Select Geophysical Methods and Groundwater Modeling: Examples from USGS studies

Claudia Faunt and a cast of others

Current Preliminary Studies

Stanford Water in the West

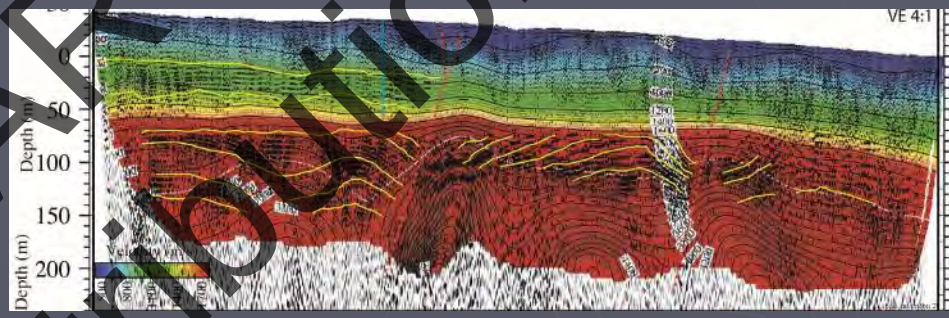
Groundwater Data Workshop Series: Geophysical Methods for Sustainable Groundwater Management

October 13, 2016

Geophysical Methods and Groundwater Models

Define Geologic Framework Model

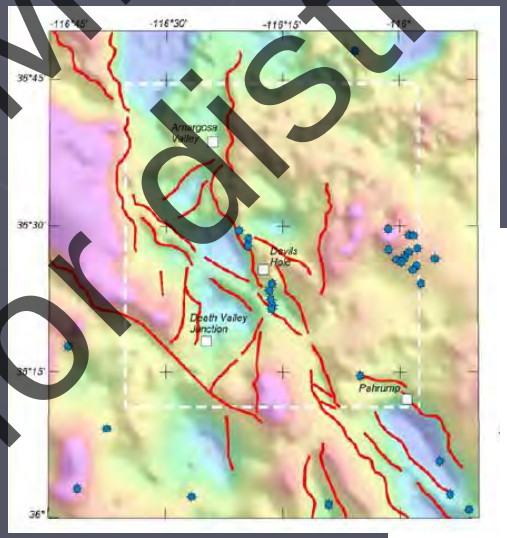
- Model Layers
- Hydraulic Properties



Water levels and storage

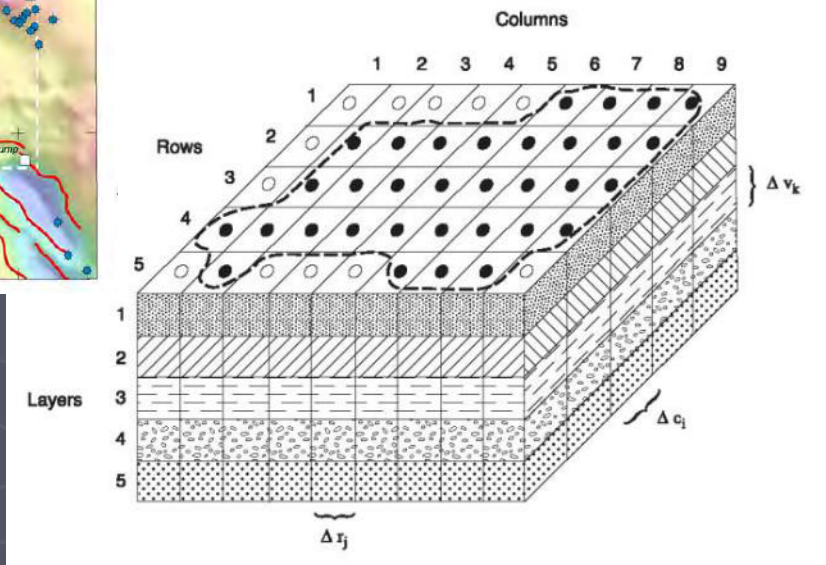
Observations for Calibration

- Subsidence
- Water Levels
- Water Quality
- Seawater Intrusion



Example Studies

- Los Angeles, CA
- Death Valley, CA and NV
- San Pedro, AZ
- Ft. Irwin, CA
- Various desert basins, CA
- Central Valley, CA



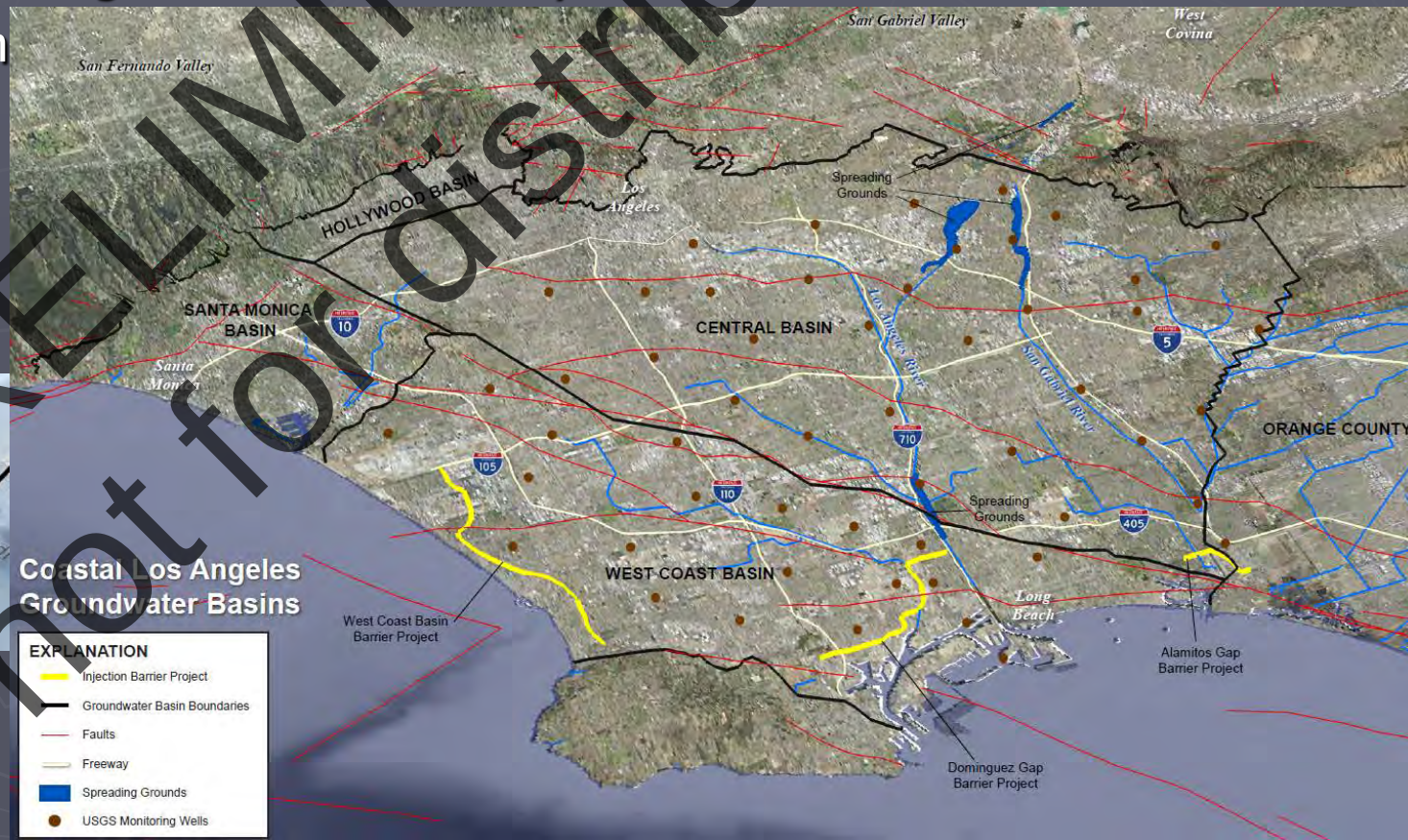
Los Angeles Basin Sequence Stratigraphic and Groundwater Flow Model

Dan Ponti and Scott Paulinski

- ~700 square miles of LA and parts of Orange County
- Objective:

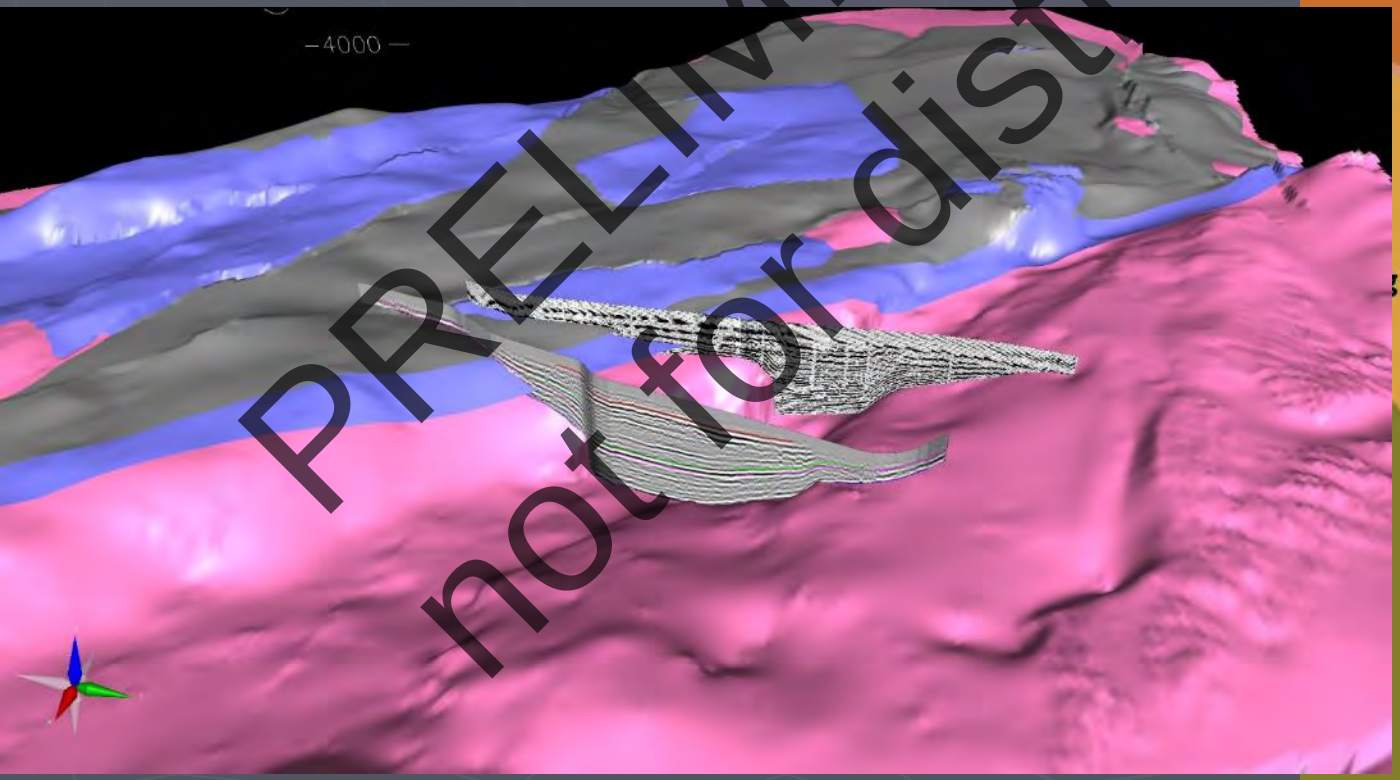
Increase understanding of artificial recharge, pumping, and other effects on LA groundwater (including seawater intrusion)

