Geophysical and Hydrogeologic Investigations for Deep Characterization

Salinas & Indian Wells Valleys

2024 California Water and Environmental Modeling Forum

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Principal Hydrogeologist

RAMBOLL
Bright ideas.
Sustainable change.

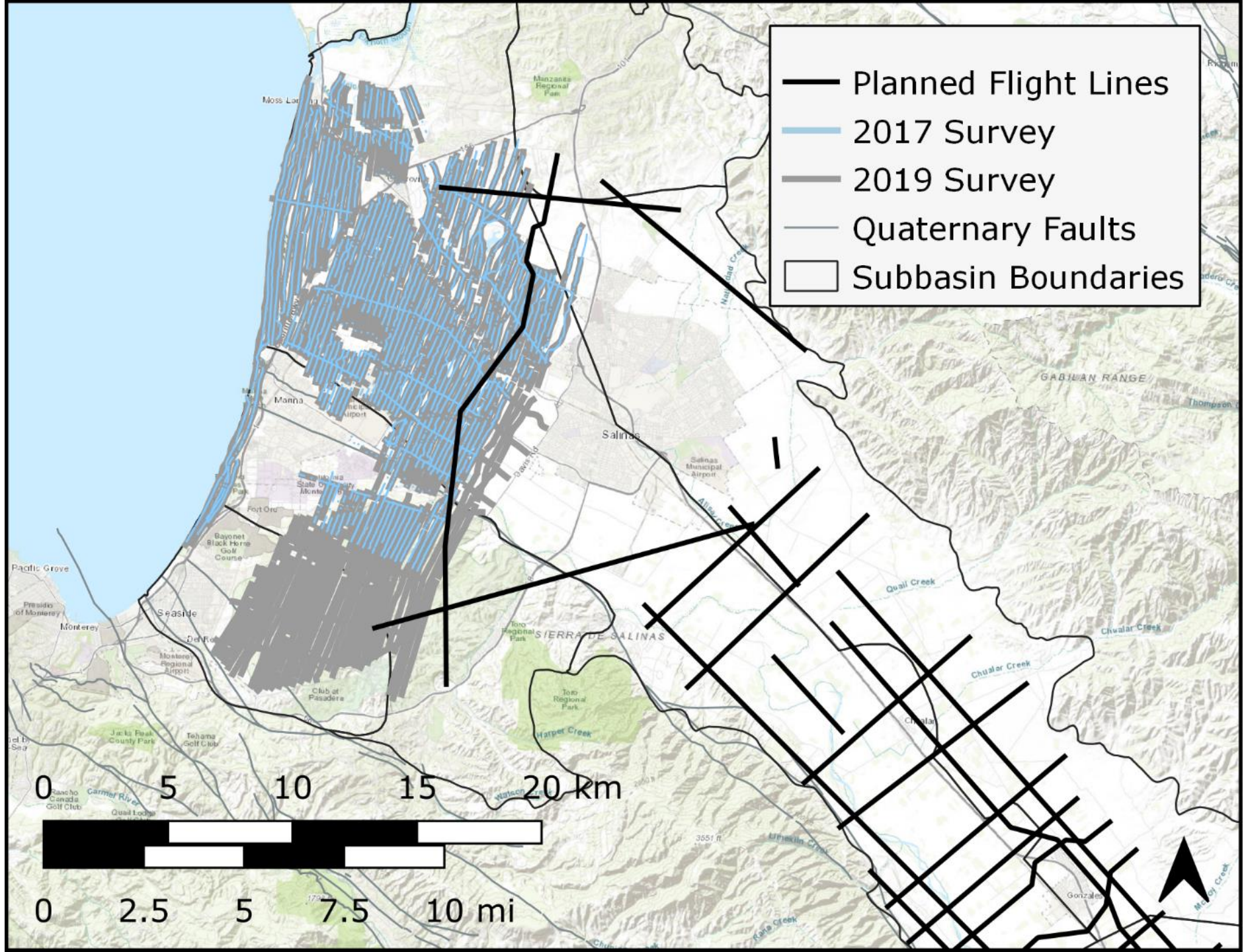
Overview – Salinas Valley Deep AEM Survey

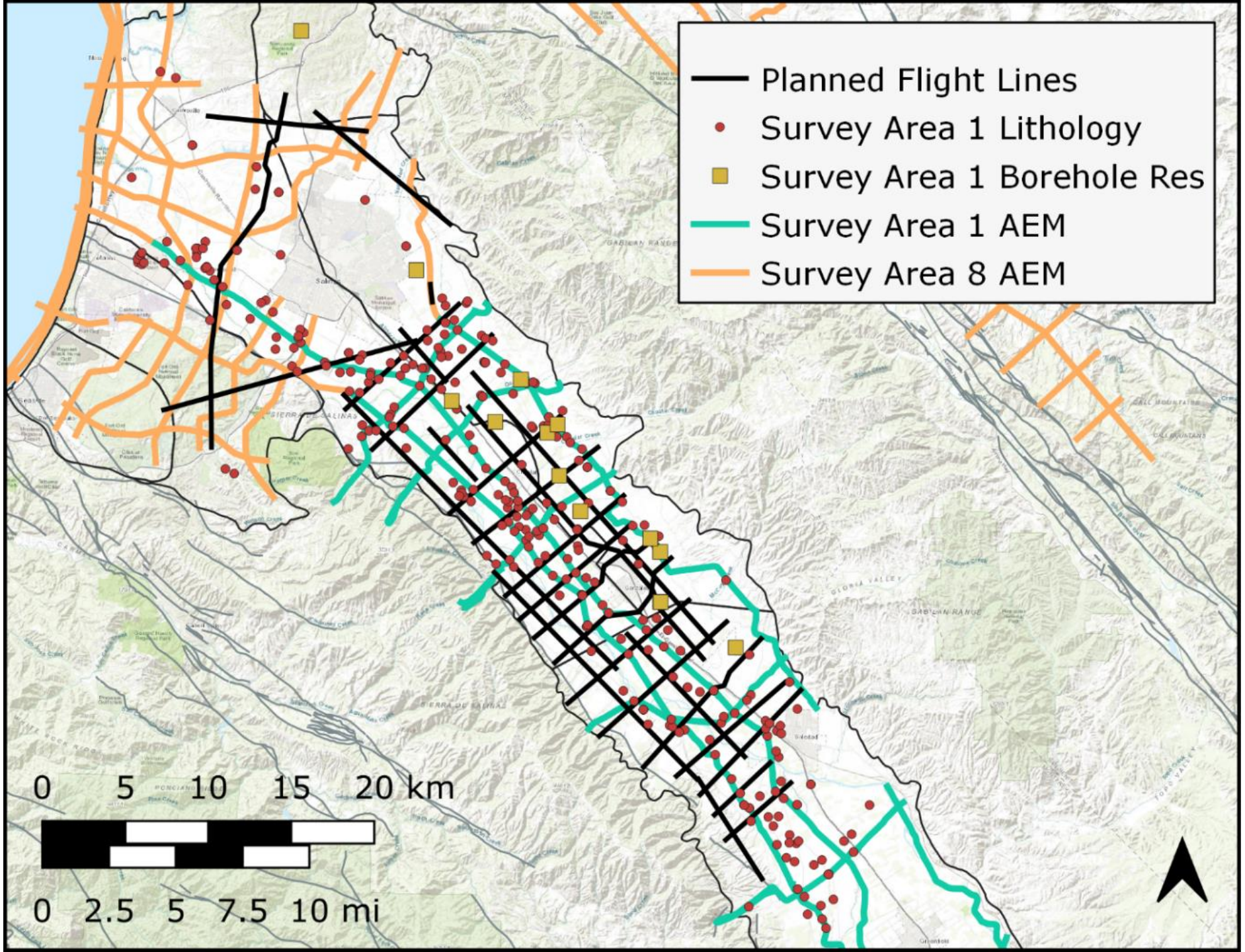
OBJECTIVES

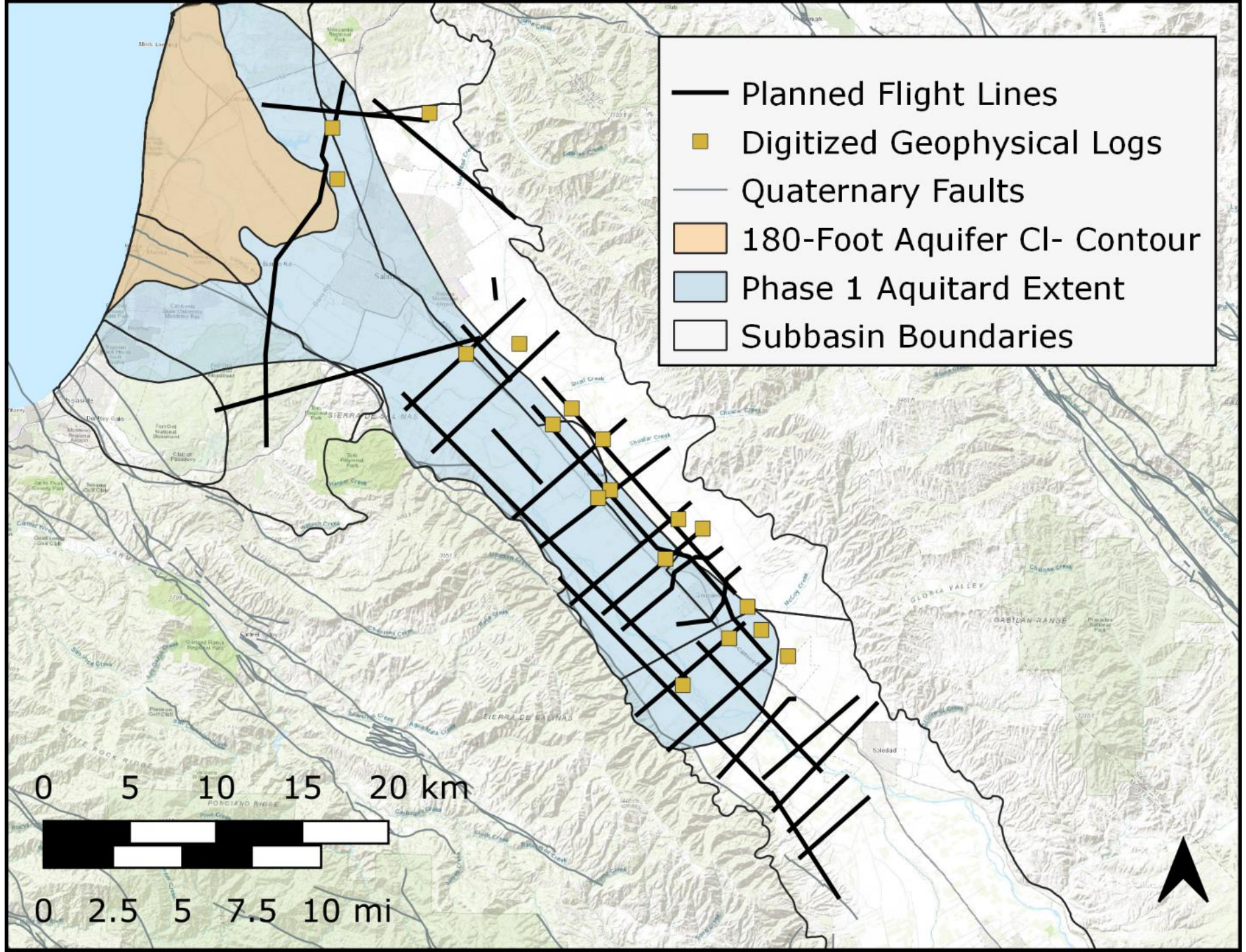
- Map 400-Foot Deep Aquitard (FDA) expected +750 ft bgs

