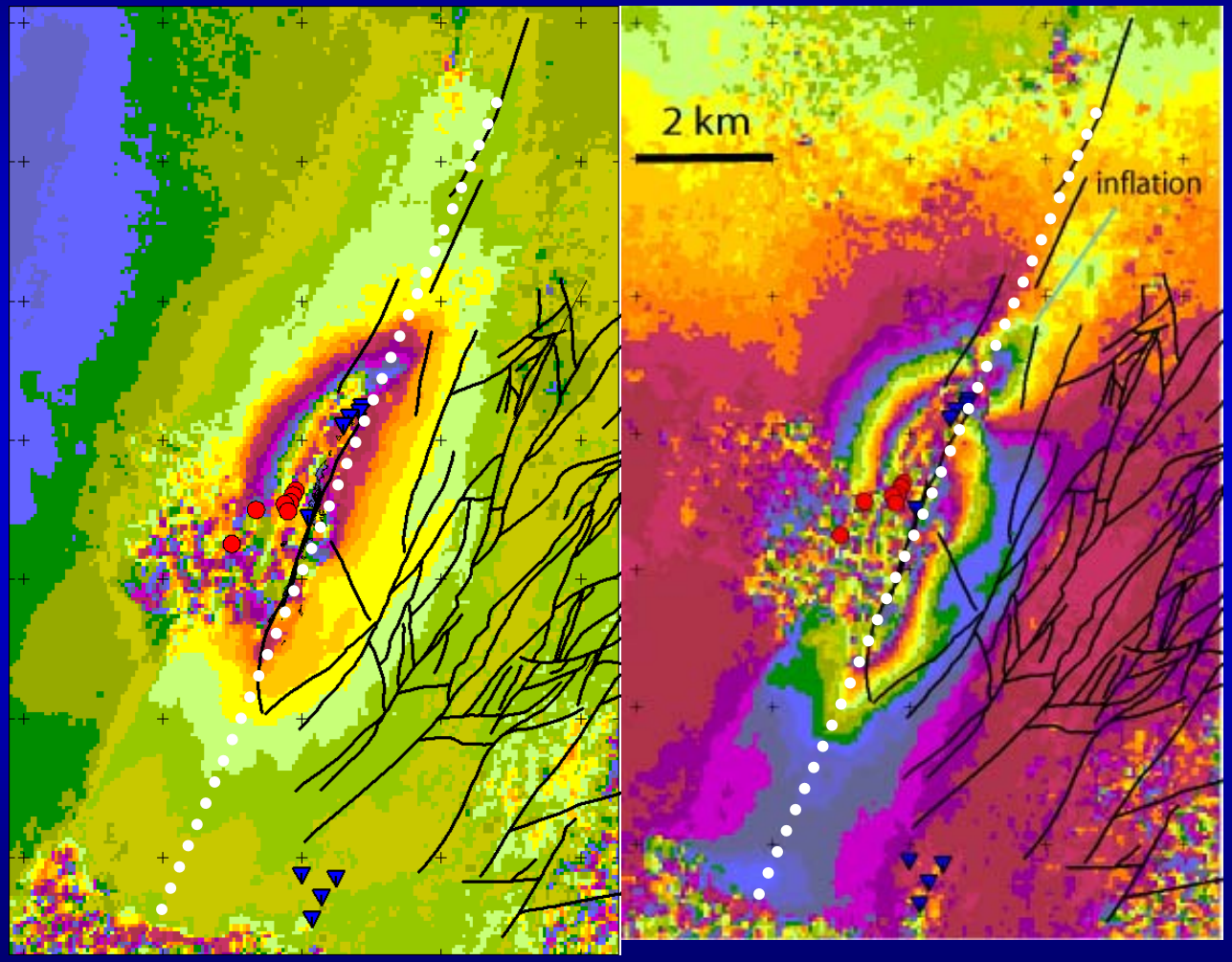
(from: Blewitt, G., 2005)

Brady H.S. displacement signal

- InSAR indicates a connected production zone over a 7 km long axis
- Weaker zone extends over ~11 km
- InSAR data adds ~ 6 km strike length relative to surface manifestations (fumaroles and sinter).