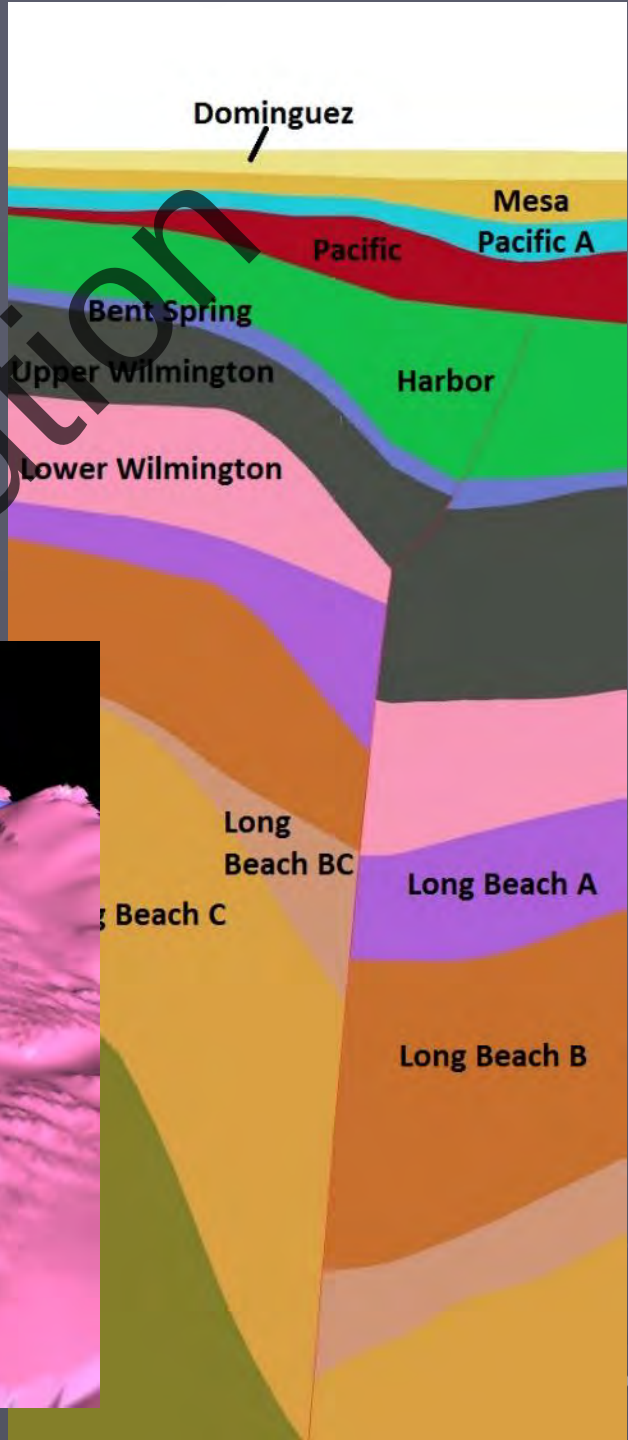
-Drilled more than 50 multi-completion monitoring wells

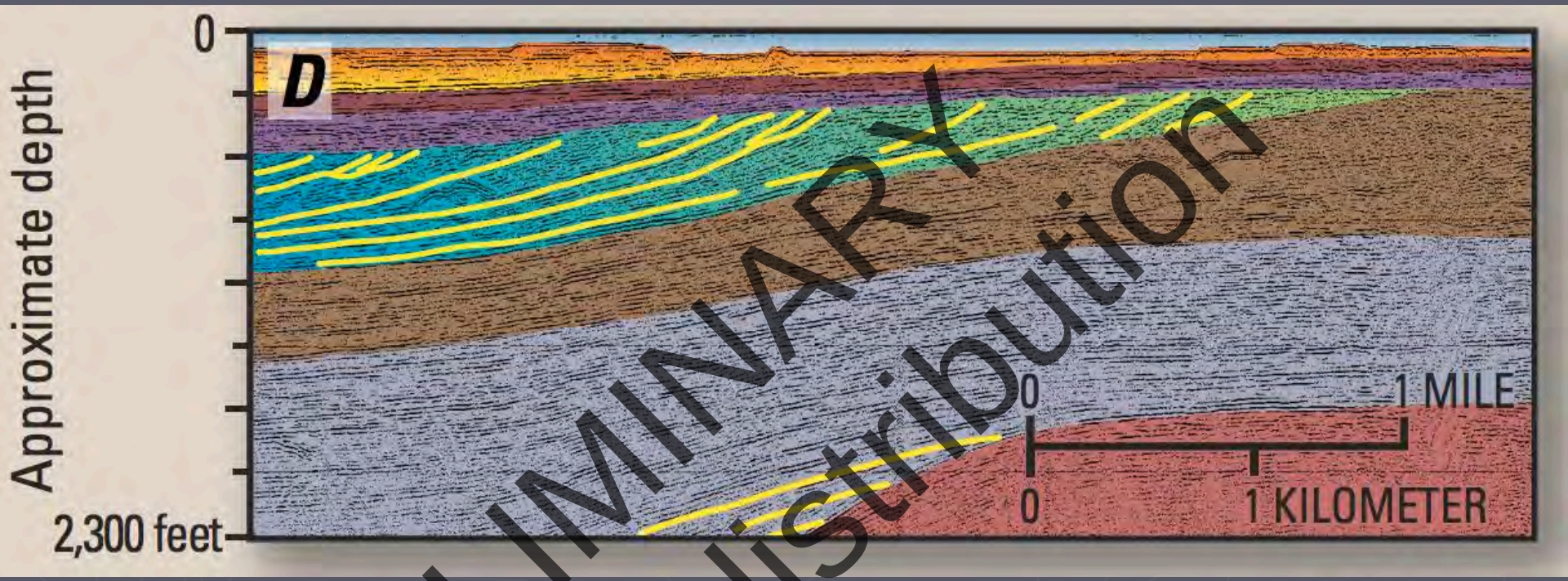


3-D Sequence-stratigraphic Model

- 13 sequences with complex faulting
- Data sources include:
  - Seismic lines
  - Borehole geophysical logs
  - Water level, chemistry, and pumping data







New studies by the U.S. Geological Survey and its cooperators show that the geology of the Los Angeles Basin is much more complex than originally conceived. A seismic profile from the Port of Long Beach (D) shows the complex geology of the area. The sediment layers, shown as different colors, provide many potential pathways for saltwater intrusion. By understanding this geology, scientists can better determine where and how fast water moves within the various beds of sediment both onshore and offshore.

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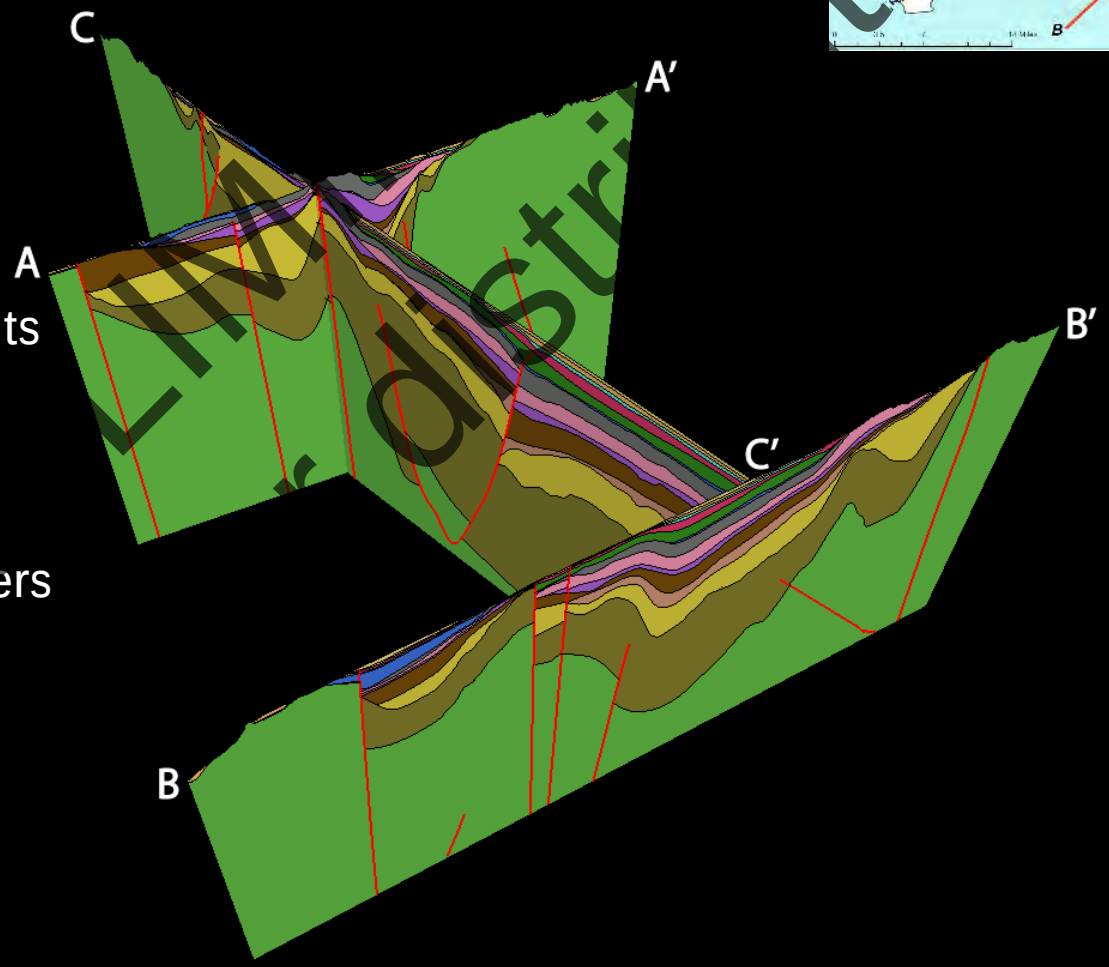
3-D Sequence-stratigraphic Model

- Study area heavily folded and faulted
- Layers pinch out
- Connections between different layers across faults
- Direct input to MODFLOW-USG (unstructured grid)

Unstructured grid flexibility used to handle

- Layer pinch-outs
- Flow between layers across faults
- Faults as barriers to flow



Death Valley – So. Amargosa

Wayne Belcher, Don Sweetkind, Rick Blakely, Vicki Langenheim, Claudia Faunt, and others

Fault definition

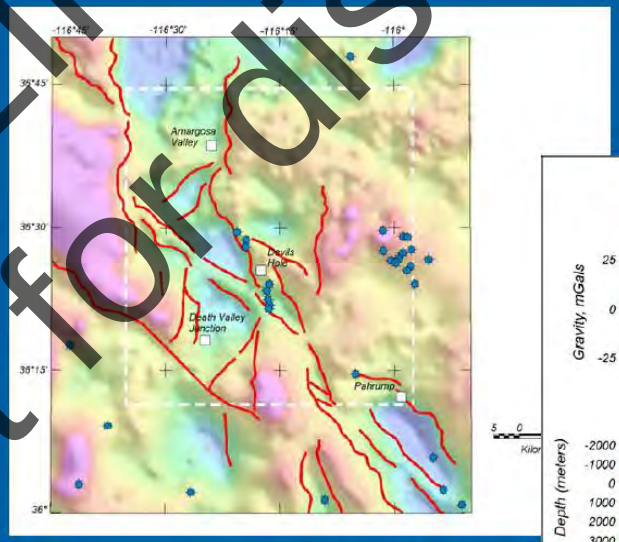
- **-Basin-fill deposits**
- **-Basement**

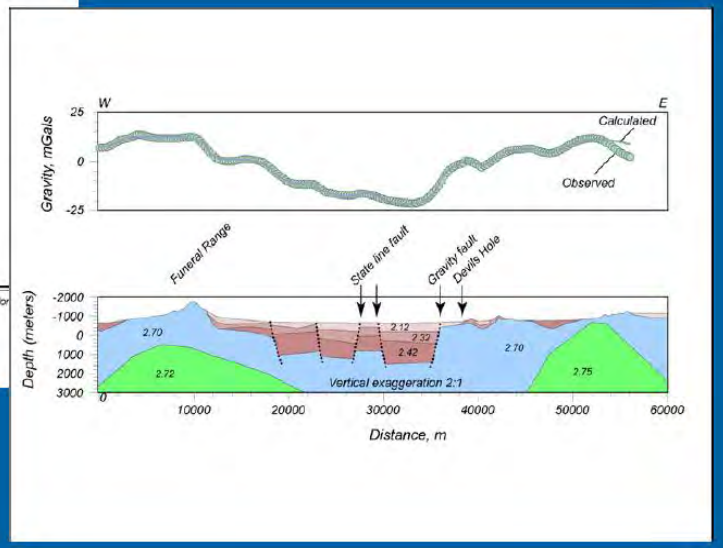
Depth to basement

Basin-fill lithologies

(Gravity, magnetics, and electrical)