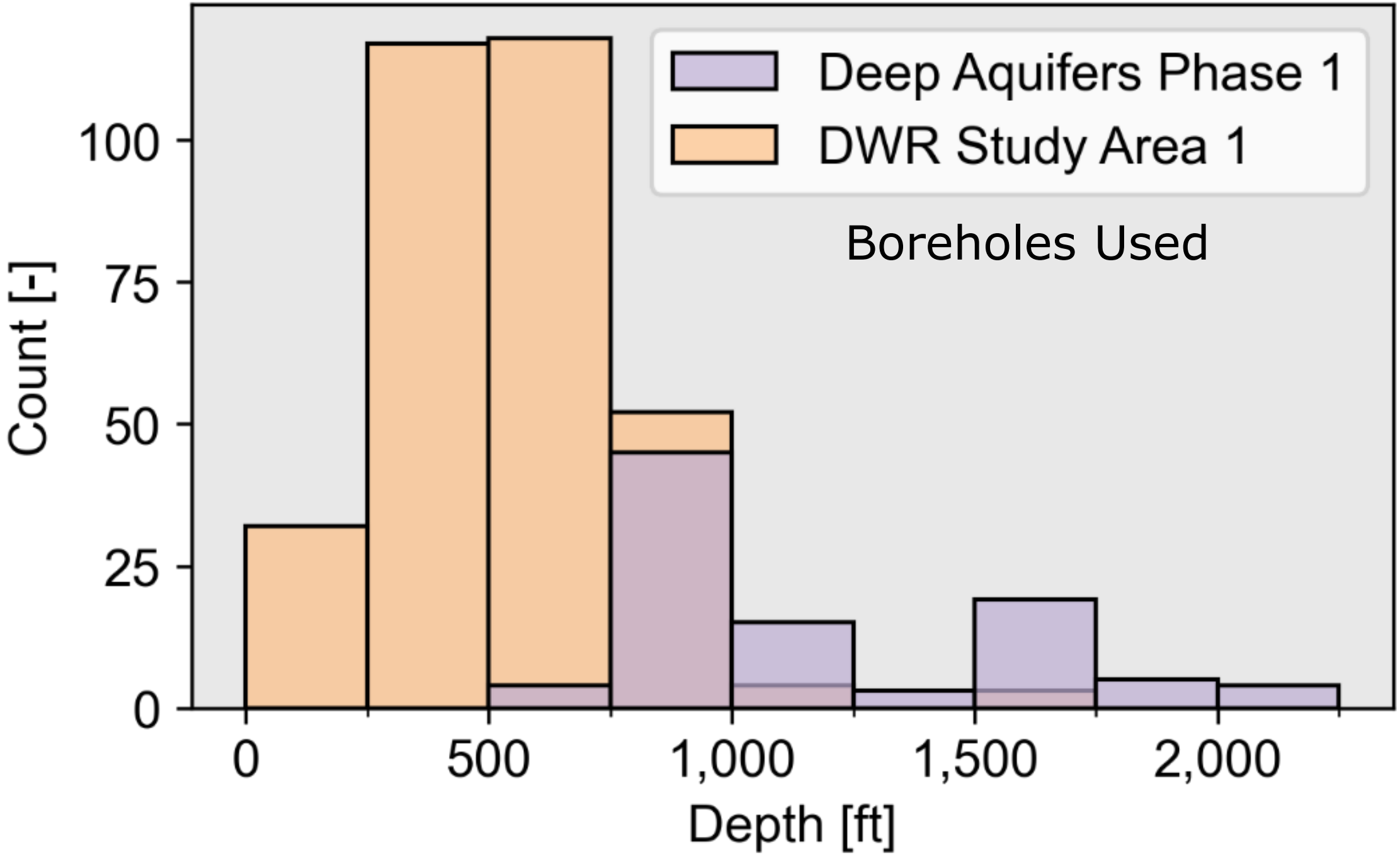
APPROACH

- Application of SkyTEM 312HPM AEM System
  - More powerful system
  - Modified setup of the SkyTEM 312HPM system, high data quality was maintained until later times
  - Deeper penetration than previous surveys
  - Depths of 1,000 ft to 2,000 ft (300 m to 600 m)
  - Ability to meet objectives
- Use of existing HCM and data
  - Borehole data included 400-FDA interpretations


Planned Flight Lines
2017 Survey
2019 Survey
Quaternary Faults
Subbasin Boundaries
0 5 10 15 20 km
0 2.5 5 7.5 10 mi
Manna
Salinas
Seaside
Monterey
Pacific Grove
GABILAN RANGE
SIERRA DE SALINAS
Quail Creek
Chualar Creek
Harper Creek
Gonzales

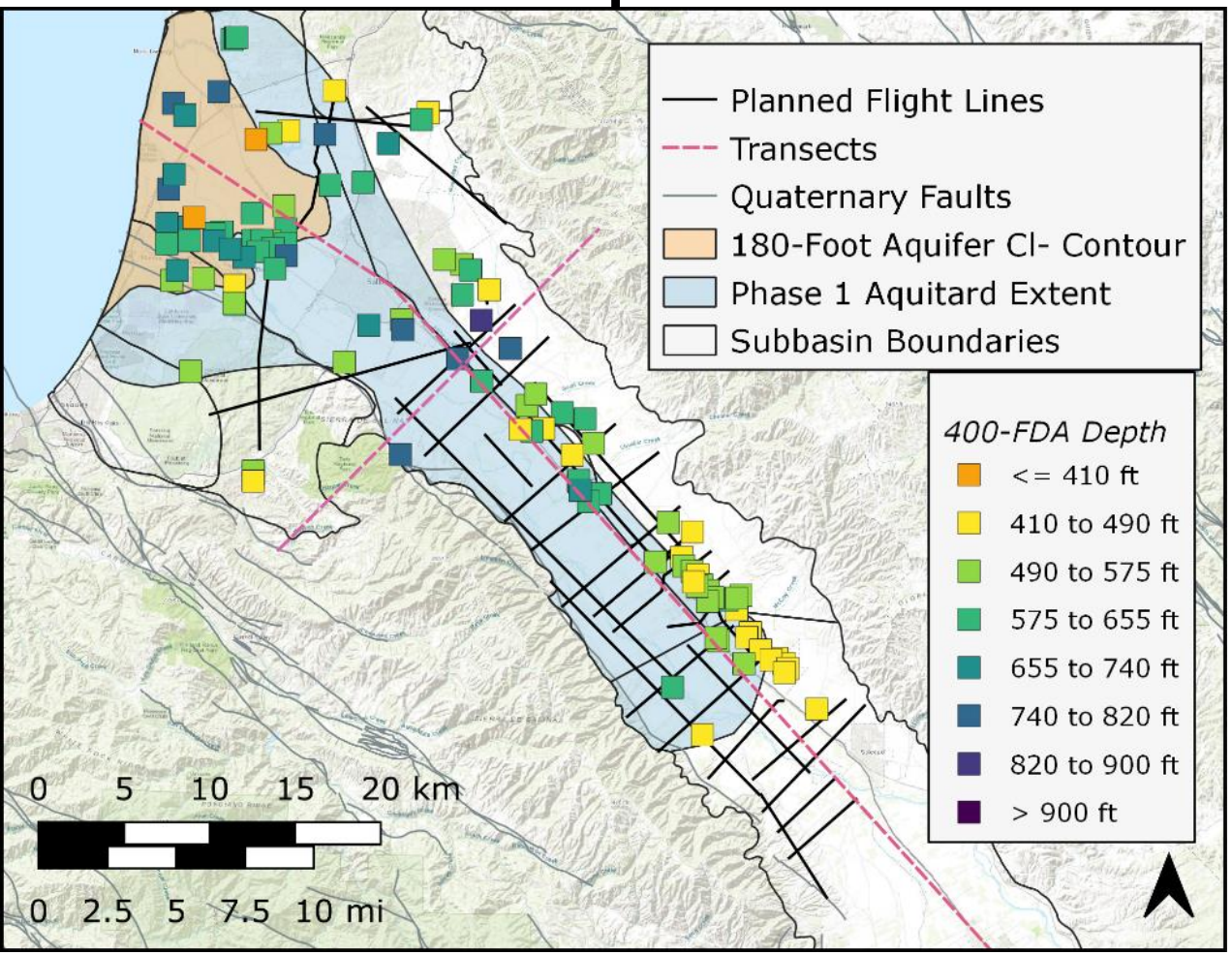

Planned Flight Lines
Survey Area 1 Lithology
Survey Area 1 Borehole Res
Survey Area 1 AEM
Survey Area 8 AEM
0 5 10 15 20 km
0 2.5 5 7.5 10 mi


Planned Flight Lines
Digitized Geophysical Logs
Quaternary Faults
180-Foot Aquifer Cl- Contour
Phase 1 Aquitard Extent
Subbasin Boundaries
0 5 10 15 20 km
0 2.5 5 7.5 10 mi


Deep Aquifers Phase 1
DWR Study Area 1
Boreholes Used
Count [-]
100
75
50
25
0
0
500
1,000
1,500
2,000
Depth [ft]

Depth to 400-Foot Deep Aquitard (FDA)