Period: 92-95

Period 95-00



Color scale: 2.8 cm per color pallet cycle

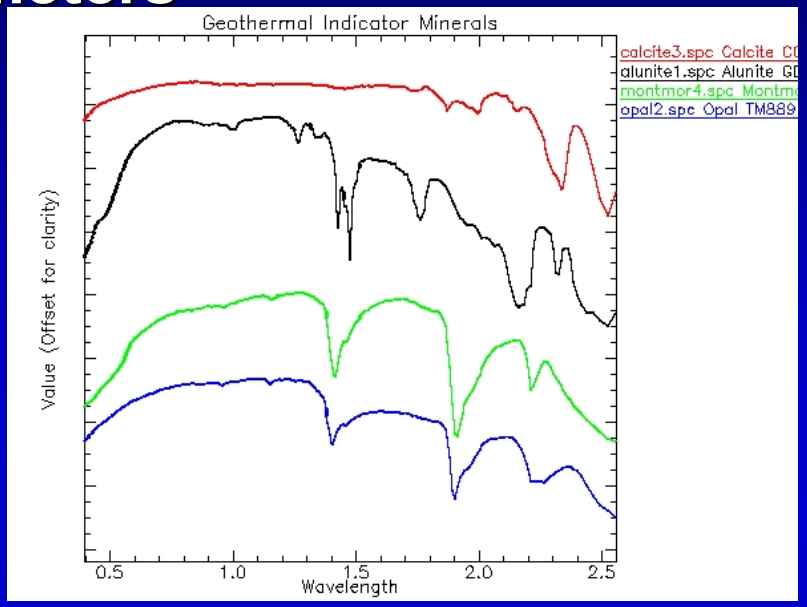
Production wells red, Injection wells blue

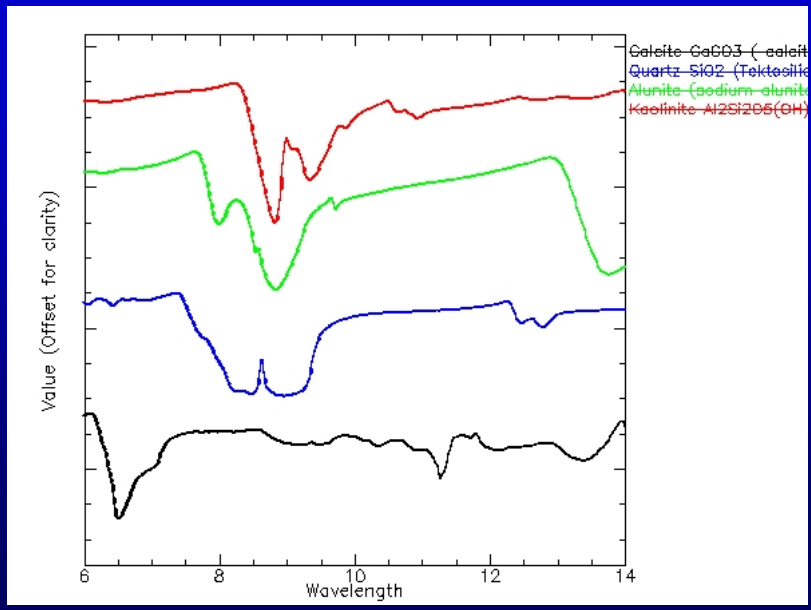
(from: Oppliger et al, 2005)

Remote Sensing

- Hyperspectral Imagery
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
- MODIS/ASTER (MASTER)
- LIDAR