Rick Blakely, Darcy McPhee, and Bob Morin
With help from Janet Tilden, Bruce Chuchel, Mike Pavelko, and Nancy Damar





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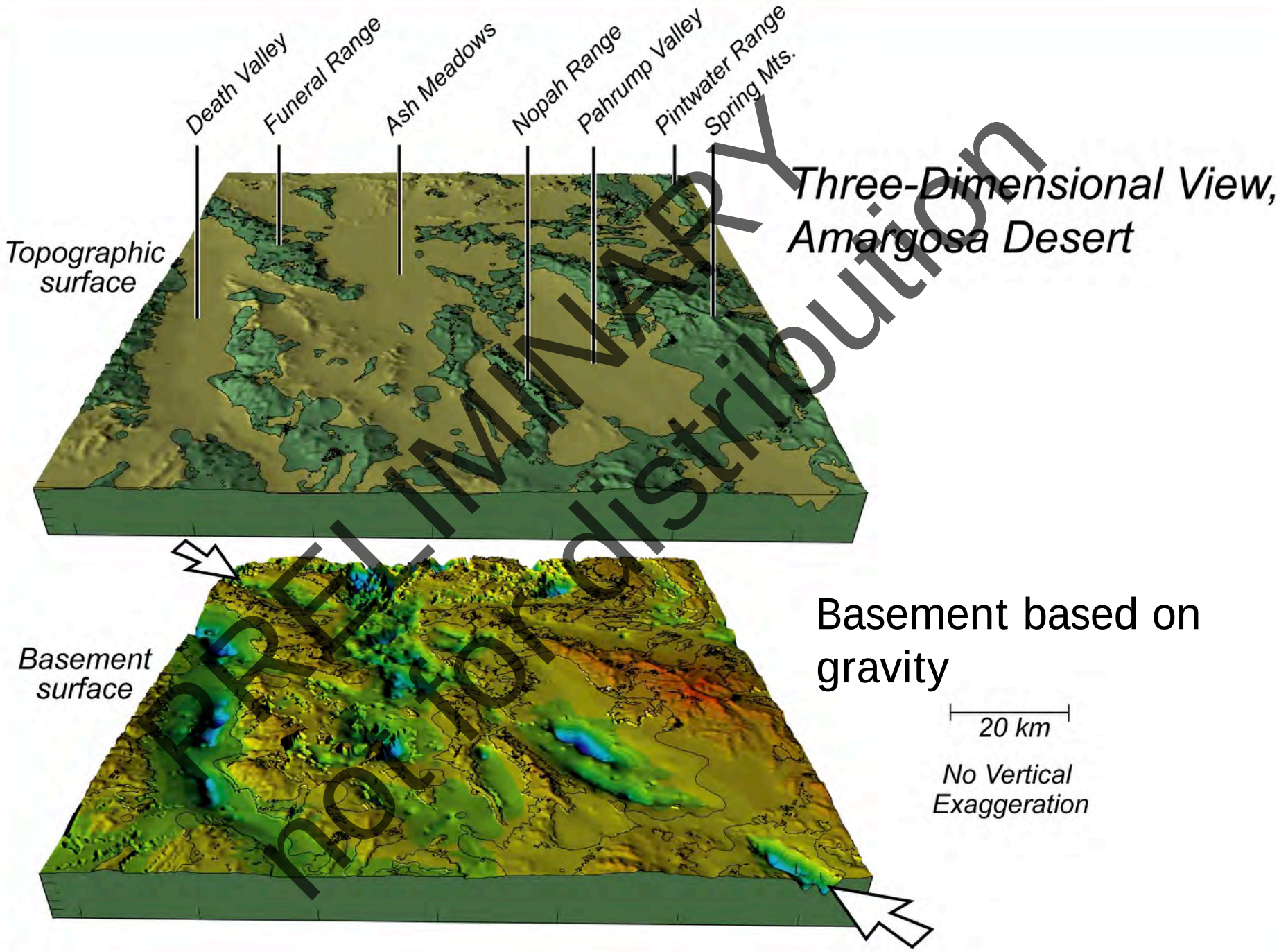
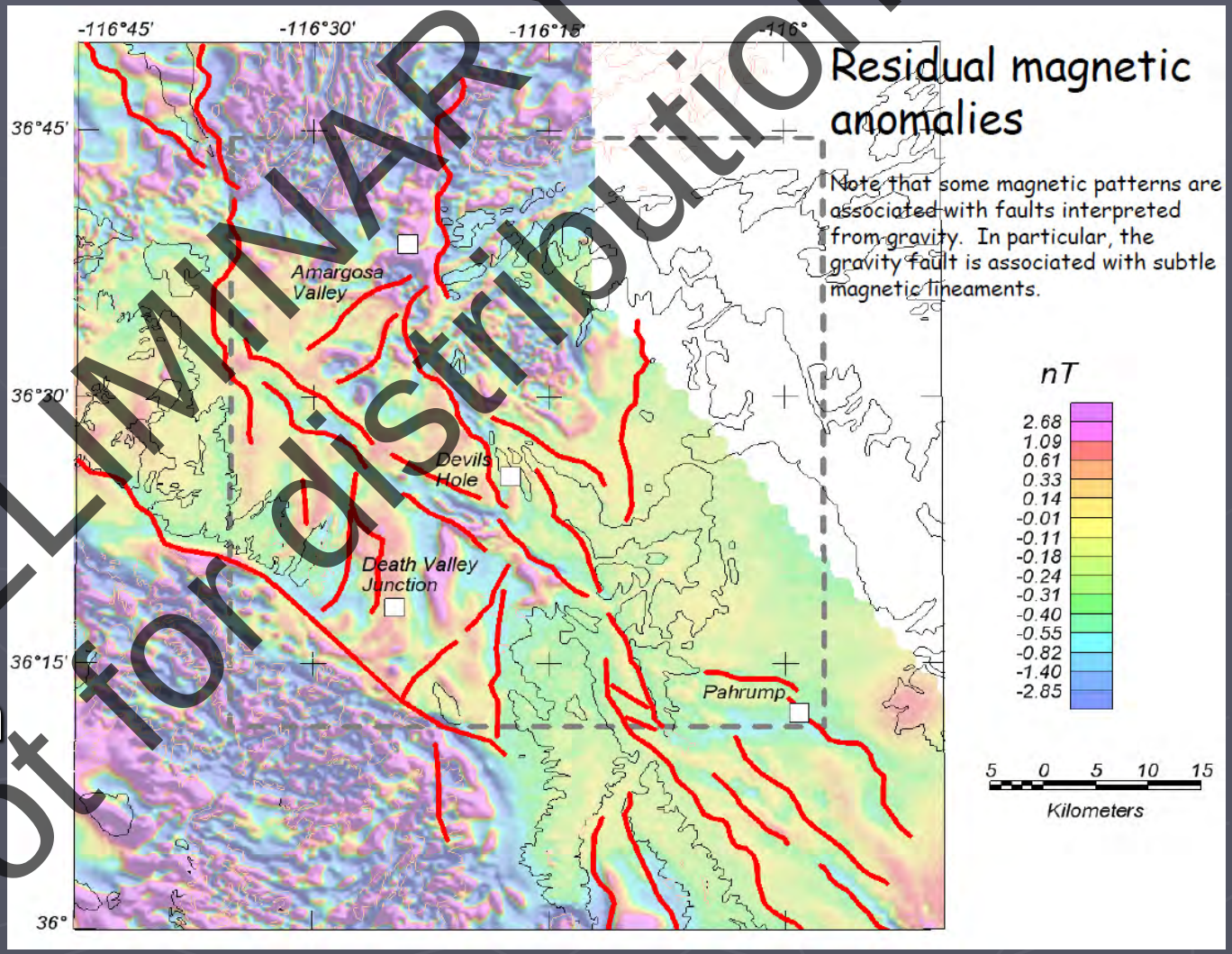