Top



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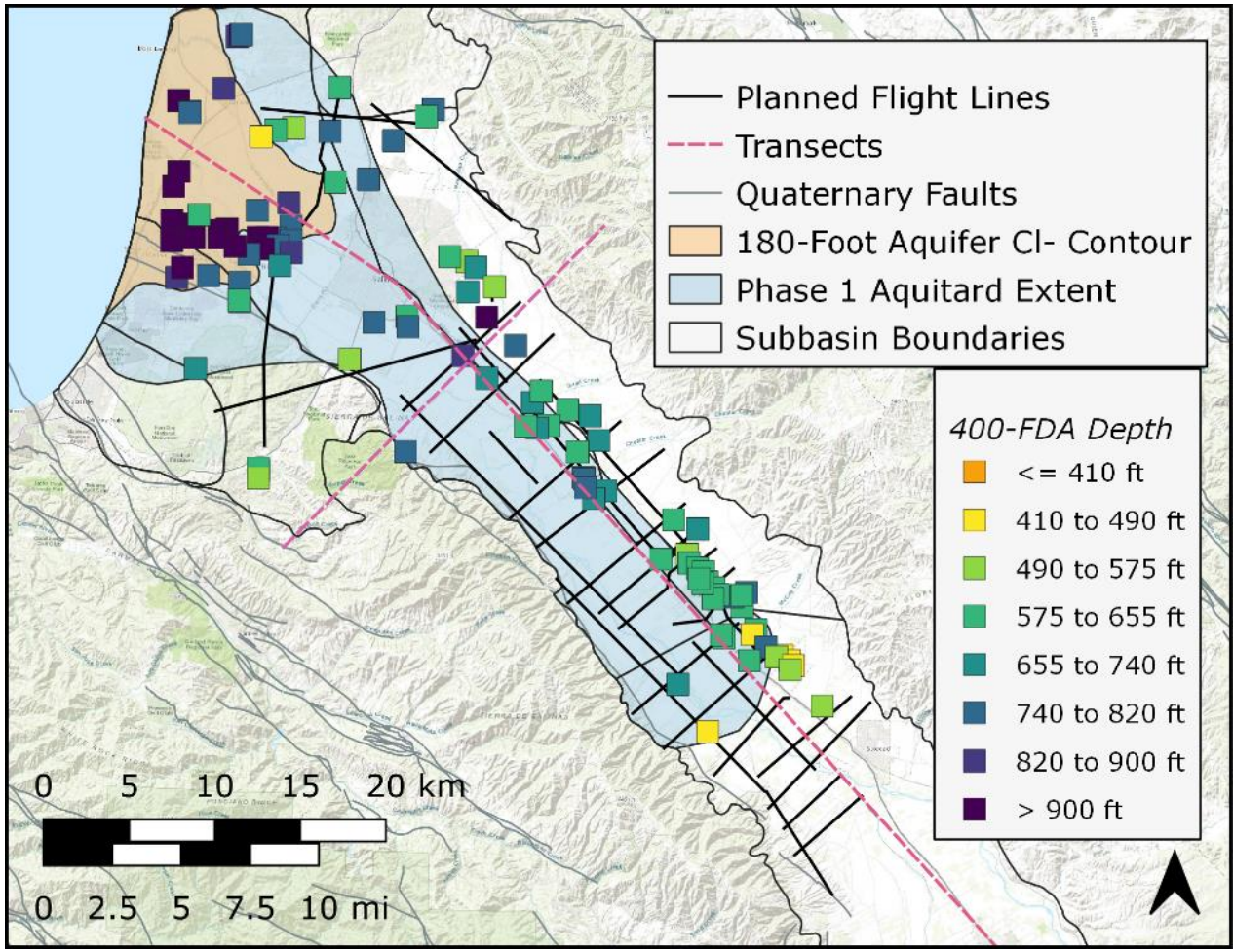
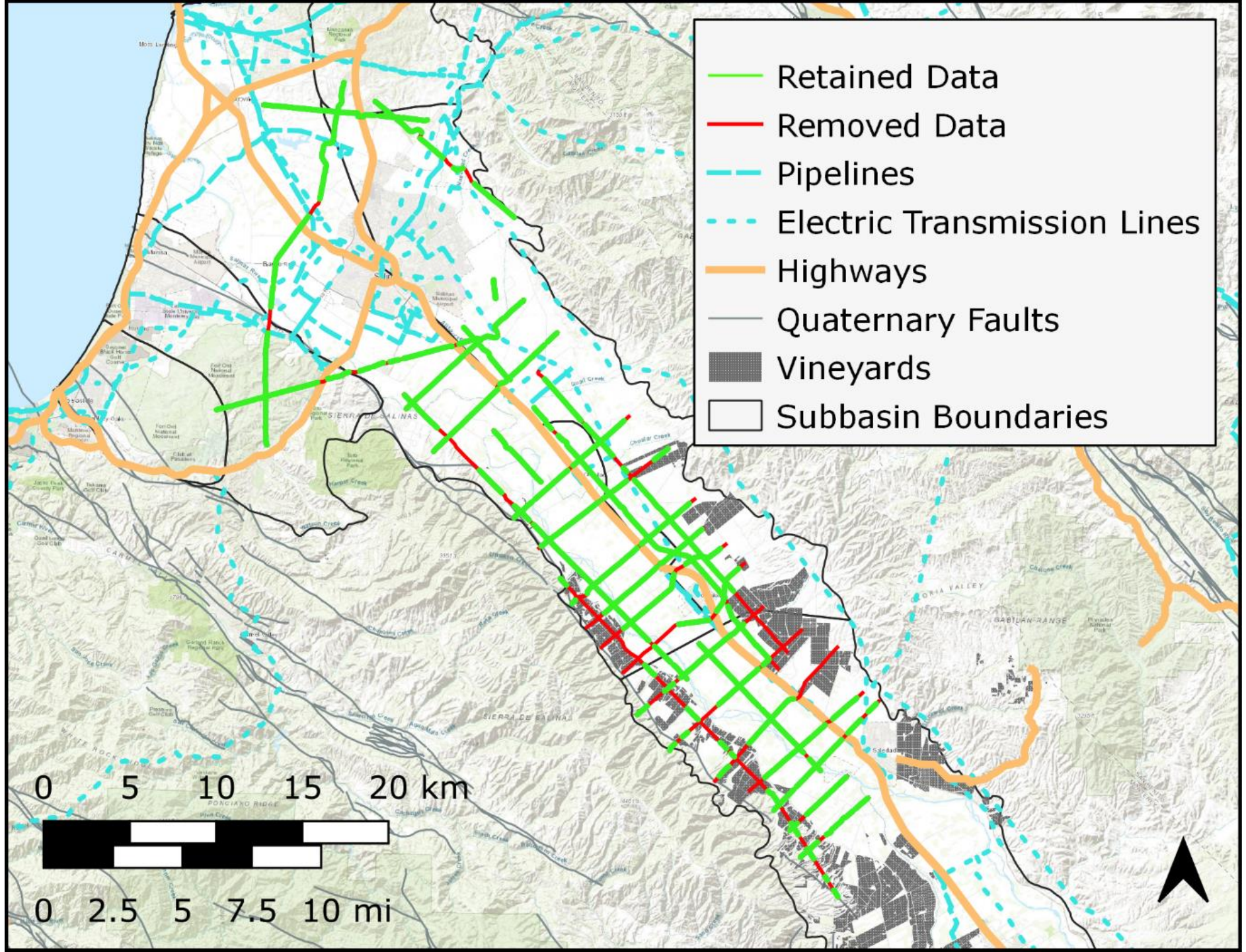
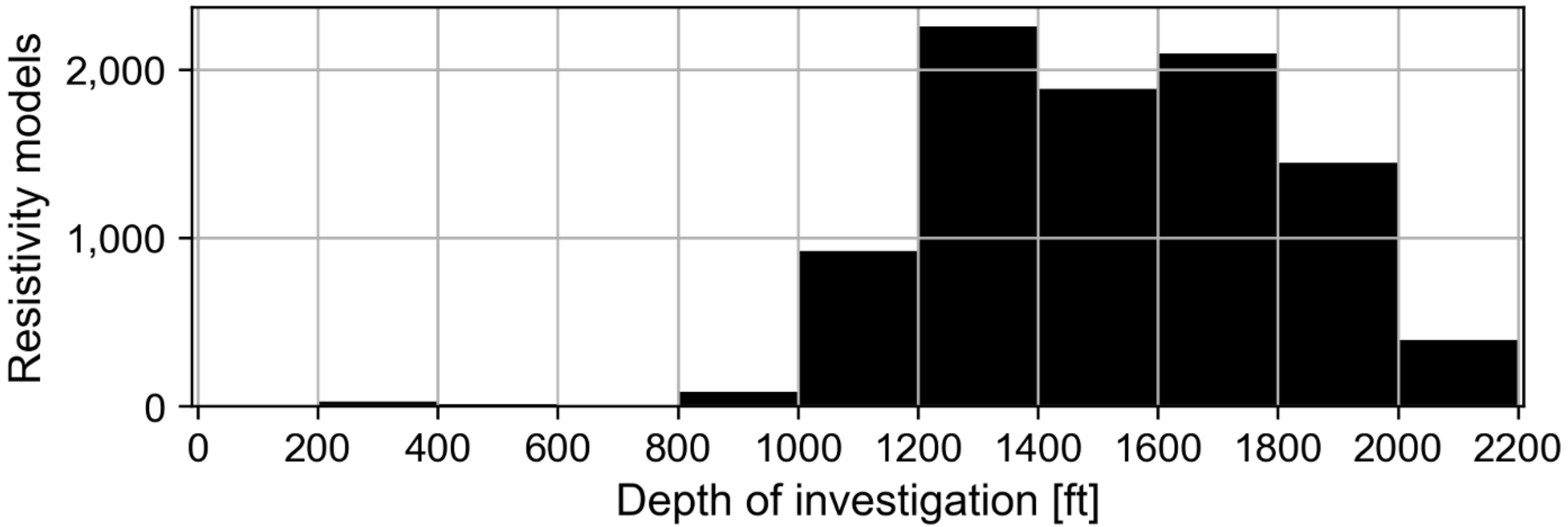
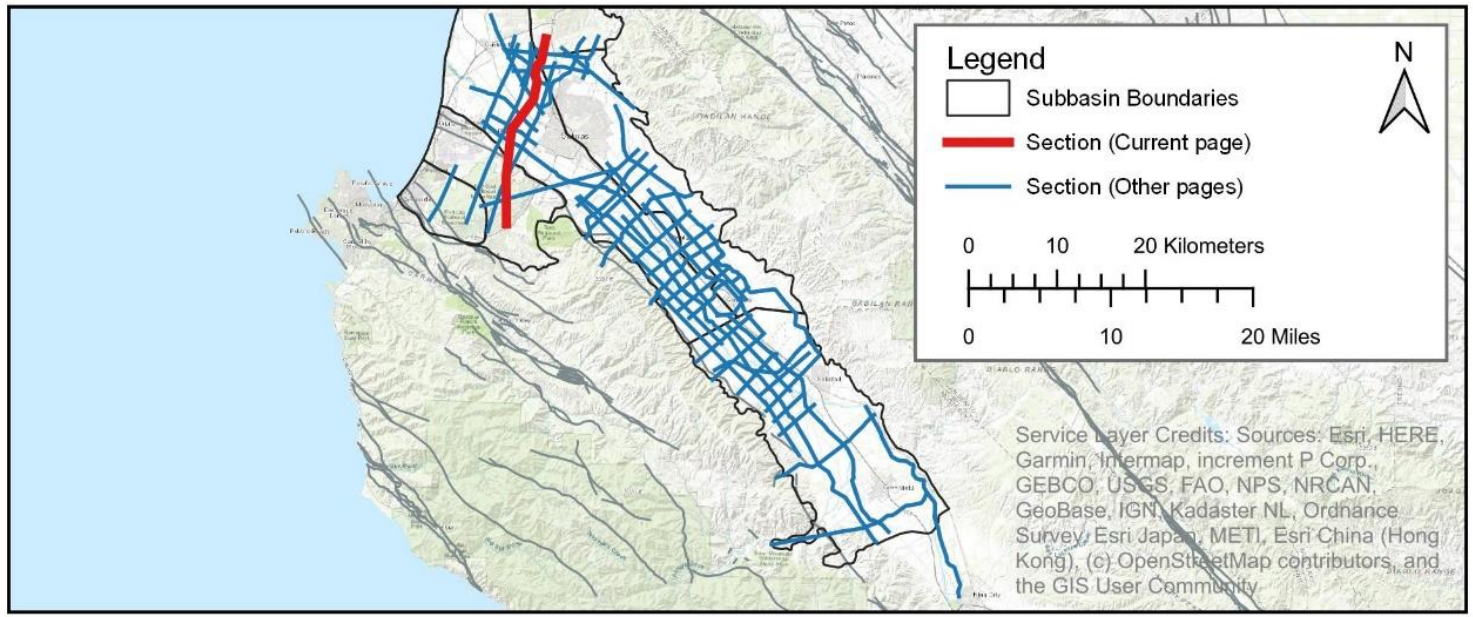


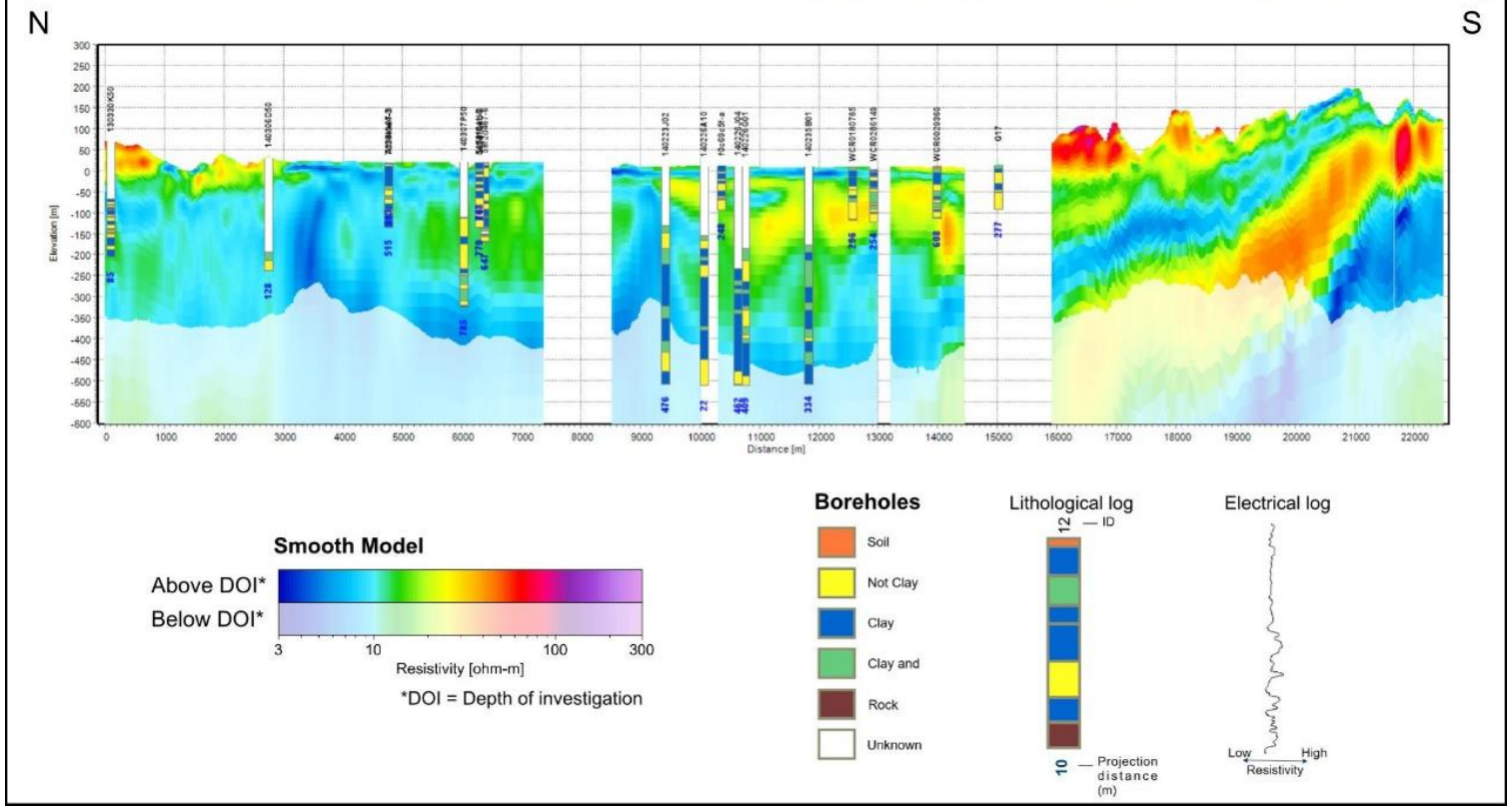
From Borehole Interpretation

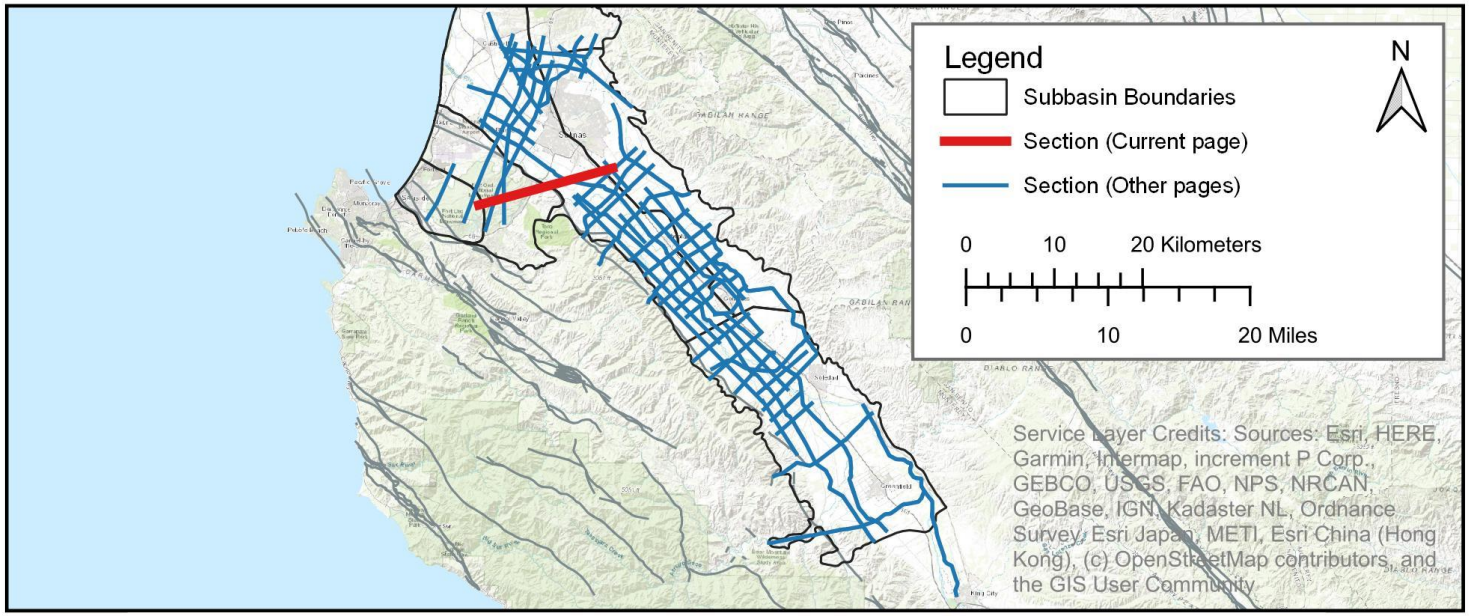
AEM Dataset	Survey	AEM System	Region	Used in analysis
DWR Statewide AEM Surveys	Survey Area 1	SkyTEM 312	Salinas Valley and Paso Robles Basins	Yes
	Survey Area 8	SkyTEM 312	Coastal Monterey Bay	Yes
Coastal Salinas Valley AEM Surveys	2017 Survey	SkyTEM 304	Coastal Salinas Valley	No
	2019 Survey	SkyTEM 312	Coastal Salinas Valley	Yes