Diagnostic Spectral Features invisible to the naked eye can be detected in the infrared range with spectroradiometers





siliceous sinter

carbonaceous travertine/tufa

sulfate and borate evaporites

hydrothermal alteration (clay)

thermal anomalies

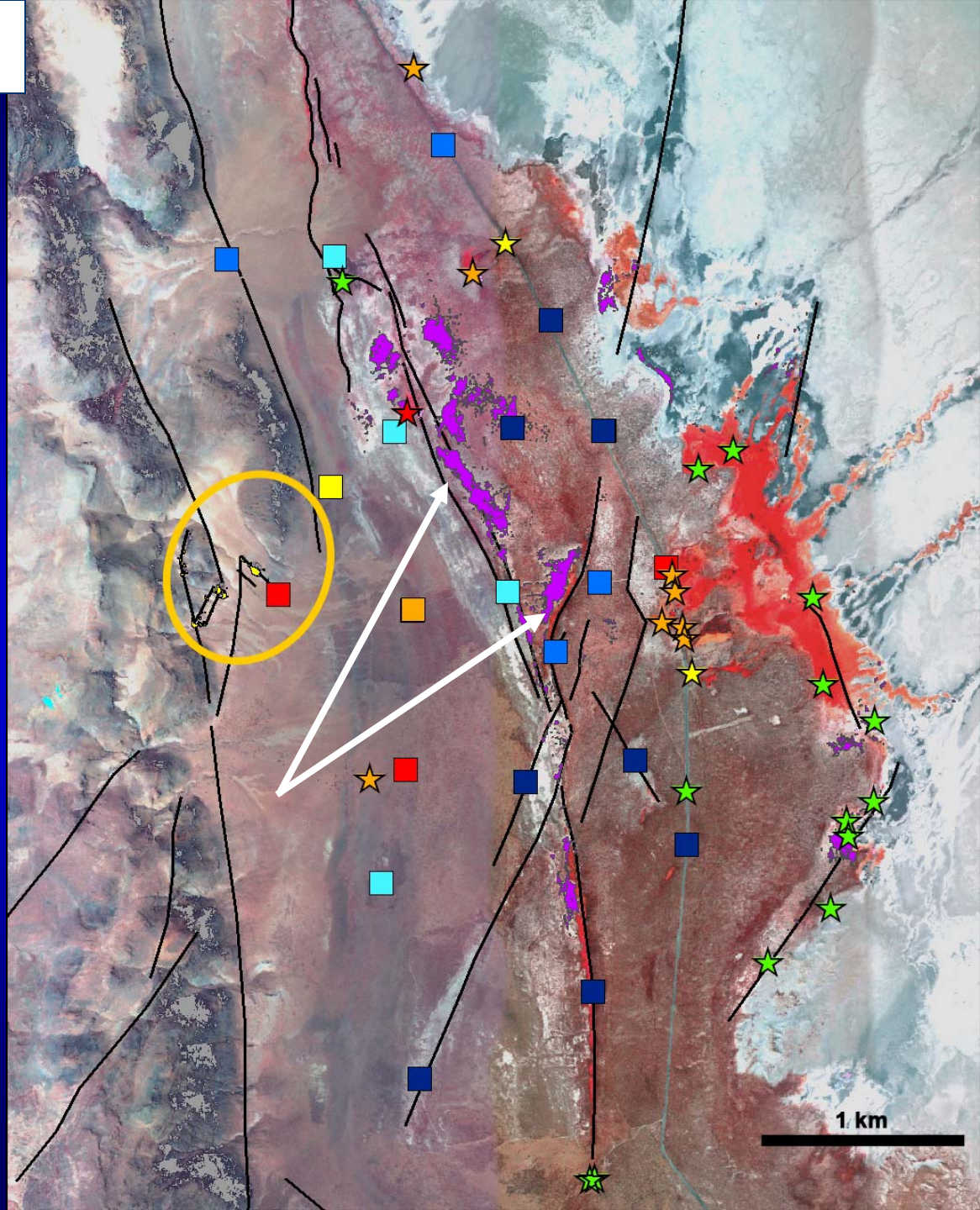
Smoke Creek Desert

2m temp measurements helped pinpoint possible upwelling zone near tufas at stepover in range front fault (orange ellipse)