Magnetic Anomalies

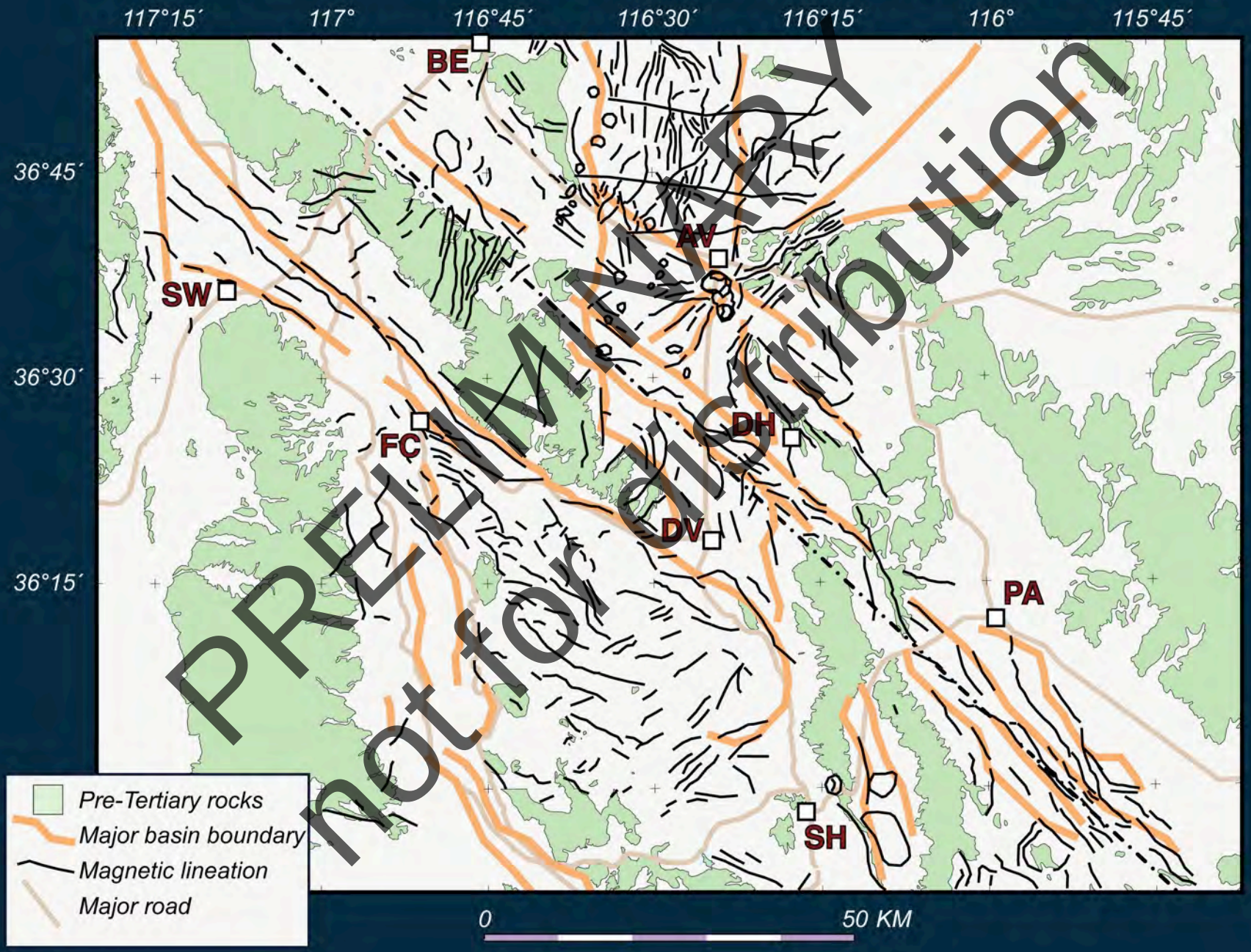
- Faults/ Structures
- Volcanic

Rock extent

Aeromagnetics augmented with TOM



Basin-Bounding Structures and Magnetic Lineations



TOM System

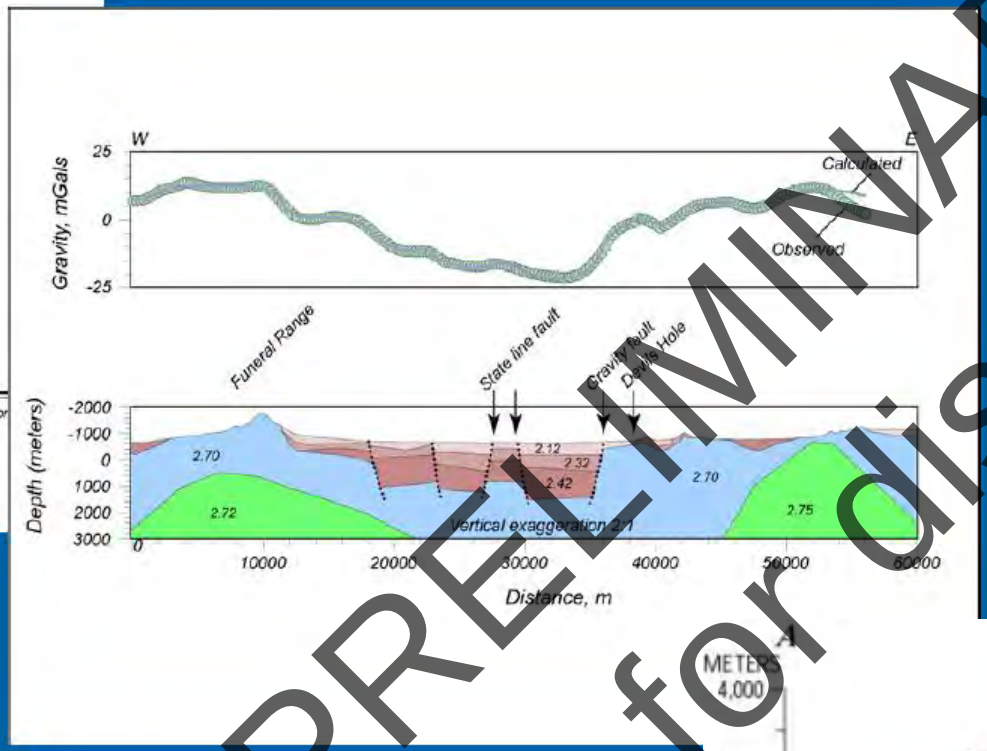
Truck-towed magnetometer system

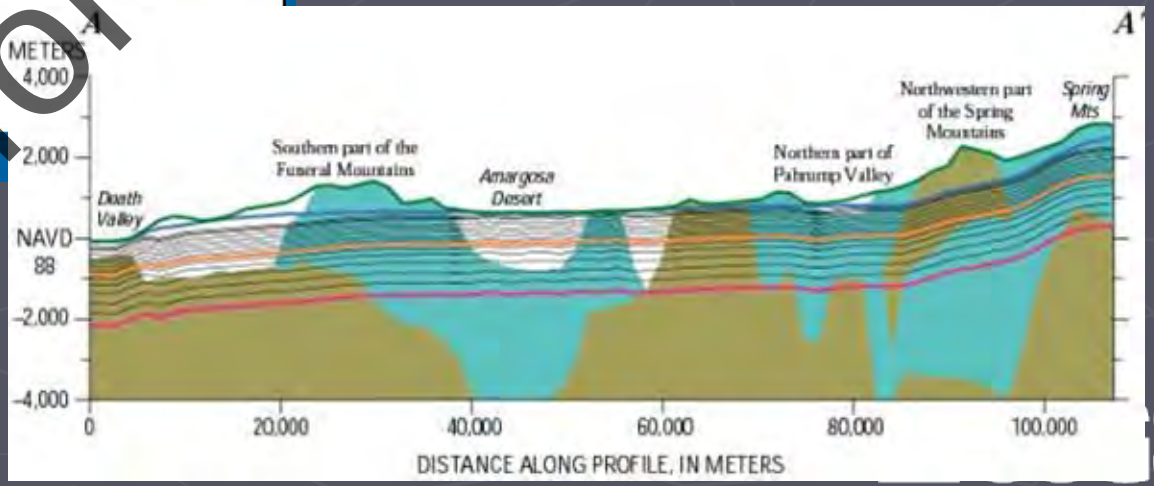
- Geometrics G856 Cesium magnetometer
- Mounted on a non-magnetic aluminum frame
- Real-time display and monitoring of the magnetic field and GPS data
- Towed 30 ft behind the vehicle
- Speeds up to 40 mph

System designed and developed by
Bob Morin, Dave Ponce, and Jonathan Glen,
USGS, Geophysics Unit of Menlo Park

USGS

Gravity surface, structures from gravity and magnetics, and model layers

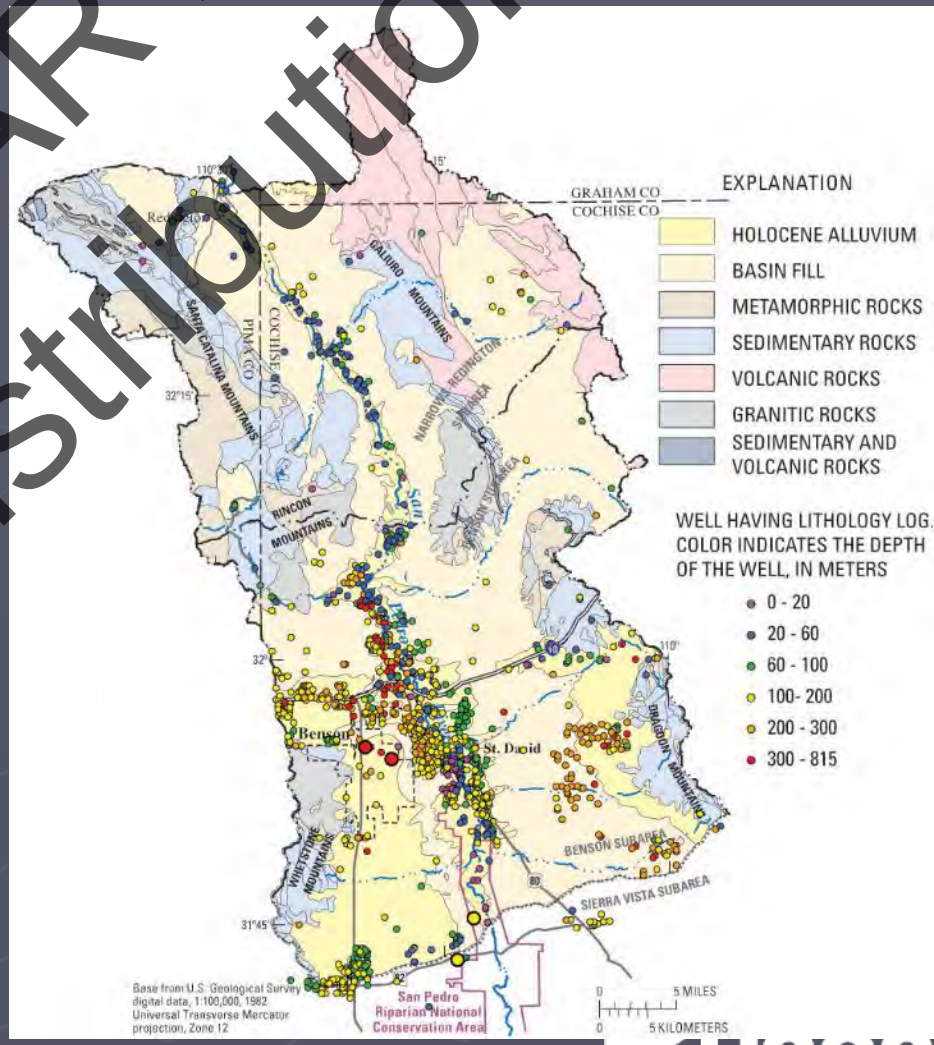




San Pedro, AZ modeling and geophysics

Jesse Dickinson

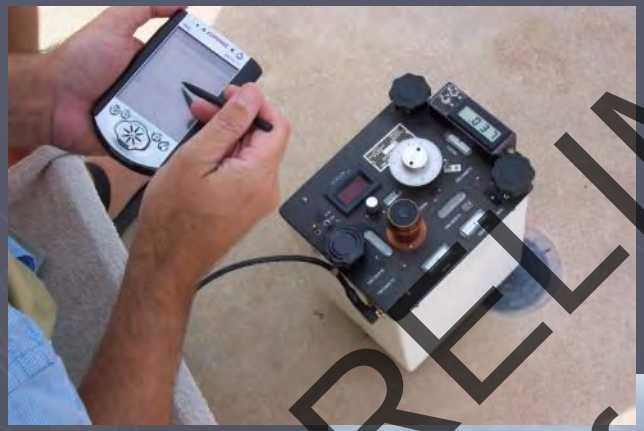
- Analyze lithology and geophysical logs to characterize bedrock, fine-grained, and coarse-grained sediments
- Gravity models to identify depth to denser bedrock underlying the basin fill sediments
- Airborne and surface TEM surveys to map fine- and coarse-grained sediments
- Classify hydrogeologic units (HGUs) based on
  - Well log lithology
  - Field measurements of geophysical properties of basin fill sediments
- Develop 3D relations of the HGUs in the hydrogeologic framework model

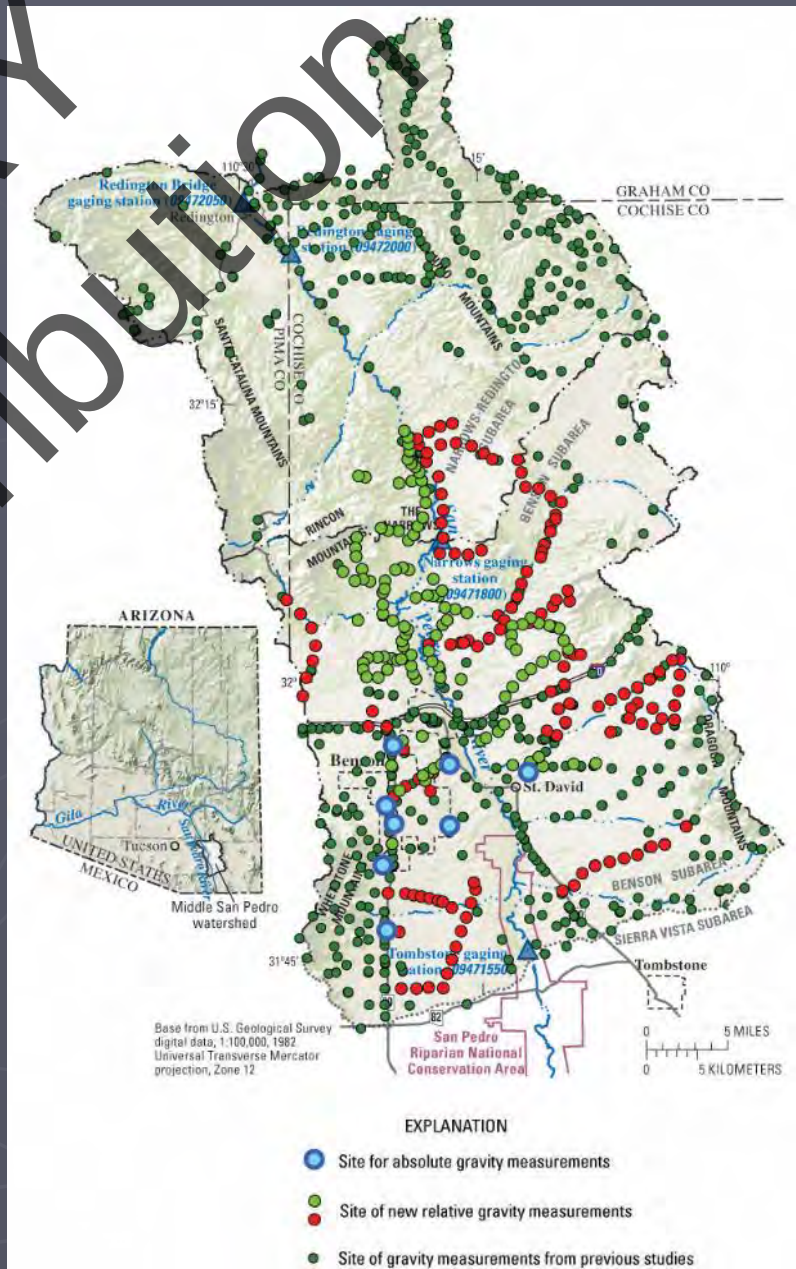


Data for constructing framework model

Gravity

-





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Data for constructing framework model