Retained Data
Removed Data
Pipelines
Electric Transmission Lines
Highways
Quaternary Faults
Vineyards
Subbasin Boundaries
0 5 10 15 20 km
0 2.5 5 7.5 10 mi


Resistivity models
2,000
1,000
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Depth of investigation [ft]


Legend
Subbasin Boundaries
Section (Current page)
Section (Other pages)
N
0 10 20 Kilometers
0 10 20 Miles
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community


N
S
Elevation [m]
Distance [m]
Smooth Model
Above DOI*
Below DOI*
3 10 100 300
Resistivity [ohm-m]
*DOI = Depth of investigation
Boreholes
Soil
Not Clay
Clay
Clay and
Rock
Unknown
Lithological log
12 — ID
10 — Projection distance (m)
Electrical log
Low High
Resistivity



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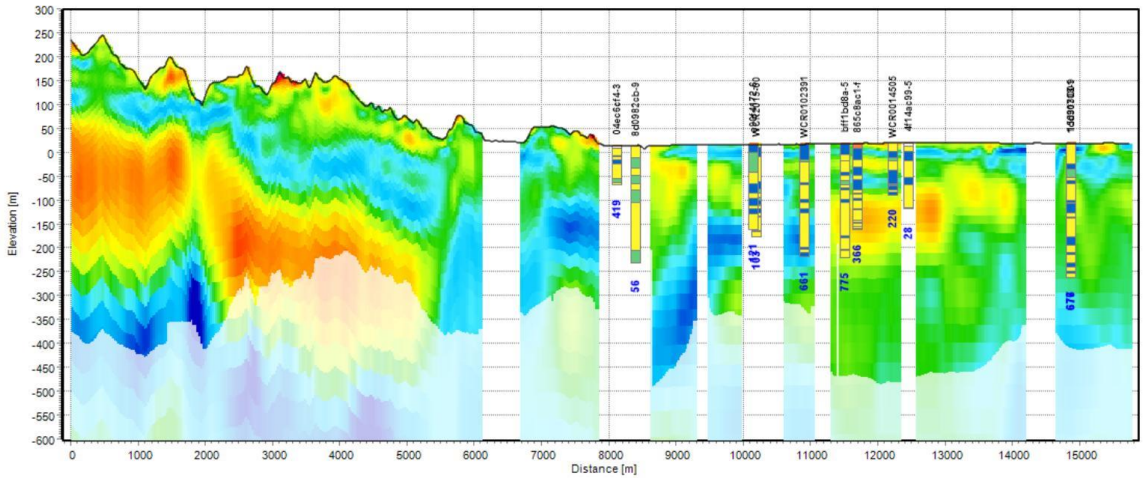


Smooth Model

Above DOI*

Below DOI*

3 10 100 300

Resistivity [ohm-m]

*DOI = Depth of investigation

Boreholes

- Soil
- Not Clay
- Clay
- Clay and
- Rock
- Unknown

Lithological log

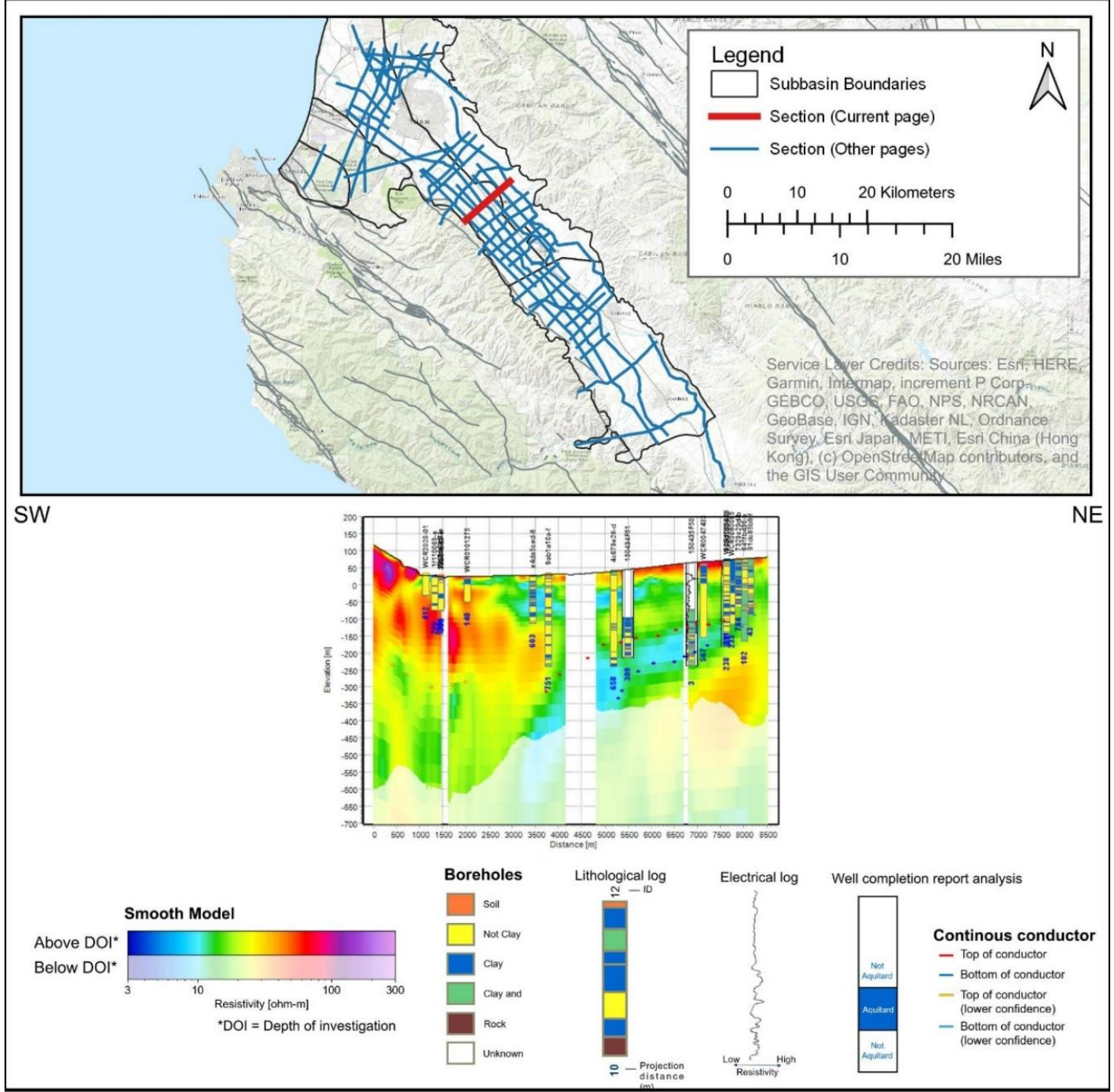
12 — ID

10 — Projection distance (m)

Electrical log

Low High

Resistivity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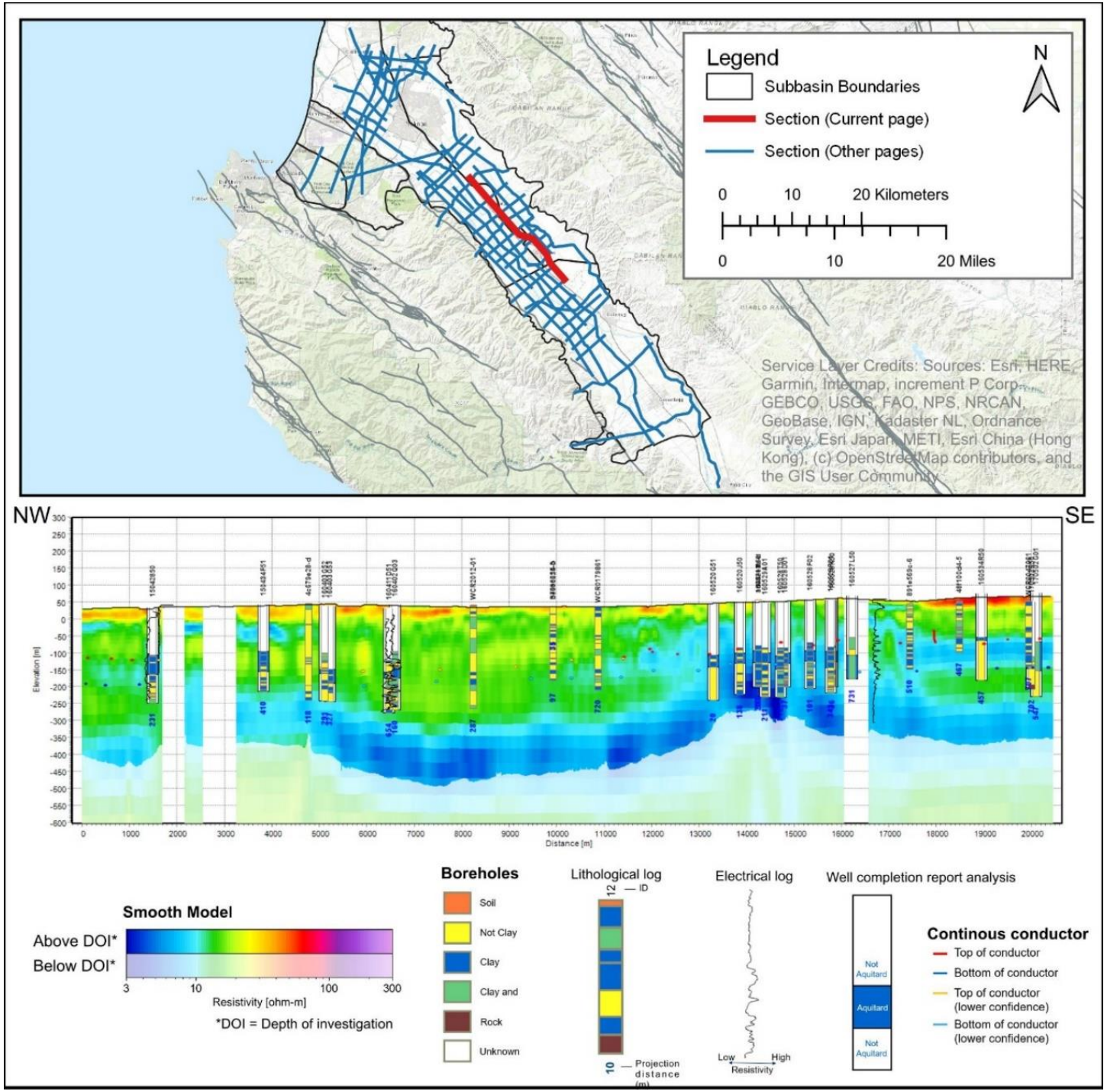
SW
NE
Elevation [m]
Distance [m]
Smooth Model
Above DOI*
Below DOI*
3 10 100 300
Resistivity [ohm-m]
*DOI = Depth of investigation
Boreholes
Soil
Not Clay
Clay
Clay and
Rock
Unknown
Lithological log
ID
Projection distance (m)
Electrical log
Low High
Resistivity
Well completion report analysis
Not Aquitard
Aquitard
Not Aquitard
Continous conductor
Top of conductor
Bottom of conductor
Top of conductor (lower confidence)
Bottom of conductor (lower confidence)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Subbasin Boundaries
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0 10 20 Miles
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community
NW
SE
Elevation [m]
Distance [m]
Smooth Model
Above DOI*
Below DOI*
3 10 100 300
Resistivity [ohm-m]
*DOI = Depth of investigation
Boreholes
Soil
Not Clay
Clay
Clay and
Rock
Unknown
Lithological log
ID
Projection distance (m)
Electrical log
Low High
Resistivity
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Not Aquitard
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Not Aquitard
Continous conductor
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Bottom of conductor
Top of conductor (lower confidence)
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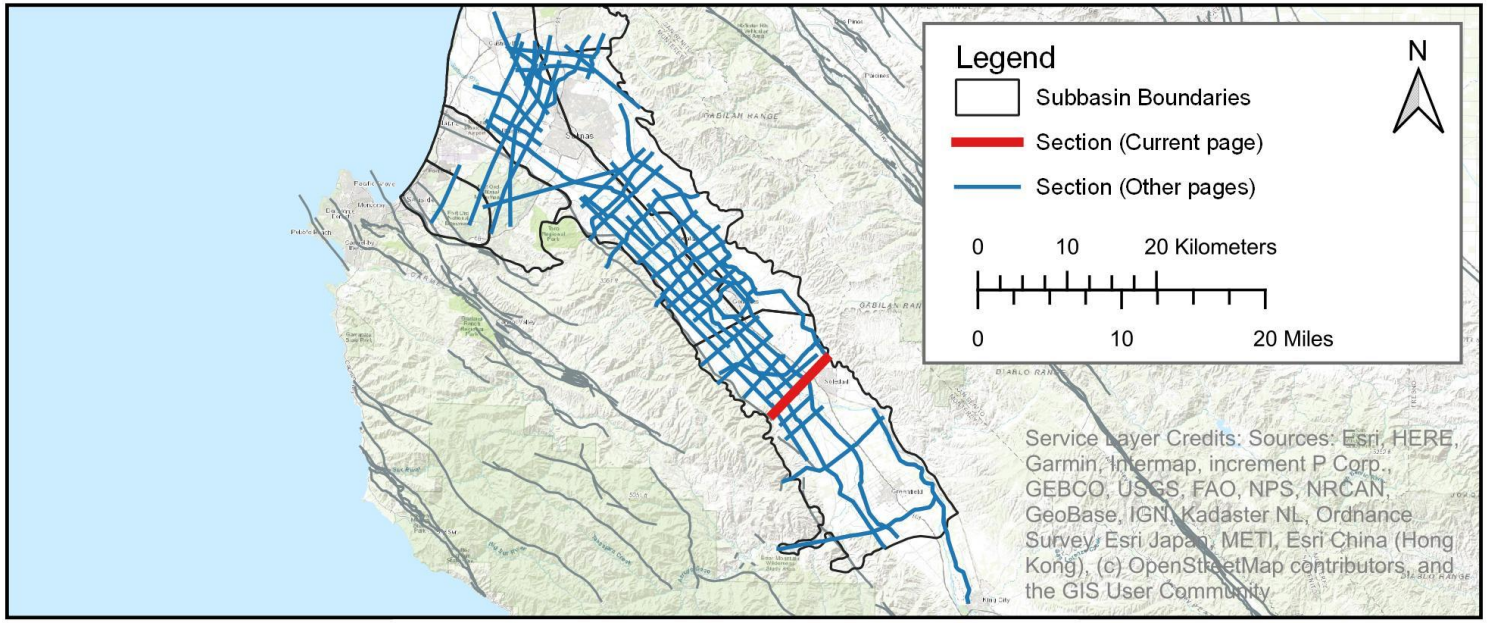
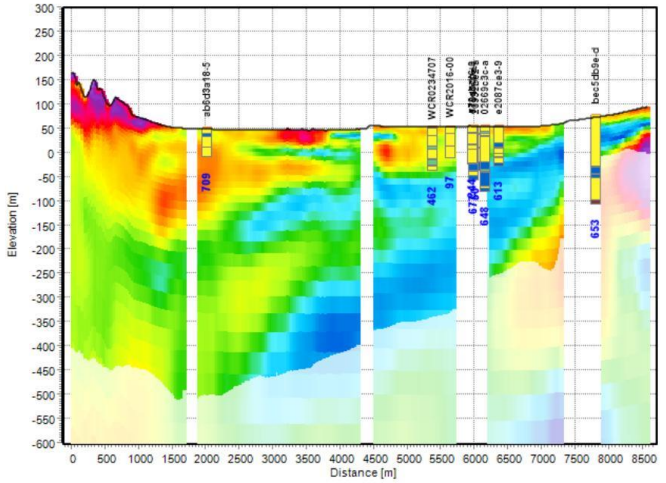