Warmer colored squares indicate warmer temperatures at a 2-meter depth

Purple = remotely sensed gypsum anomaly

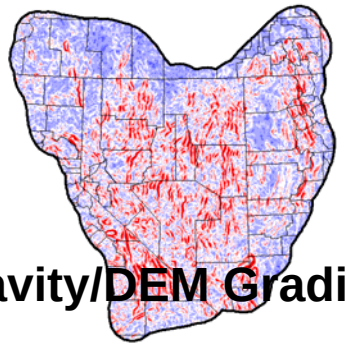
Yellow, orange, and red stars are warm and hot wells and springs



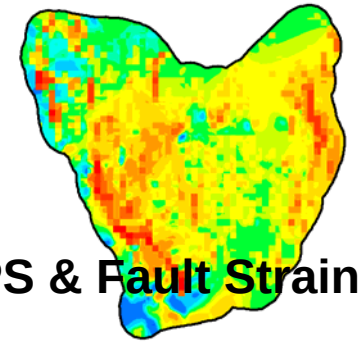
Data Base Mining

- Rich Deposits: NAVDAT, EARTH CHEM, CDOGGR, SCEC, NCEDC, NV Seismic Lab, NBMG, Great Basin Research Data Base, SMU Temp
- Google Earth
- Plate Boundary Observatory
- ArcView and ArcInfo are powerful and versatile