Surface Transient Electromagnetic (TEM) surveys

- Identify changes in electrical resistivity in the subsurface
- Low resistivity related to clay and silt
- High resistivity related to bedrock

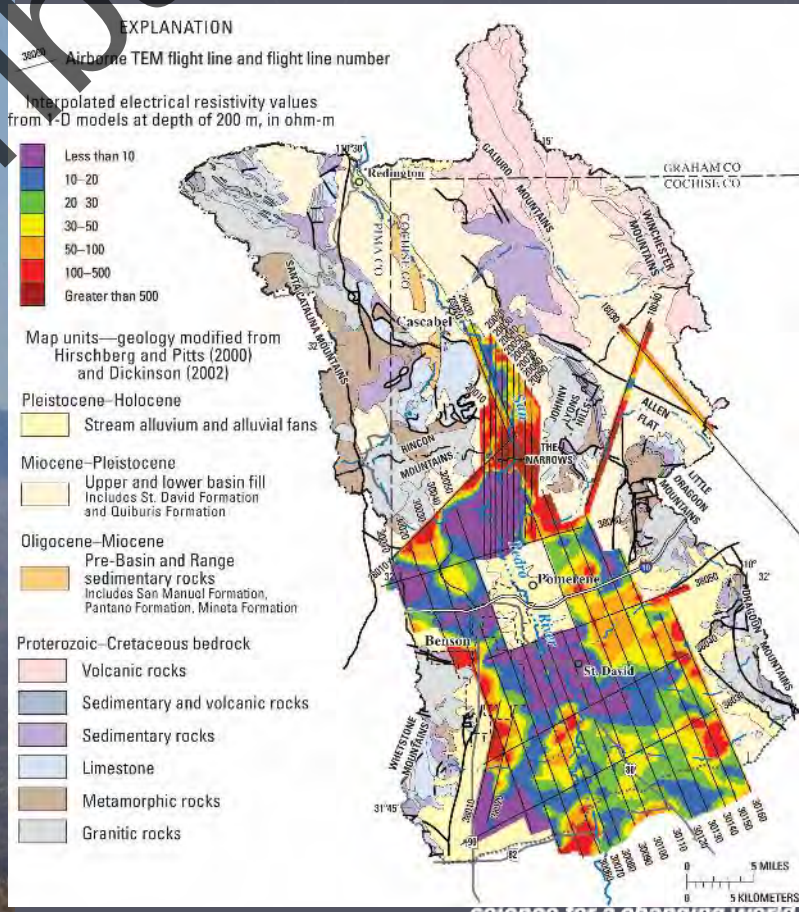
Data for constructing framework model

Aerial Transient Electromagnetic (TEM) Surveys

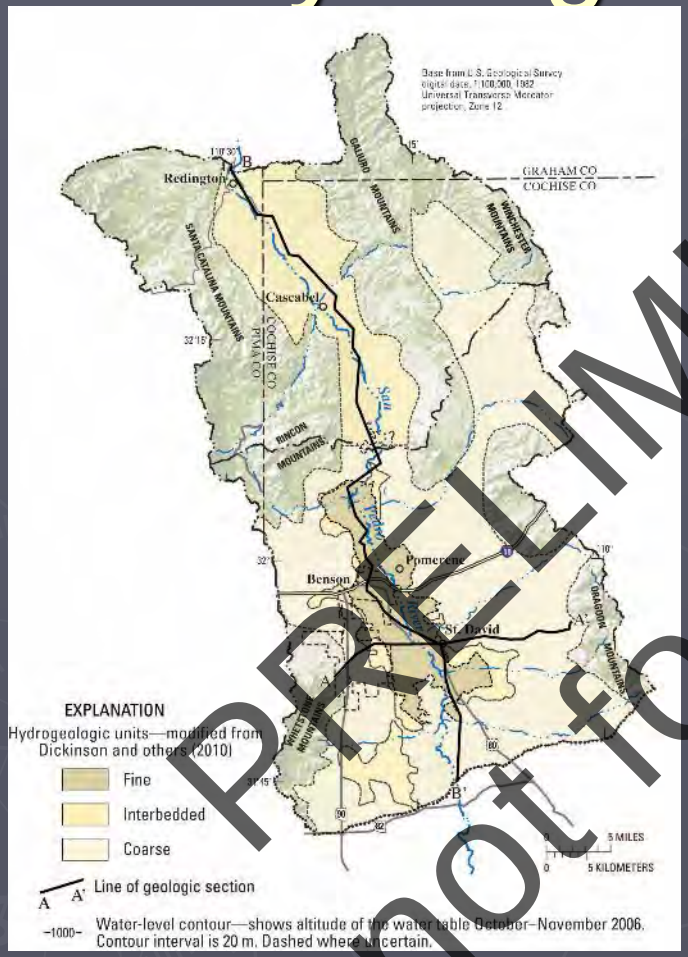
- Electromagnetic surveys - GEOTEM
- Map subsurface electrical properties
  - Aquifer is electrically conductive
  - Silt and clay conducts electricity better than sand and gravel
  - Bedrock is not electrically conductive

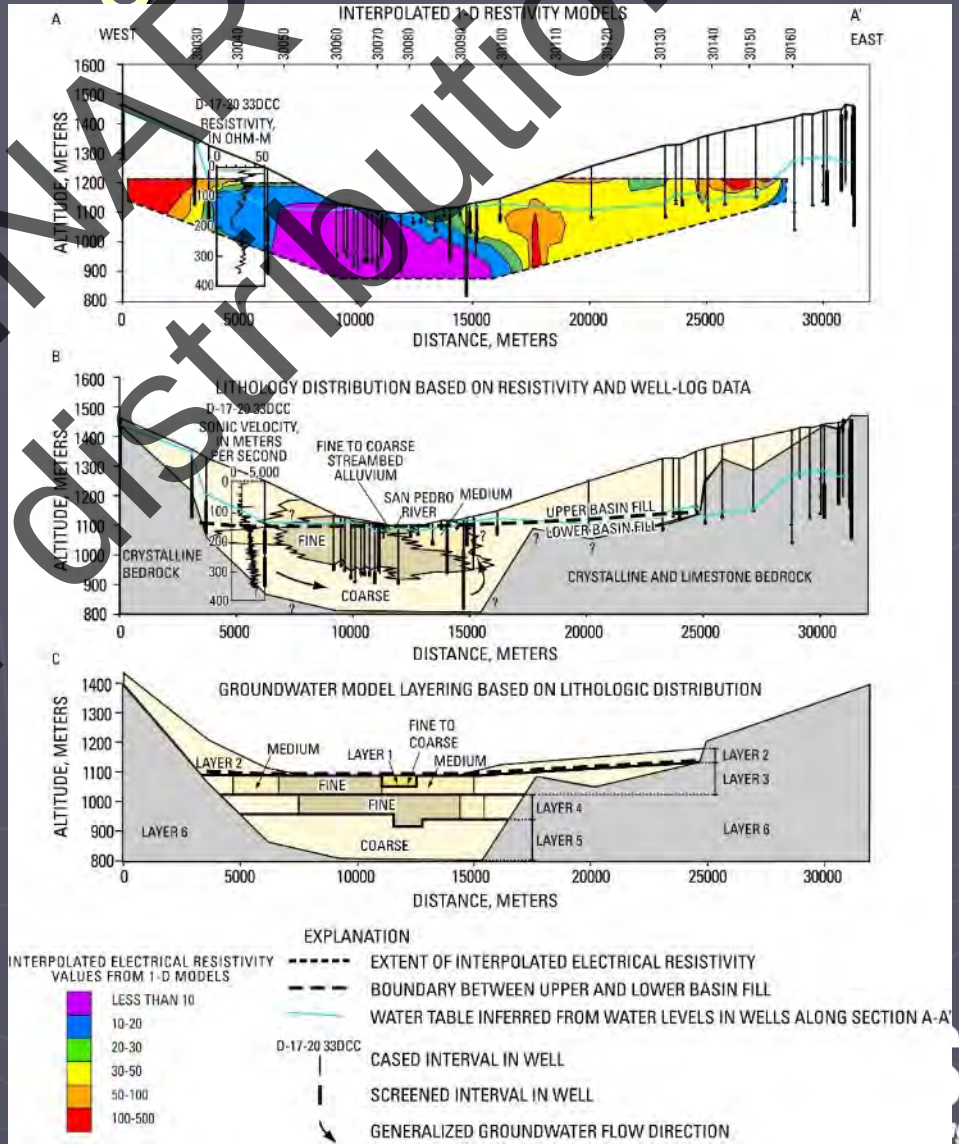
•Aircraft and transmitter

•Receiver birds



Resistivity, HGUs, and model layering along E-W section



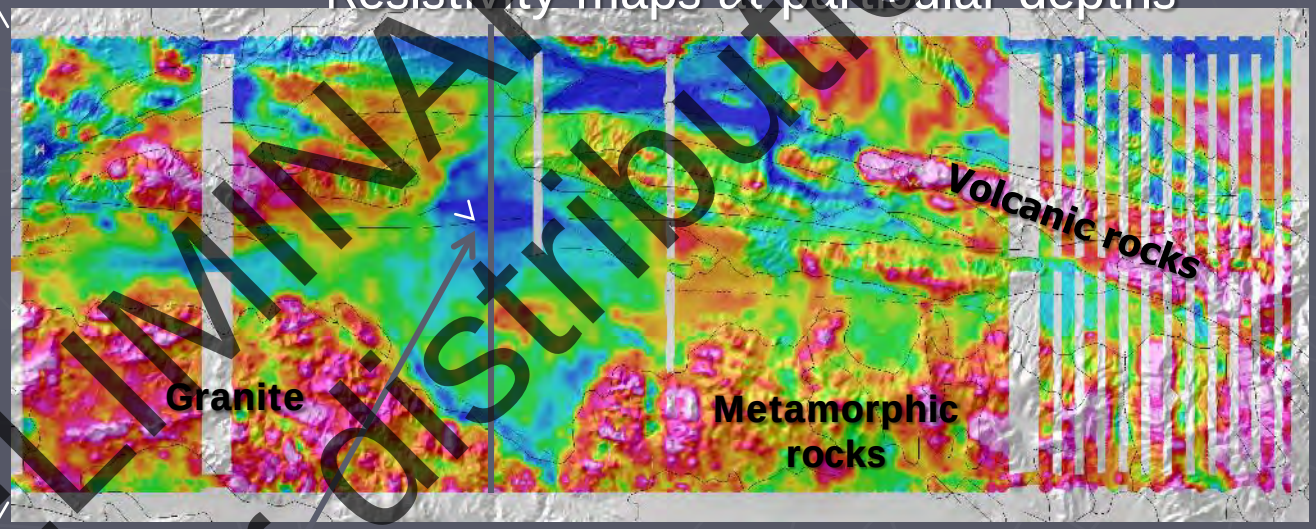


Ft. Irwin National Training Center, CA

Jill Densmore, Lyndsey Ball, Geoff Cromwell,
and Linda Woolfenden

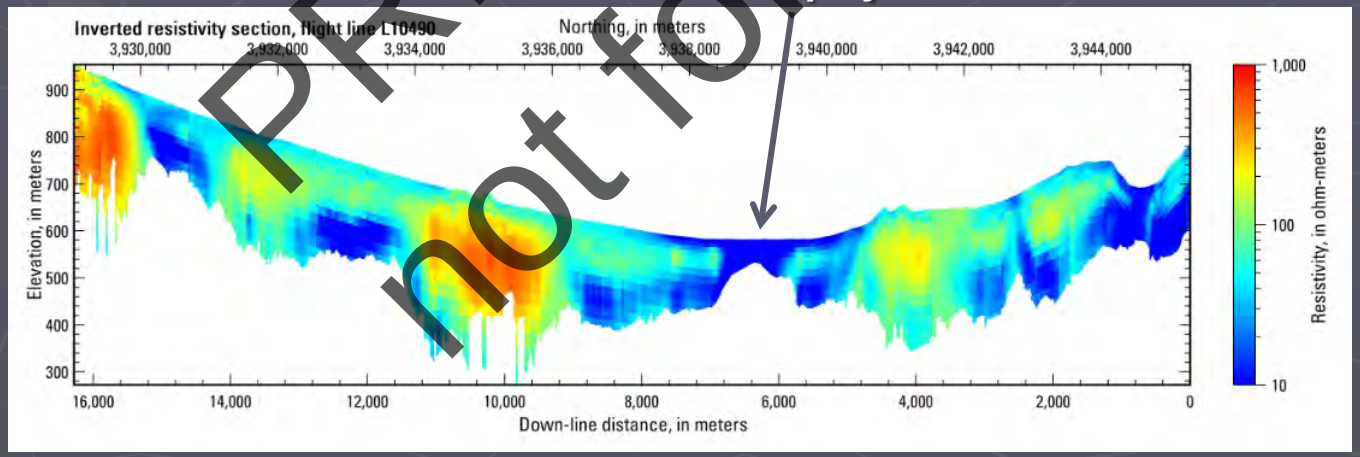
Airborne Electromagnetic Modeling (AEM)
Gravity