SW

NE



Smooth Model

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Below DOI*

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Resistivity [ohm-m]

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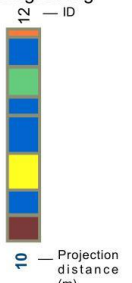
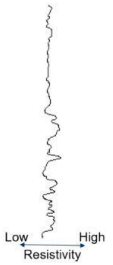
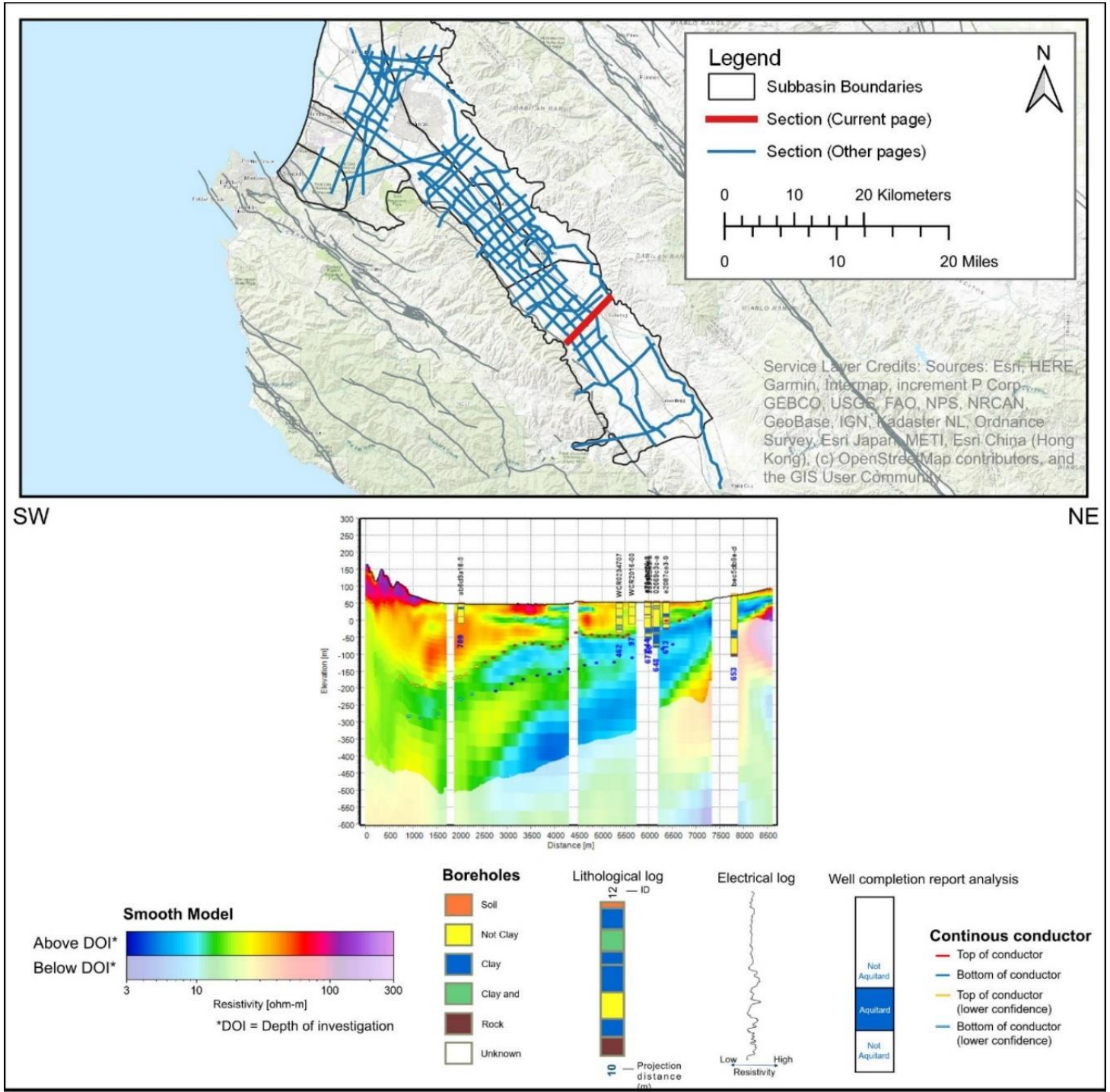
- Clay
- Clay and
- Rock
- Unknown

Lithological log



Electrical log

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NE
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Distance [m]
Smooth Model
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ID
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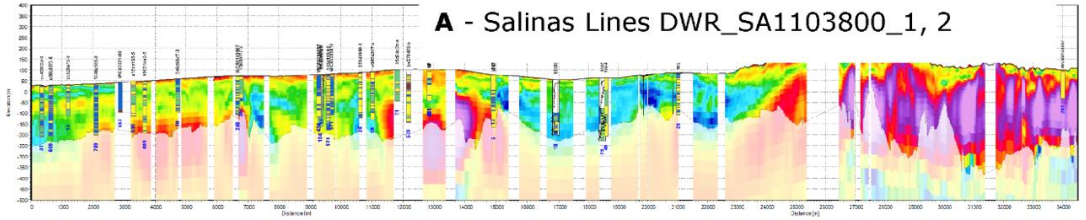
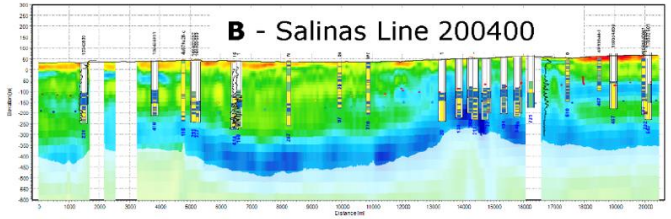
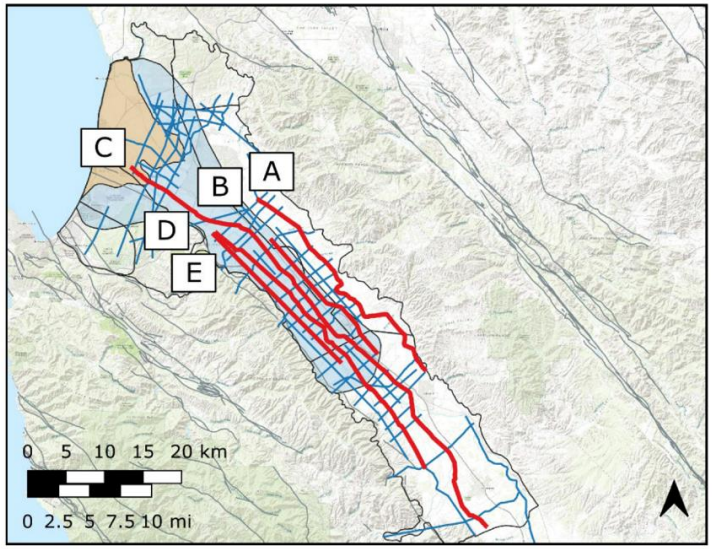
Electrical log
Low High
Resistivity
Well completion report analysis
Not Aquitard
Aquitard
Not Aquitard
Continous conductor
Top of conductor
Bottom of conductor
Top of conductor (lower confidence)
Bottom of conductor (lower confidence)

- Note coarsening from east side of basin to west
- Alluvial fan dominated on east and fluvial dominated on west