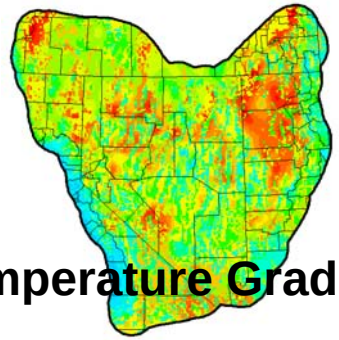
Great Basin Geothermal Potential Map



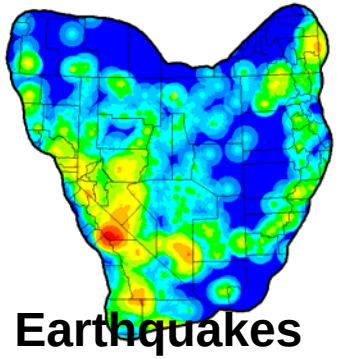
Gravity/DEM Gradient



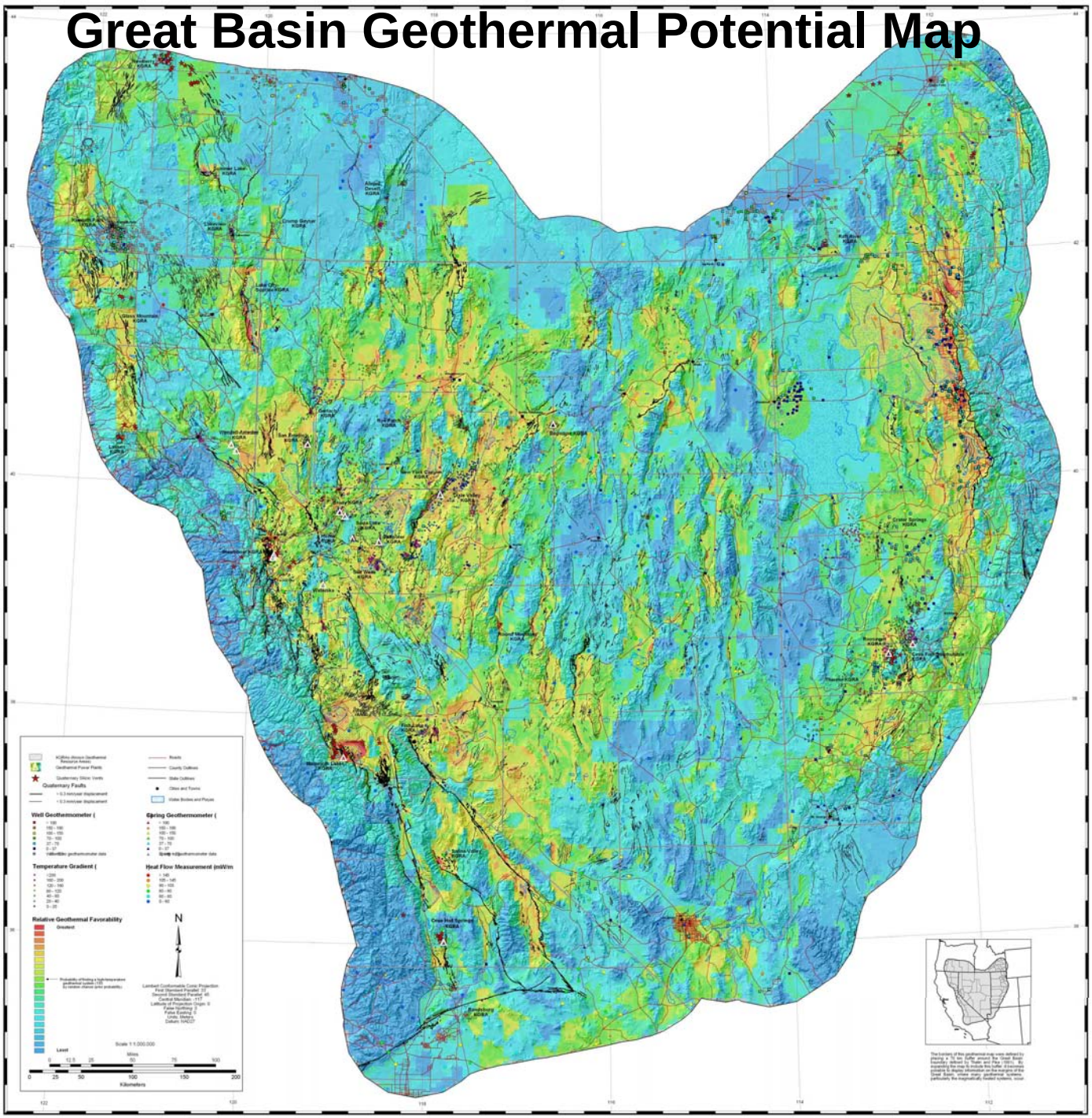
GPS & Fault Strain



Temperature Gradient