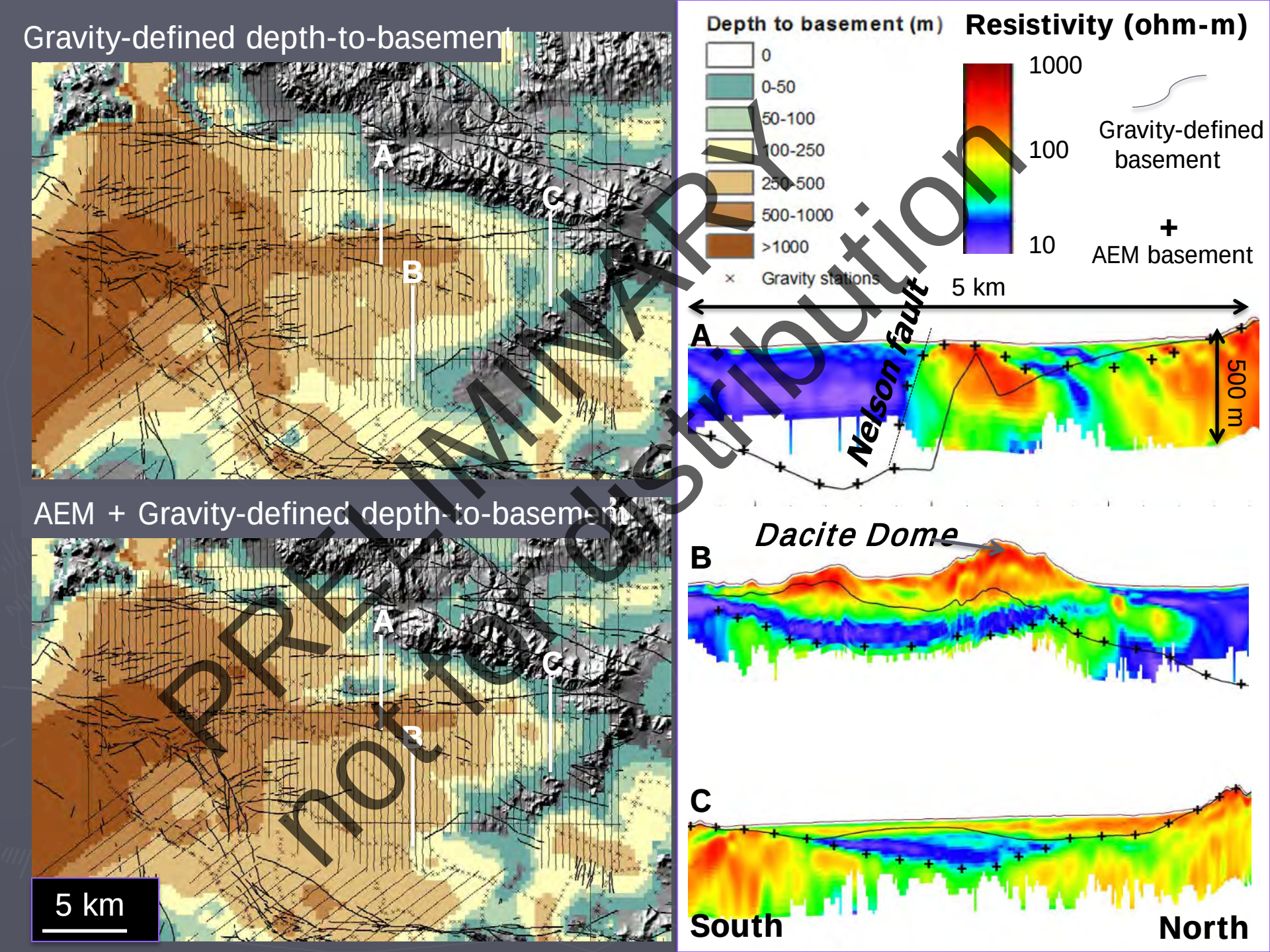
Resistivity maps at particular depths



Resistivity cross sections along flight lines

Saline playa



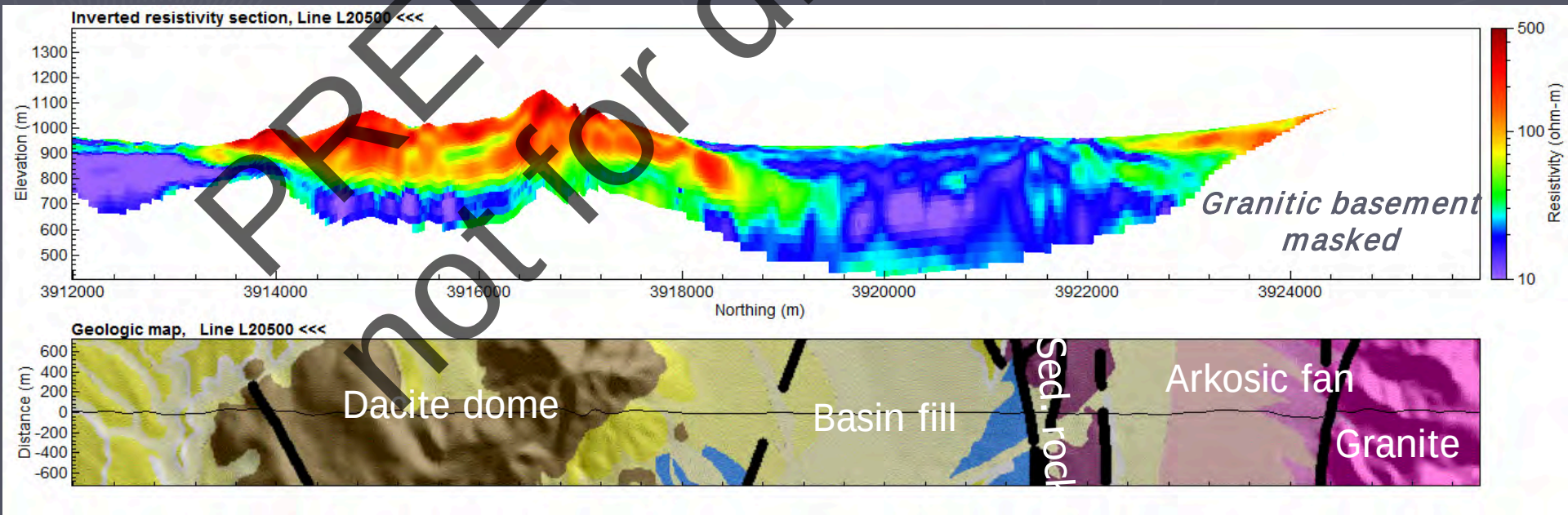

Gravity-defined depth-to-basement
A
B
C
AEM + Gravity-defined depth-to-basement
A
B
C
5 km
Depth to basement (m)
0
0-50
50-100
100-250
250-500
500-1000
>1000
Gravity stations
Resistivity (ohm-m)
1000
100
10
Gravity-defined basement
AEM basement
5 km
A
Nelson fault
500 m
Dacite Dome
B
C
South
North
PRELIMINARY
not for distribution

Translation between basin fill resistivity and hydraulic conductivity

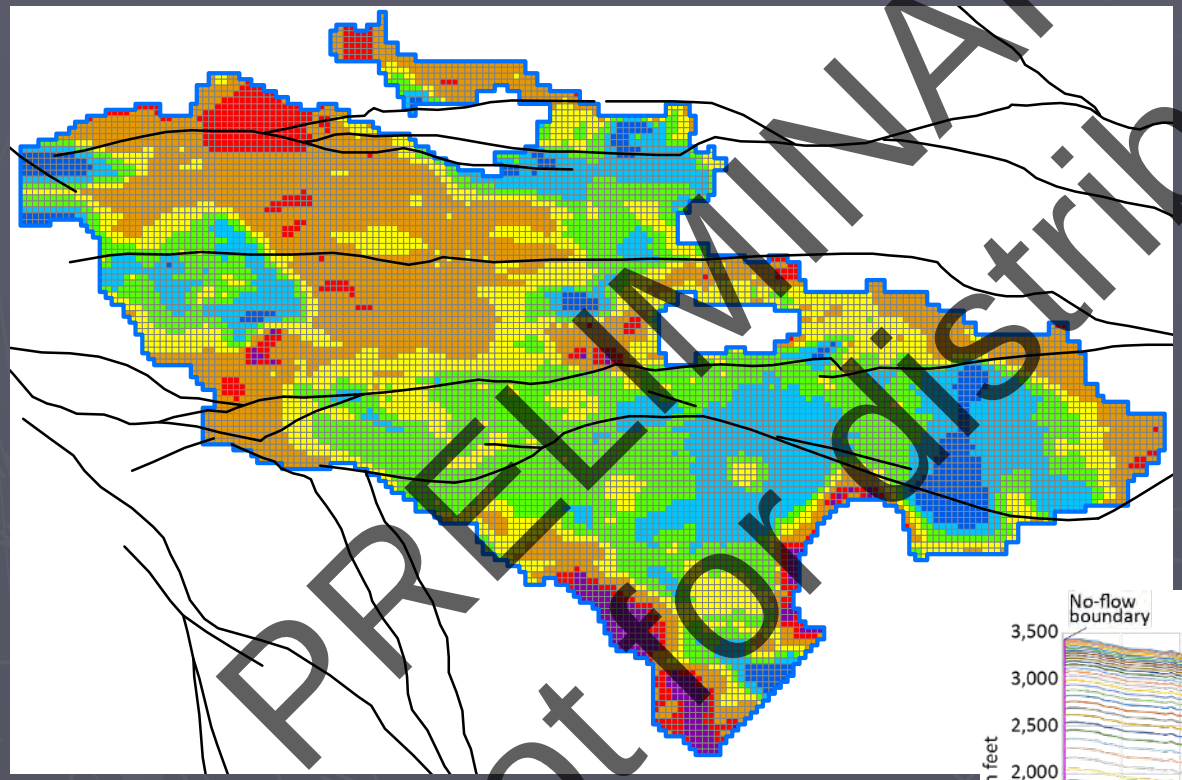
Few wells = limited ability to develop resistivity-K relations

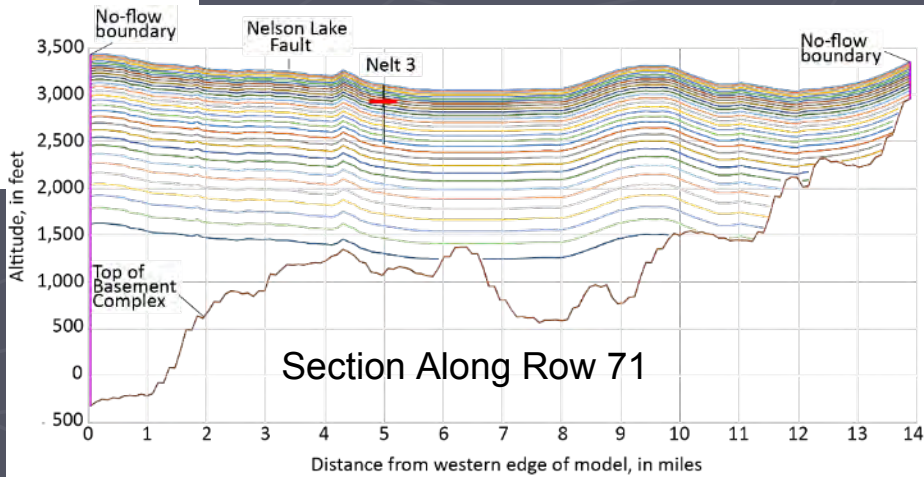
Resistivity "zones" used to develop geologically realistic K geometry within the basin-fill deposits