Northeast

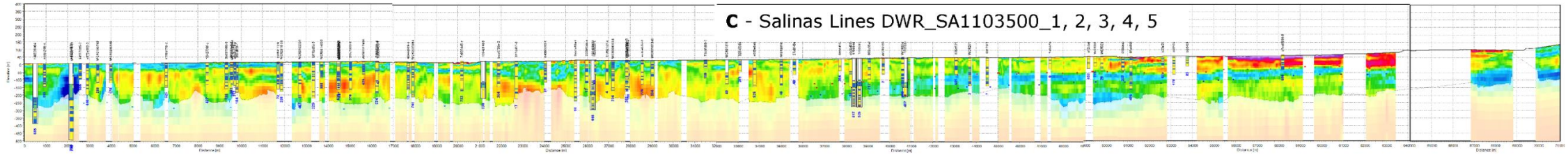


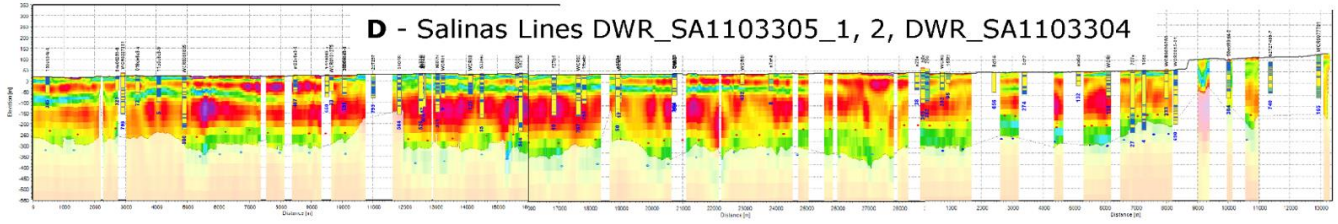


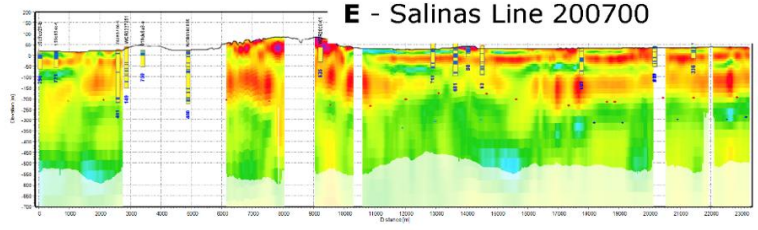


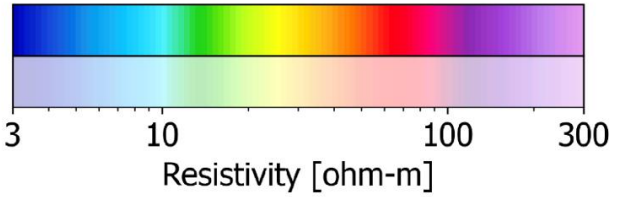
Northwest

Southeast



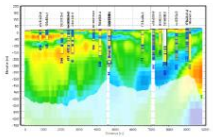




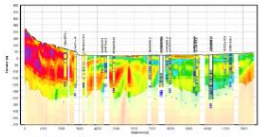


Southwest

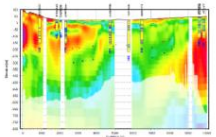
Northwest



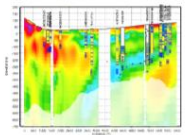
A - Salinas Line 100400



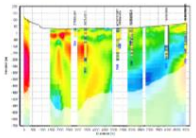
B – Salinas Line DWR_SA1102601



C - Salinas Line 100500

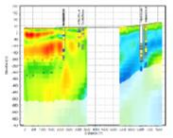


D - Salinas Line 100600



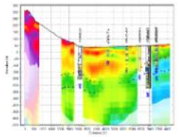
E - Salinas Line 100800

Southwest

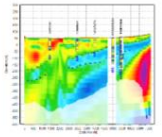


F - Salinas Line 101000

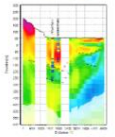
Northeast



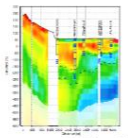
G - Salinas Line 101200



H - Salinas Line 101500

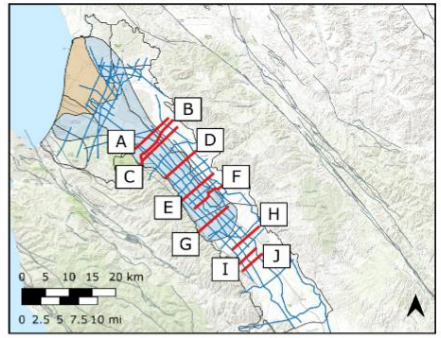


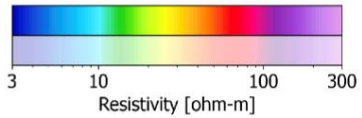
I - Salinas Line 101700



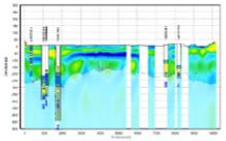
J - Salinas Line 101800

Southeast

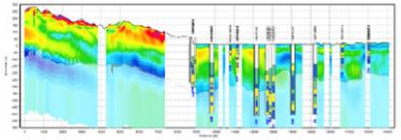




Northwest

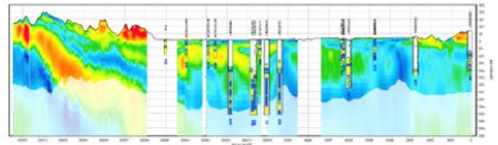


A - Salinas Line 2019_07



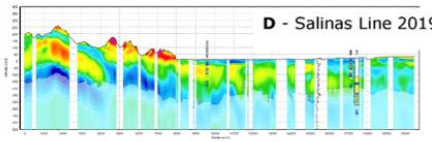
B - Salinas Line 2019_06

Southwest

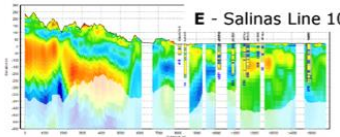


C - Salinas Line 100200

Northeast



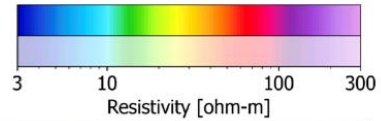
D - Salinas Line 2019_05

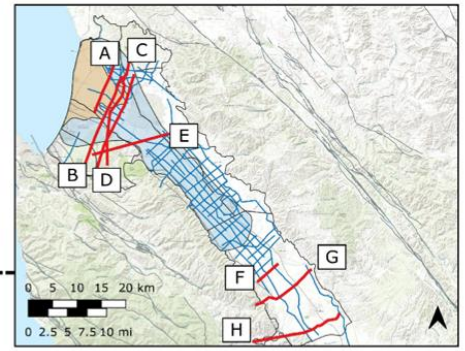


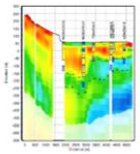
E - Salinas Line 100300

Northernmost profiles

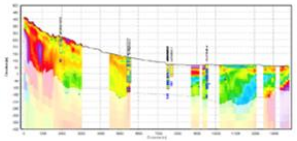
Southernmost profiles



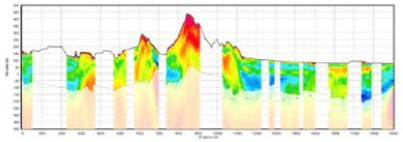




F - Salinas Line 101800



G - Salinas Line DWR_SA1104301

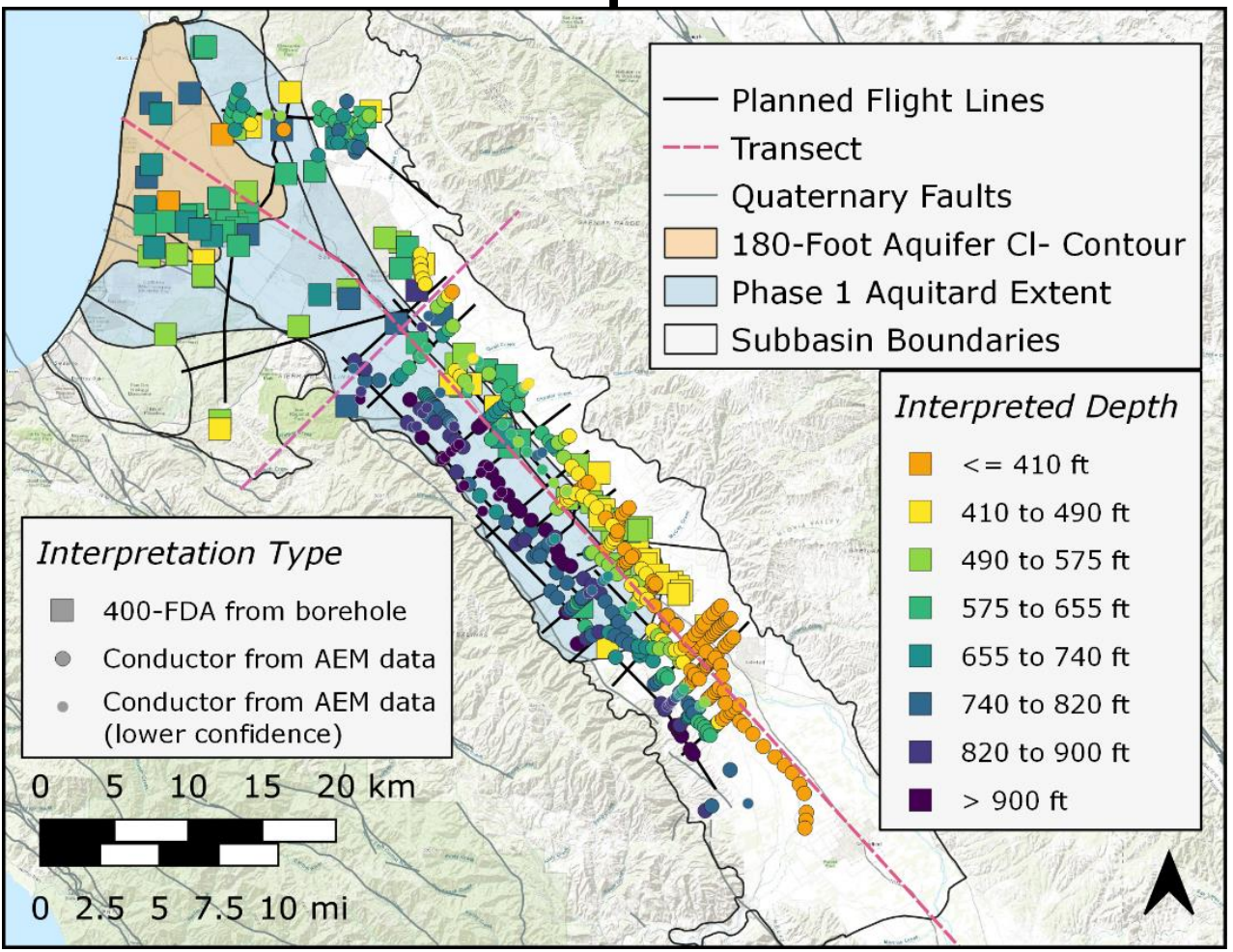


H - Salinas Line DWR_SA1104101

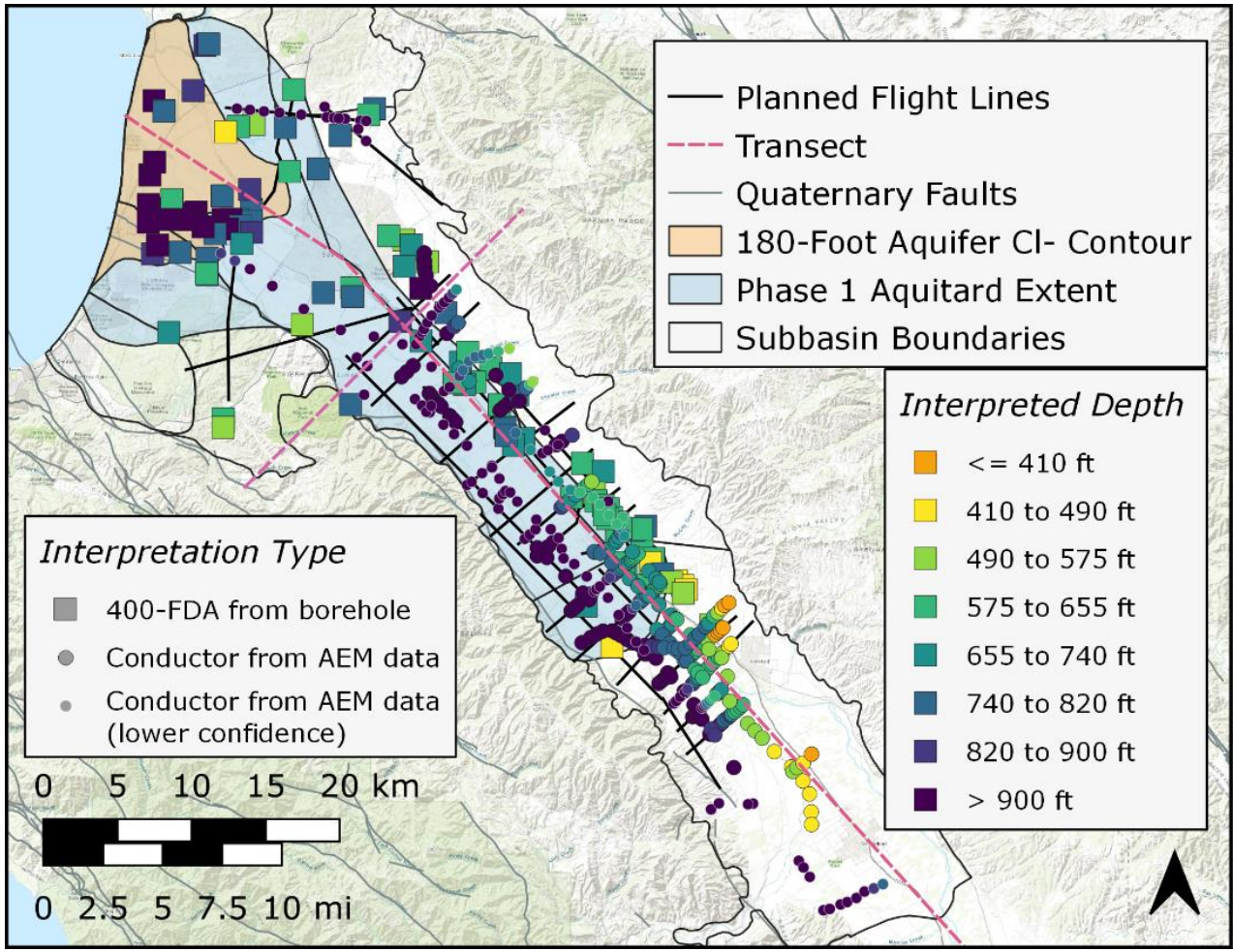
Southeast

Depth to 400-Foot Deep Aquitard (FDA)