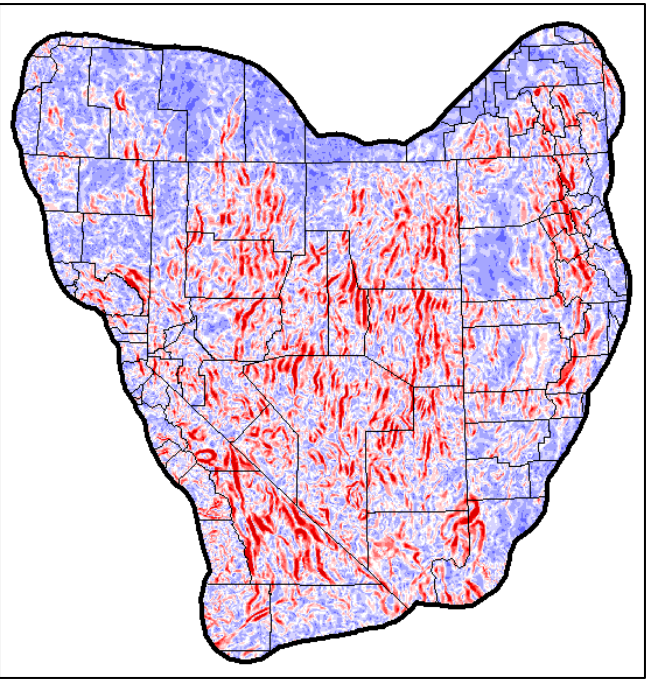


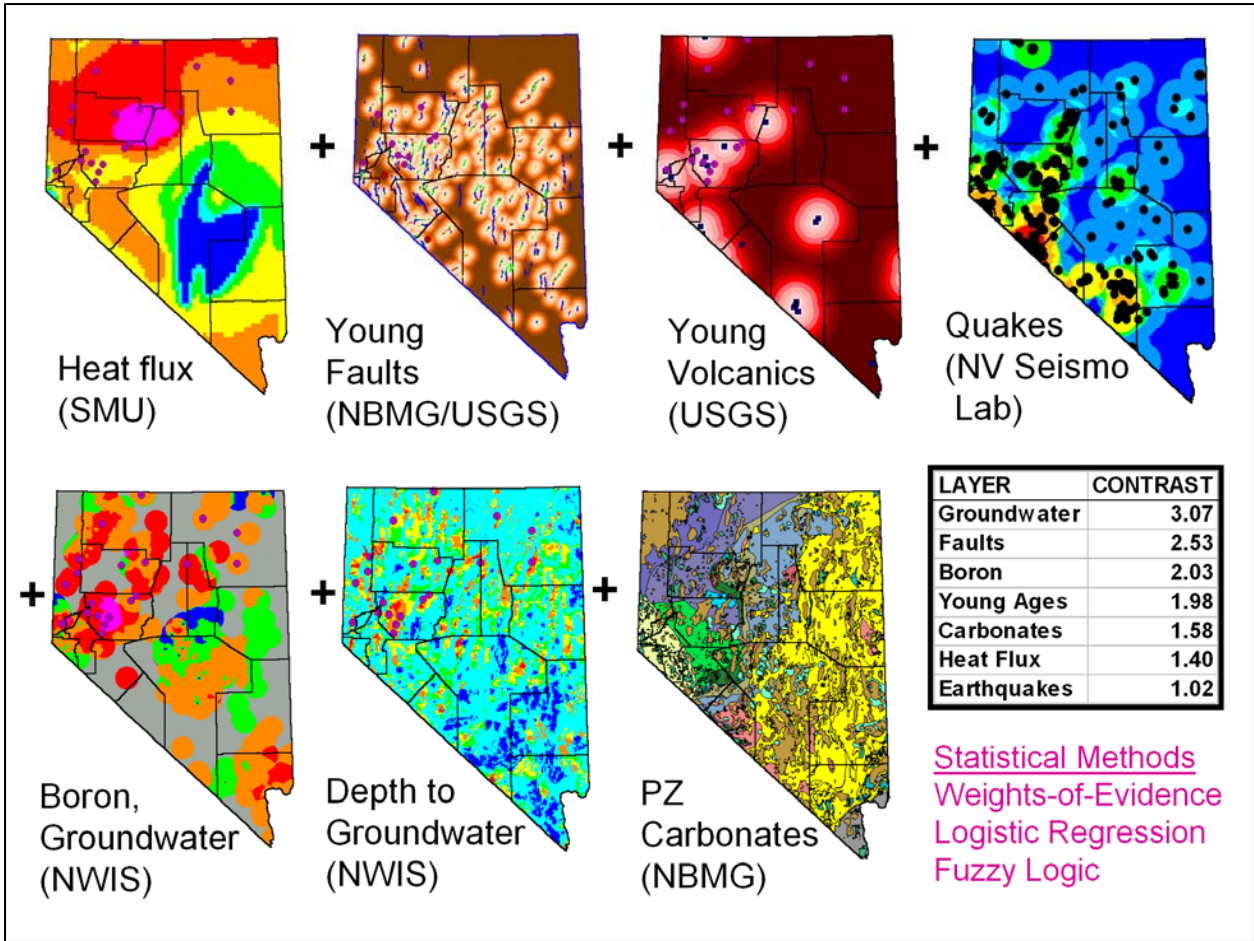
Earthquakes



Improved geothermal favorability maps:

- maintain database of geothermal systems
- search and obtain digital data as “evidence”