Model retains flexibility and can honor geologic variability while minimizing the number of model parameters / model complexity



- Groundwater Models
  - Basement based on gravity modified by AEM
  - Parameter zones based on AEM resistivity zones mapped to grid
  - Relative values used for hydraulic conductivity

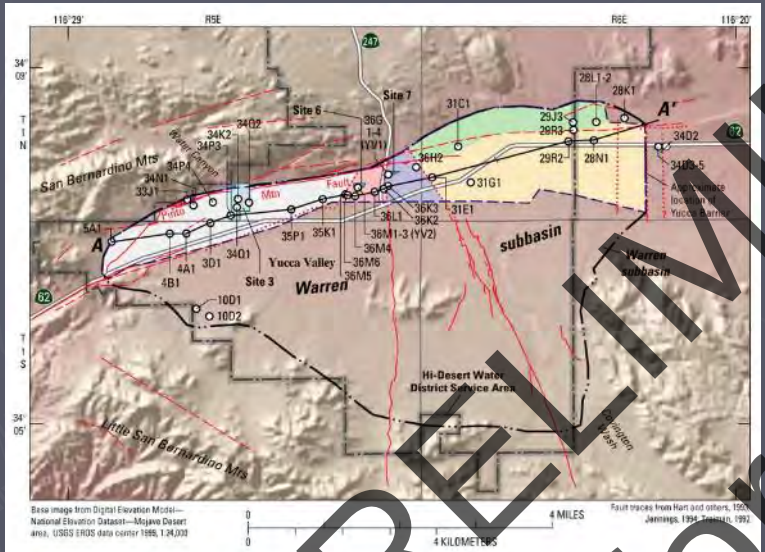


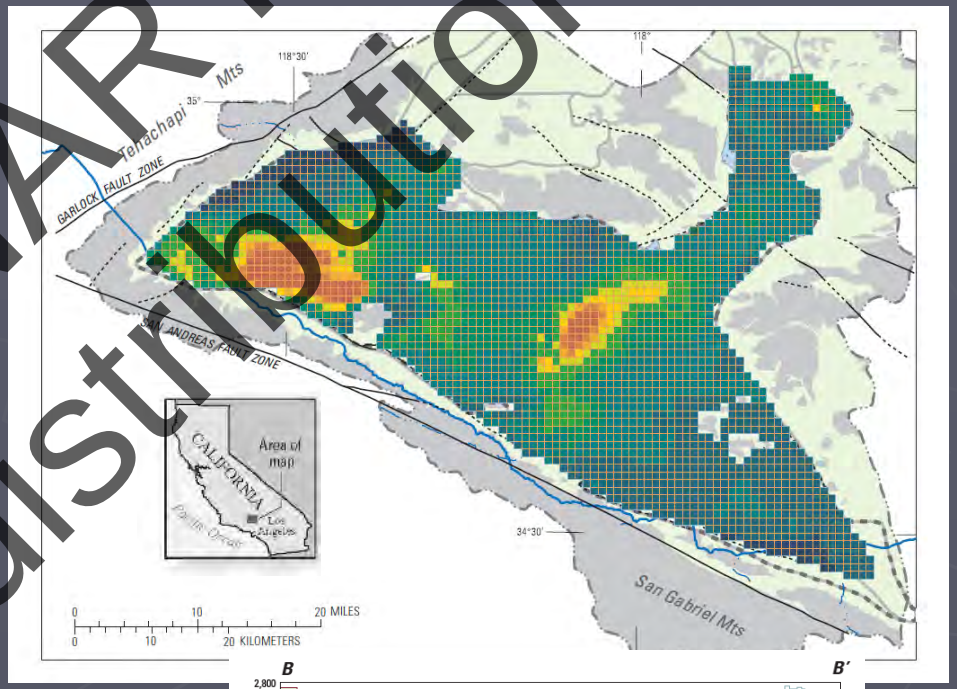


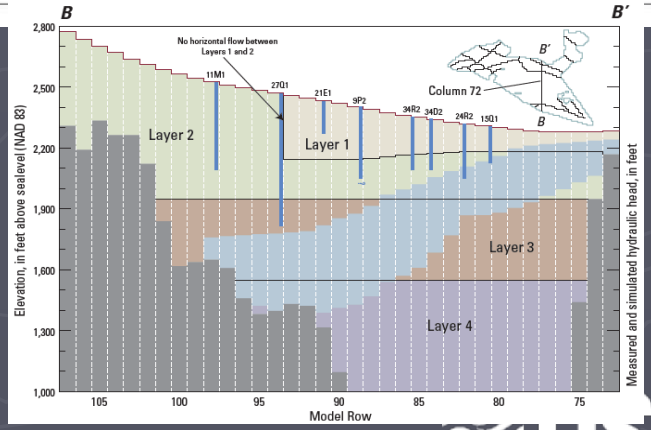
California Desert Basins

Tracy Nishikawa, Dave O'Leary, Vicki Langenheim, Allen Christensen, and others

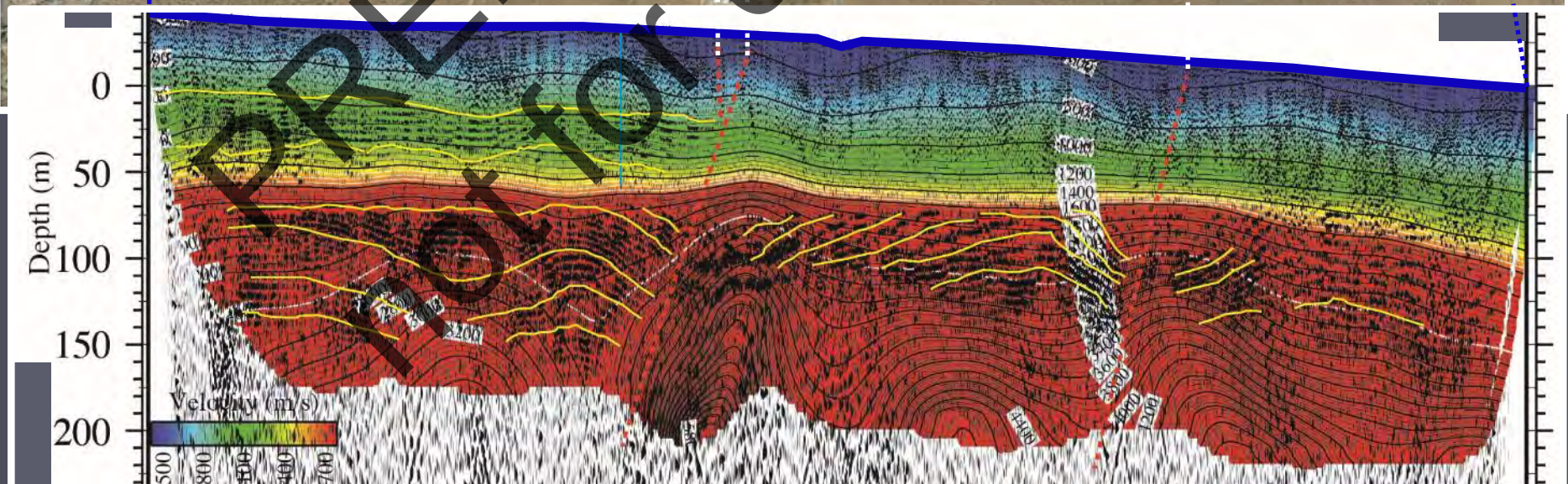
- Gravity for depth to basement







Seismic Data in Joshua Tree Area
-ties with borehole resistivity



Recharge monitoring with gravity

Jeff Kennedy

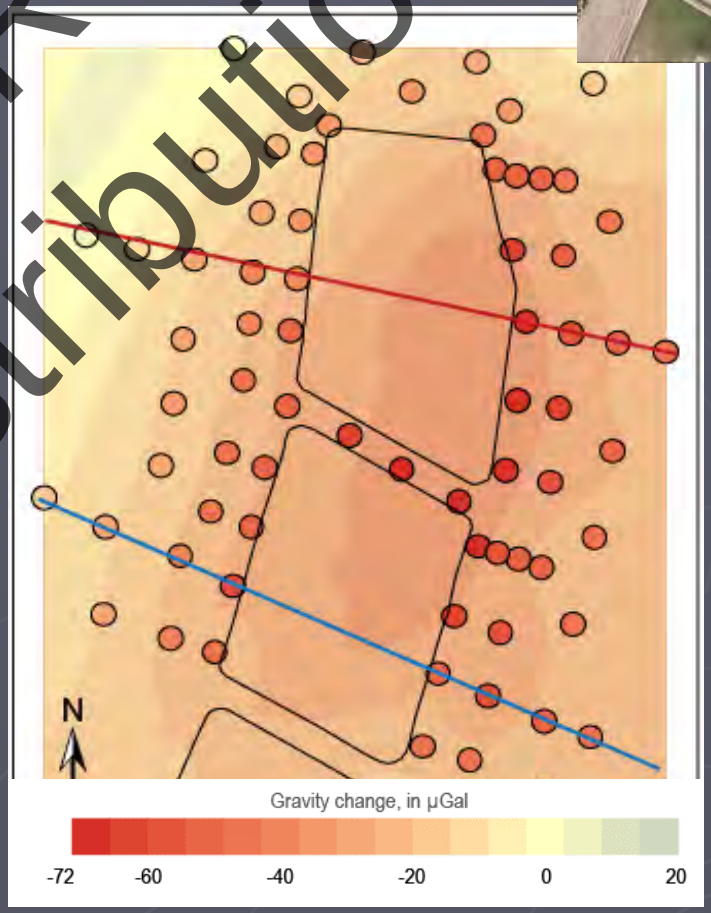
- **Time-lapse gravity data can be used for monitoring and modeling artificial recharge through a thick unsaturated zone**
- Gravity methods provide data to track recharge without the cost and regulatory requirements of monitoring wells, and to develop better models.