Top



Bottom



Conclusions Salinas Valley Deep AEM Survey

SkyTEM 312HPM AEM System successful application

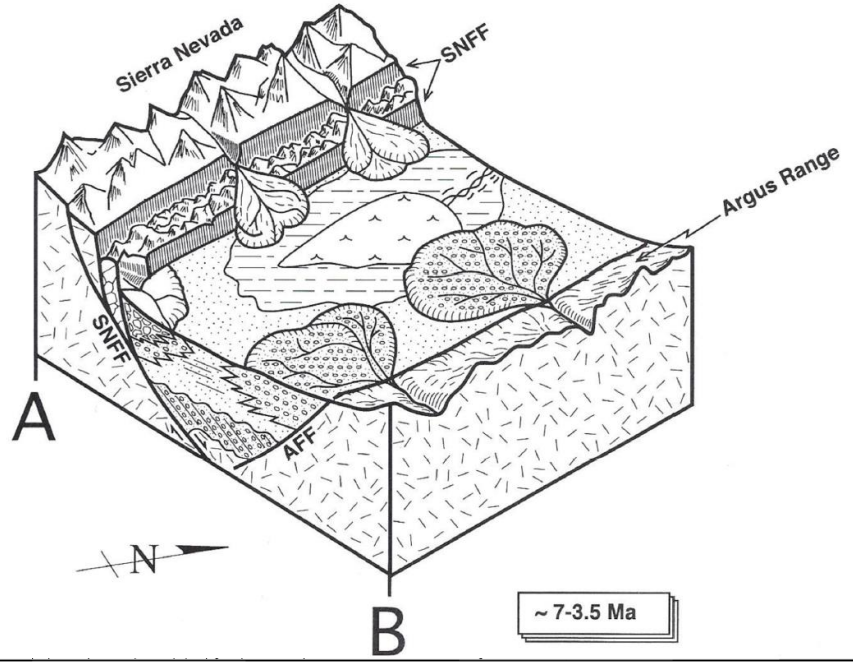
- More powerful system
- Modified setup of the SkyTEM 312HPM system, high data quality was maintained until later times helped
- Deeper penetration than previous surveys
- Depths of 1,000 ft to 2,000 ft (300 m to 600 m)
- Ability to meet project objectives thru deeper high resolution imaging

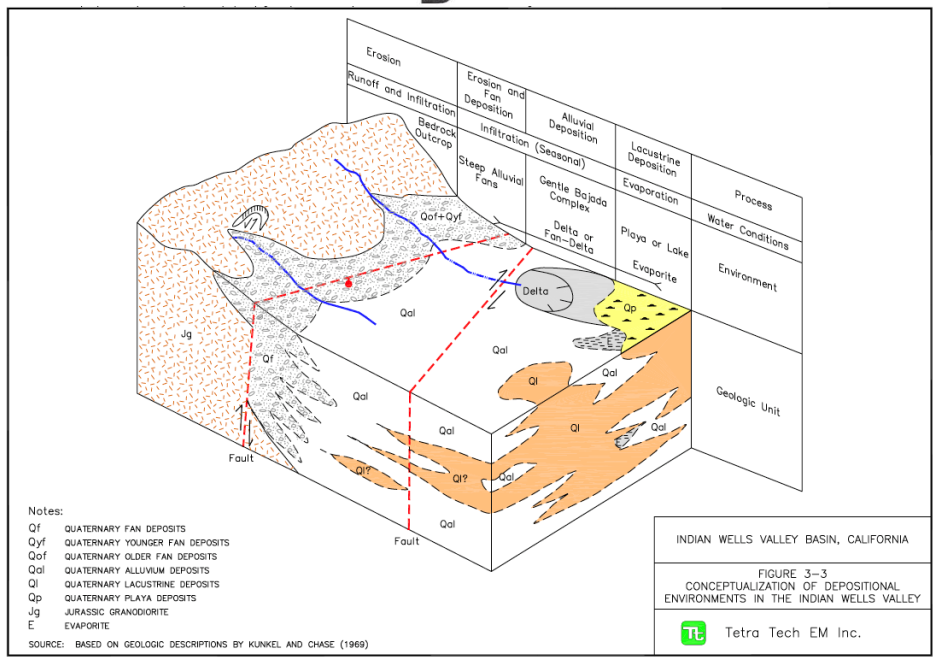
Overview – Indian Wells Valley Deep Studies

- 600 mi^2 COD basin northeast corner Sierra Nevada, northwest corner Mojave desert
- Extensively studied including by US Navy Geothermal Program, USGS, BUR, locals
  - Indian Wells Valley Water District, Meadowbrook Dairies, Mojave Pistachios, Searles Valley Minerals, Coso Geothermal, US Navy interested in developing brackish groundwater resource

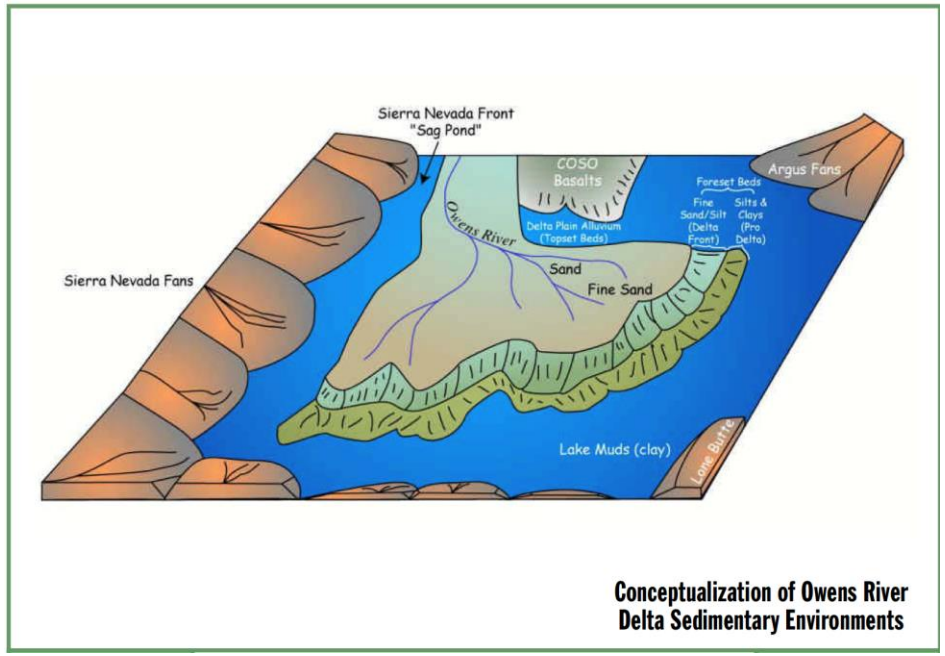
- AEM selected to map brackish groundwater resources
- Extended survey to cover entire basin to assist with GSP development
- Developed comprehensive WCR database and 3D HCM in Geoscene3D