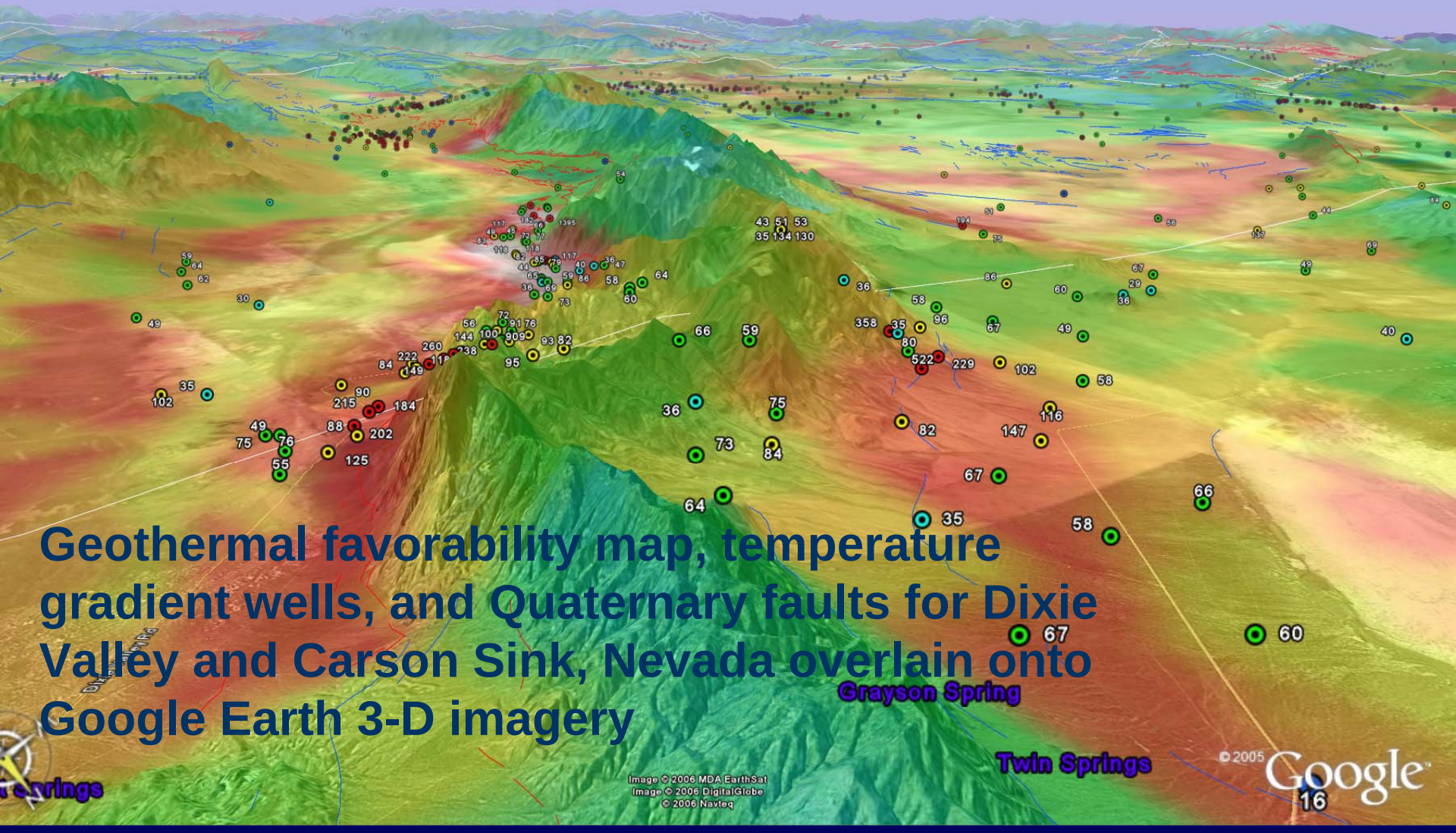




LAYER	CONTRAST
Groundwater	3.07
Faults	2.53
Boron	2.03
Young Ages	1.98
Carbonates	1.58
Heat Flux	1.40
Earthquakes	1.02

Statistical Methods
Weights-of-Evidence
Logistic Regression
Fuzzy Logic

Digital databases can be overlain onto world map engines such as Google earth for rapid visualization and assessment



Geothermal favorability map, temperature gradient wells, and Quaternary faults for Dixie Valley and Carson Sink, Nevada overlain onto Google Earth 3-D imagery

“Where oil is first found, in the final analysis, is in the minds of men”

Wallace Pratt, eminent Humble Oil Company geologist, scholar, and businessman (1952)