Stationary, continuously-recording gravity meters

Portable gravity meters and GPS

Recharge monitoring with gravity
Jeff Kennedy

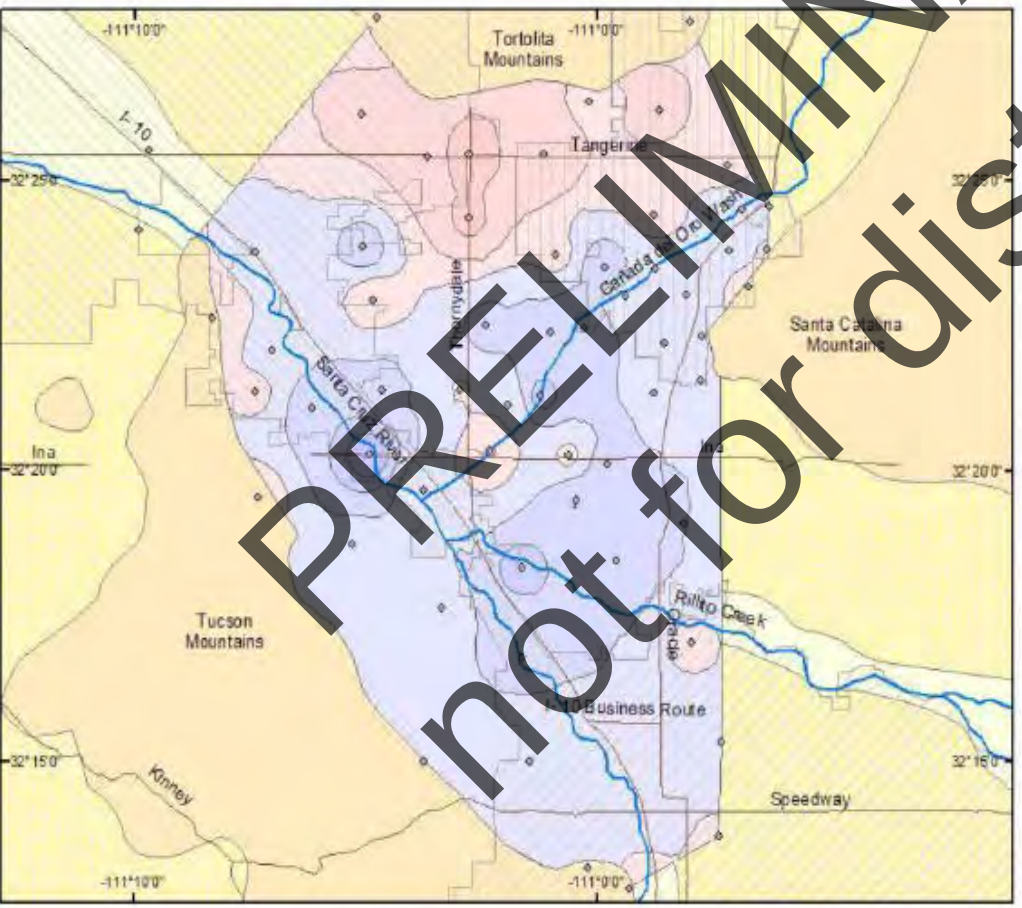
- Gravity measures aquifer storage change using sensors on the land surface
- A recent project in Arizona used gravity to track groundwater at an artificial recharge facility with spreading basins.
- There are two main applications:
  - Spatial maps of gravity/storage change, shown here
  - Continuous data



Map showing the change in gravity after one month of basin drying. Gravity data reveal that the greatest decrease in storage is to the east, toward withdrawal pumps. Storage accumulates to the east.

How can gravity data be used in a hydrologic investigation?

- In an unconfined aquifer, collocated gravity and water level measurements can determine specific yield.
- Gravity data can map aquifer-storage change.



Carruth, 2014

Aquifer storage change in Tucson Basin from spring 2006 to spring 2008

Explanation

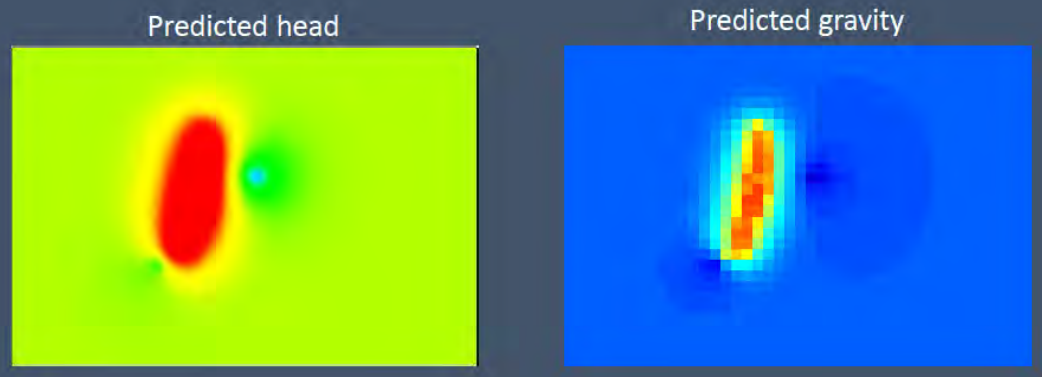
Storage Change (feet)

- -3 to -2
- -2 to -1
- -1 to 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4

- Benchmark
- Marana
- Oro Valley
- Tucson
- Channel Deposits
- Older Alluvium
- Crystalline Rock
- River
- Road

Gravity and Groundwater Modeling

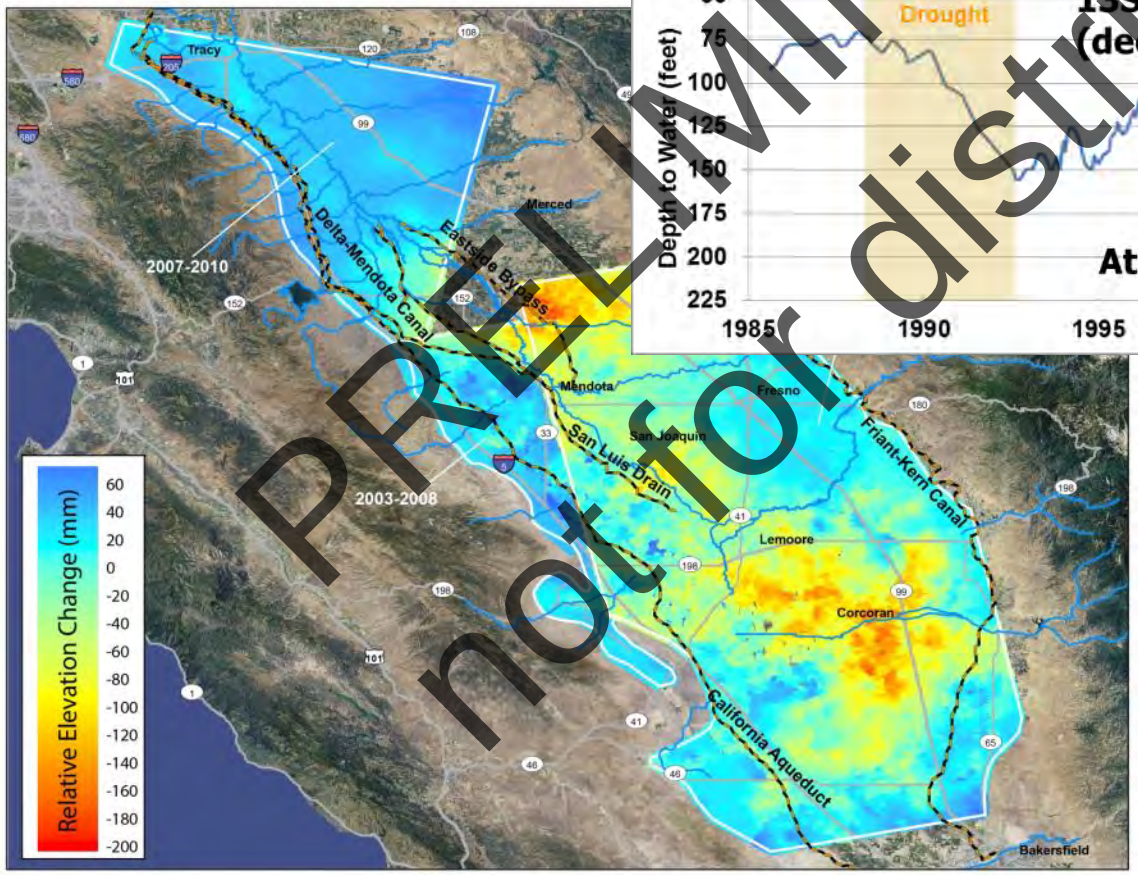
- In response to head changes in an unconfined aquifer, gravity data behave as spatially low-pass filtered head data—the greater the depth to water, the heavier the filter.
- Importantly, unlike water level data, gravity data provide information about unsaturated-zone properties: initial, saturated, and residual water content.
- Gravity can be predicted directly from a groundwater flow model – unlike every other geophysical method, no additional parameters are needed.



Central Valley, CA

Claudia Faunt, Michelle Sneed, Jon Traum and others

The recent drought, land-use changes, and restrictions on surface-water flows have resulted in extensive pumping, large groundwater-level declines, widespread land subsidence, and salinity issues



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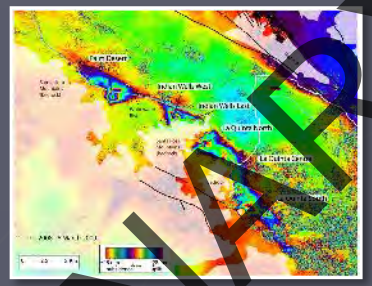
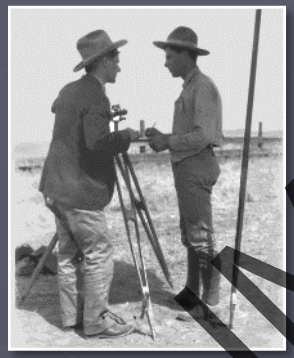
How is subsidence measured?

Bench Mark Surveys

InSAR/PSInSAR



Spirit Leveling



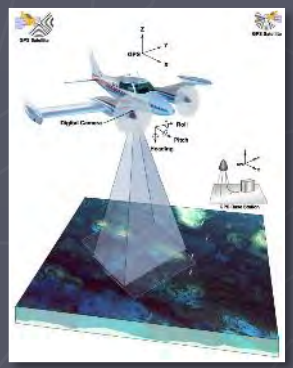
Extensometer

Tripod LiDAR

Campaign GPS

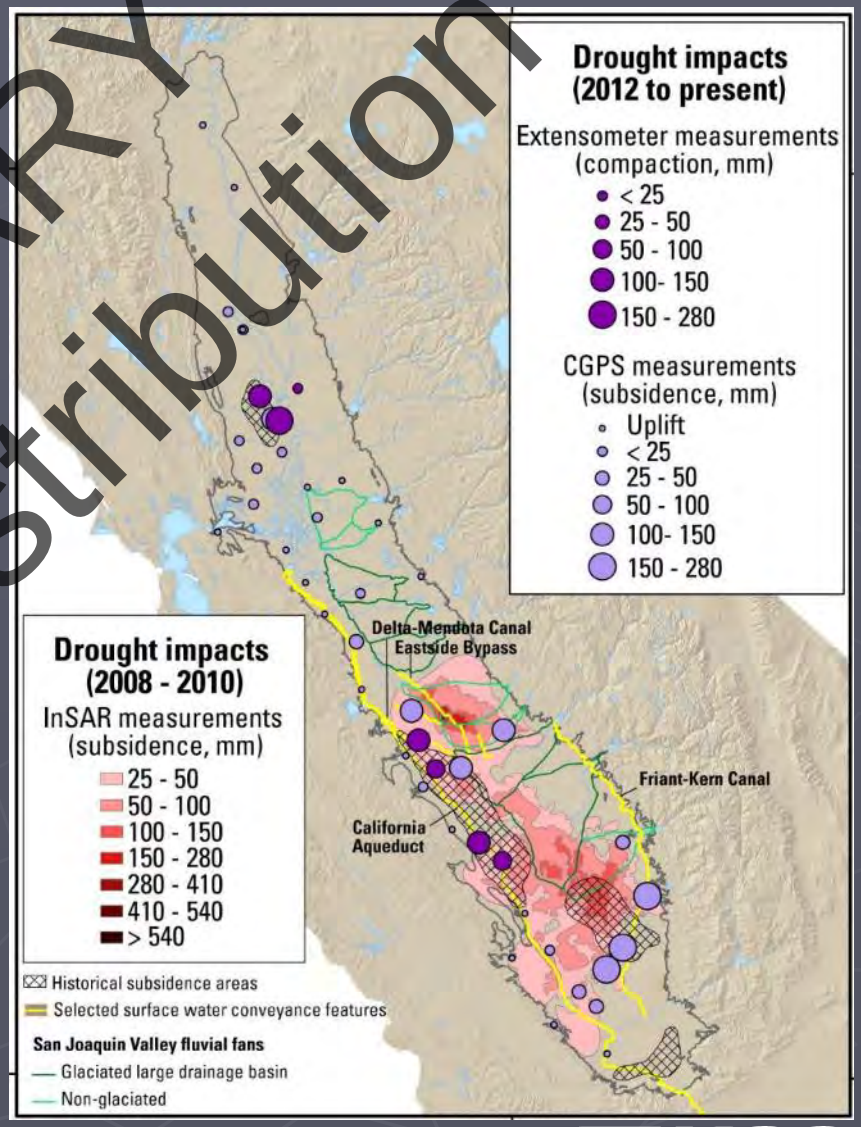
Continuous GPS

Airborne LiDAR



Subsidence Observations

- GPS Surveys
- Continuous GPS
  - 27 sites on valley floor
- InSAR and LiDAR
- Used as calibration targets for modeling



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Water levels and storage

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