Monastero et al., 2001

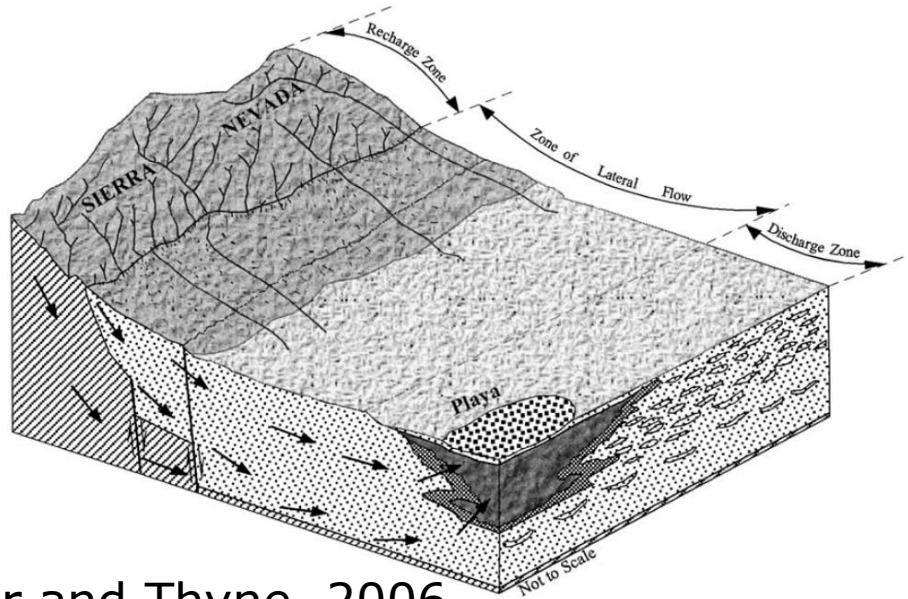




US EPA, 2004

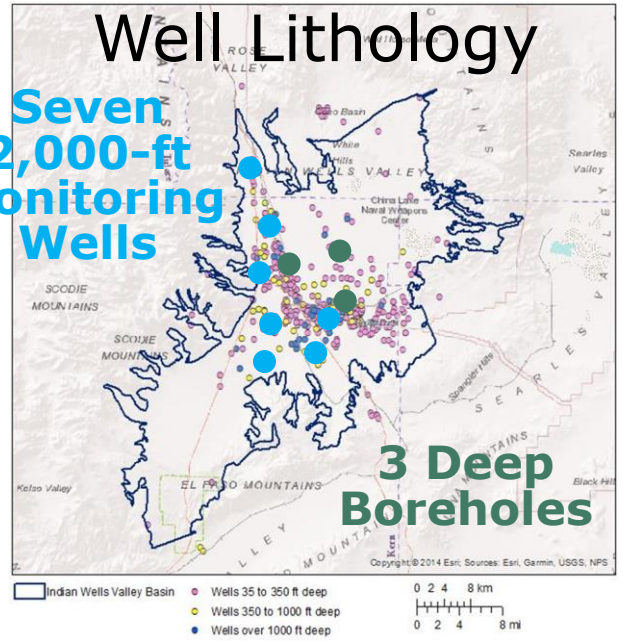


Guler and Thyne, 2006

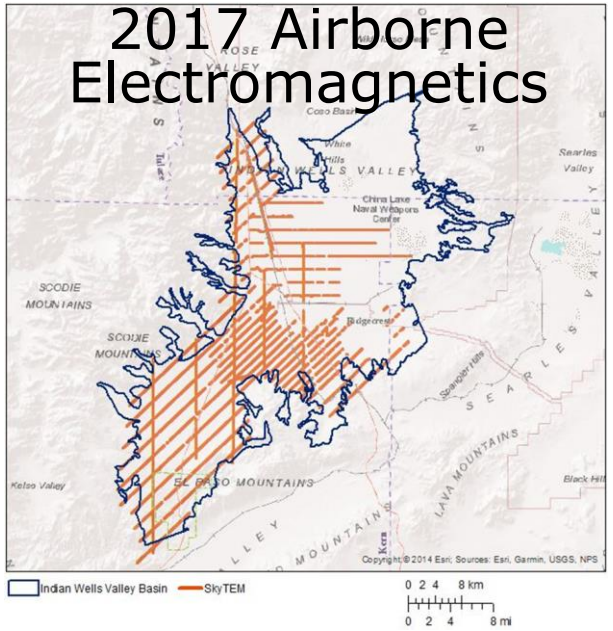


IWV Datasets Used - Groundwater in Storage Estimate

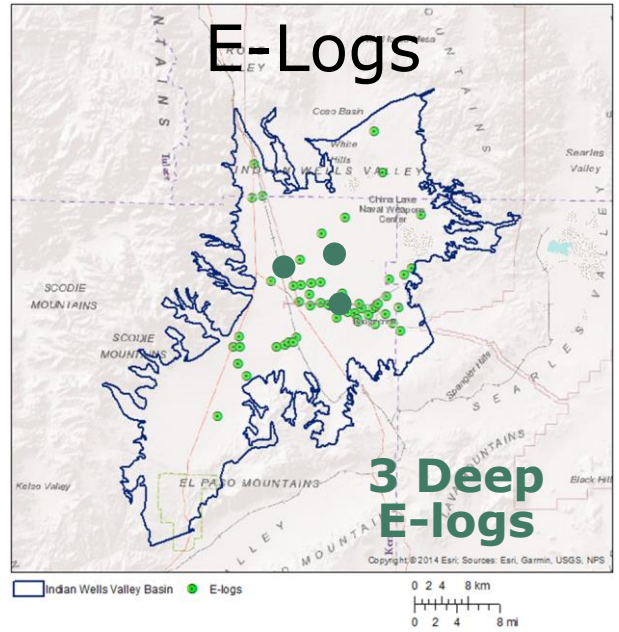
Well Lithology



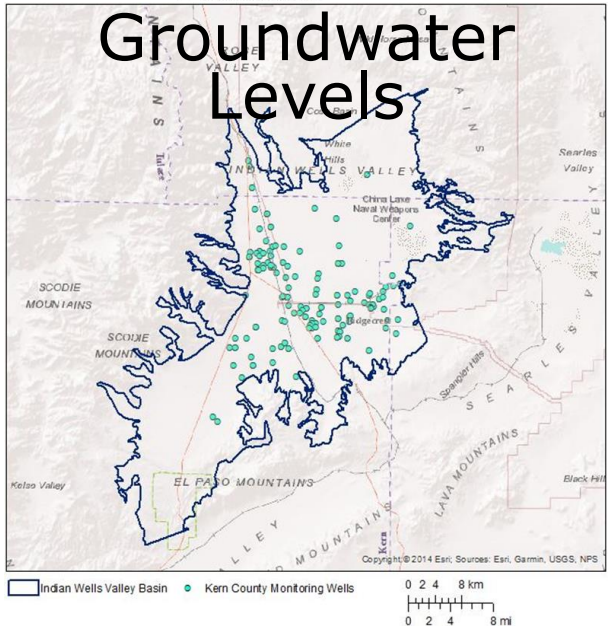
2017 Airborne Electromagnetics



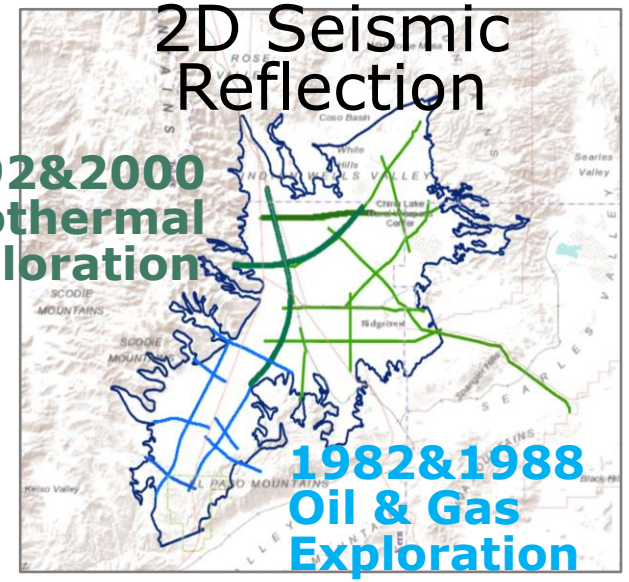
E-Logs



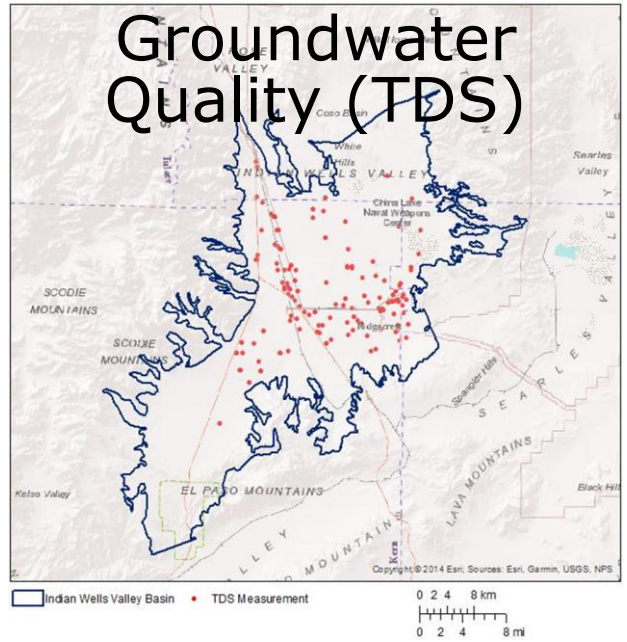
Groundwater Levels

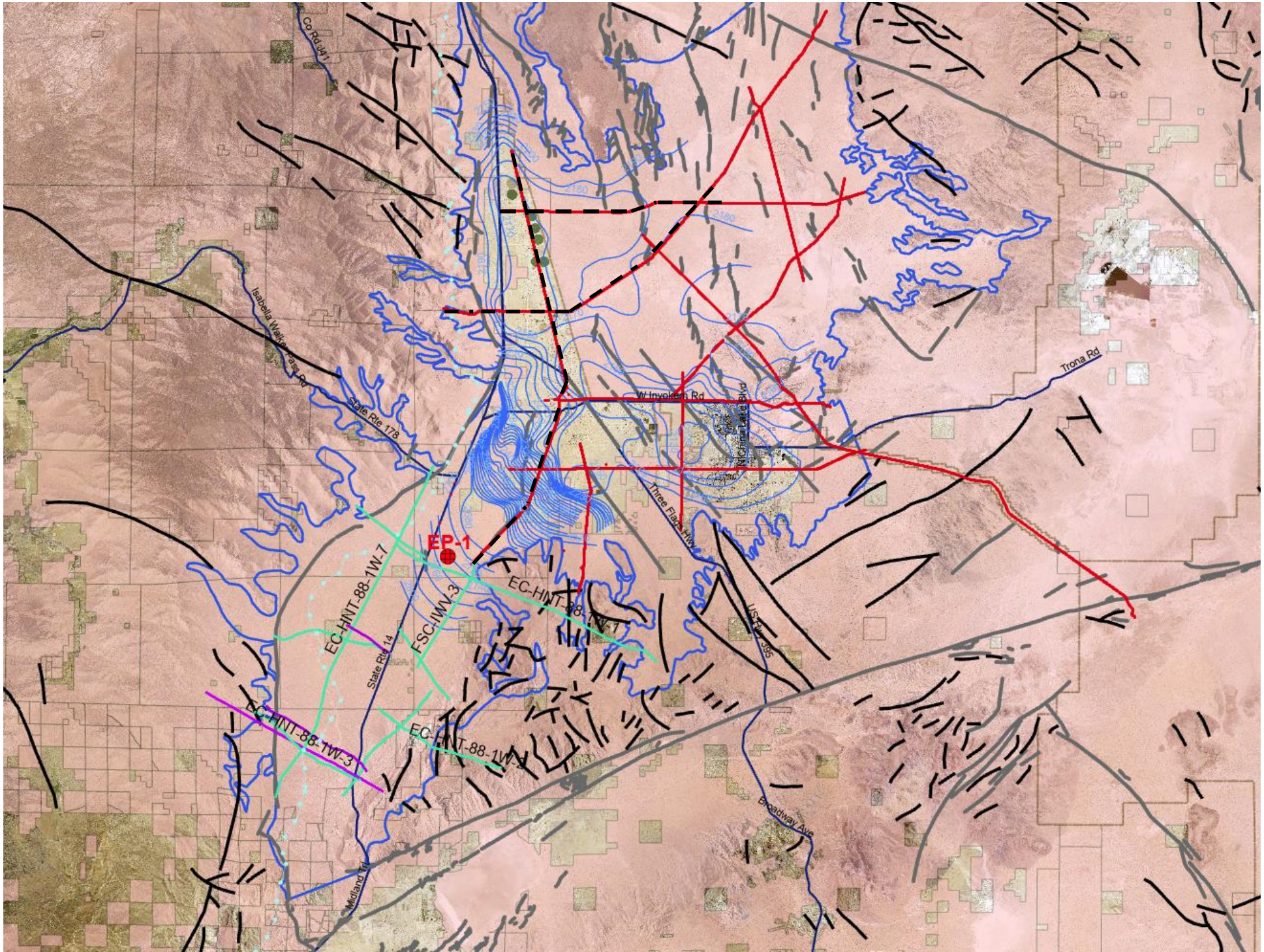


2D Seismic Reflection

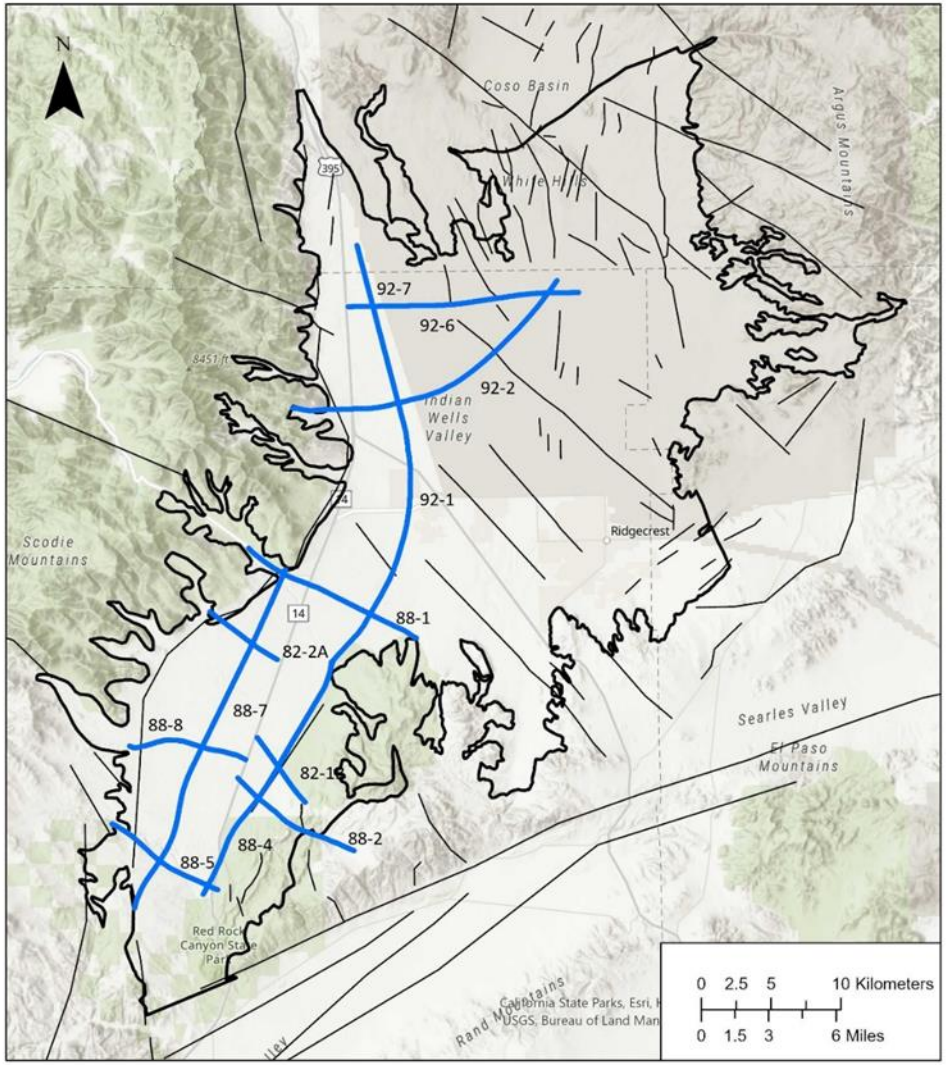


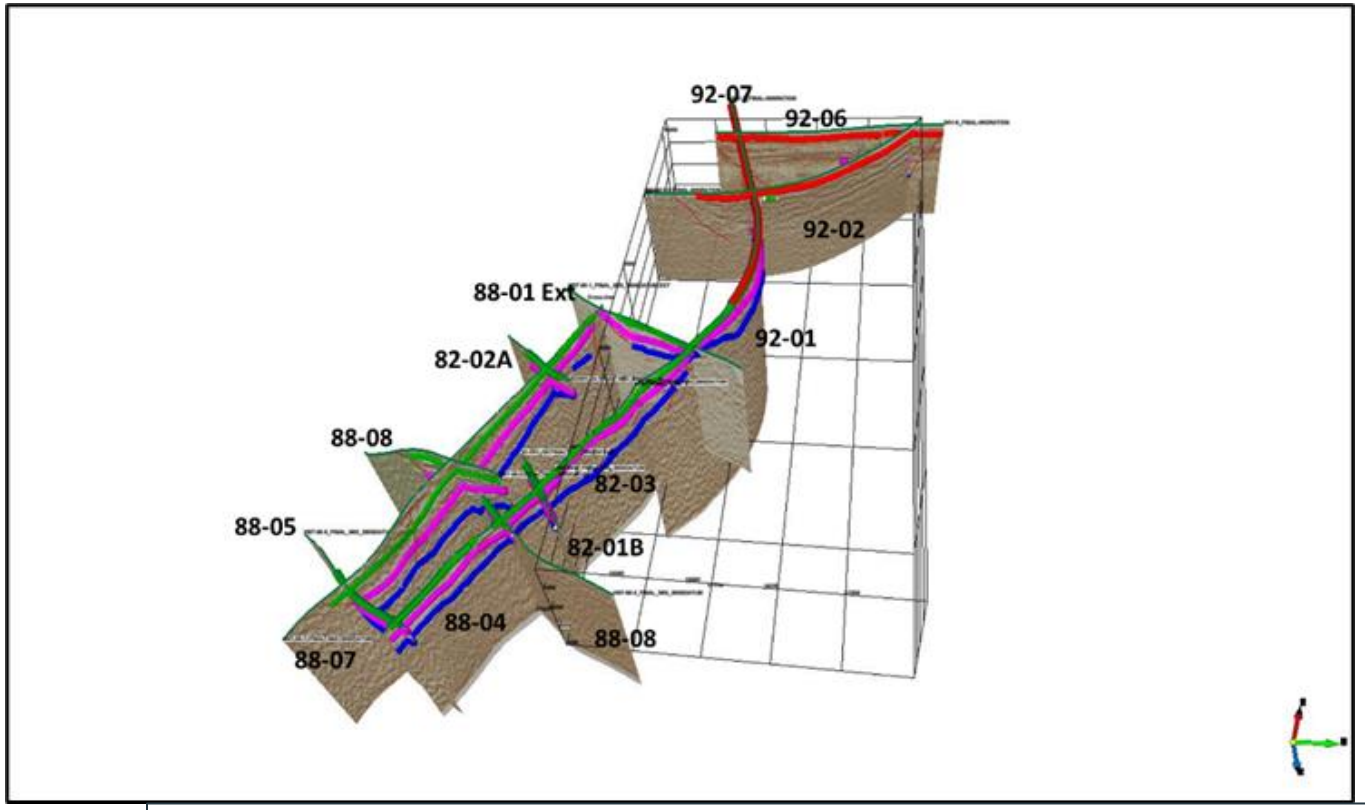
Groundwater Quality (TDS)




Co Rd 141
Isabella Walker Pass Rd
State Rte 178
W Inyokern Rd
Trona Rd
Three Flags Hwy
EP-1
EC-HNT-88-1W-7
FSC-IW-3
EC-HNT-88-1W-1
State Rte 14
US Hwy 395
EC-HNT-88-1W-3
EC-HNT-88-1W-2
Broadway Ave

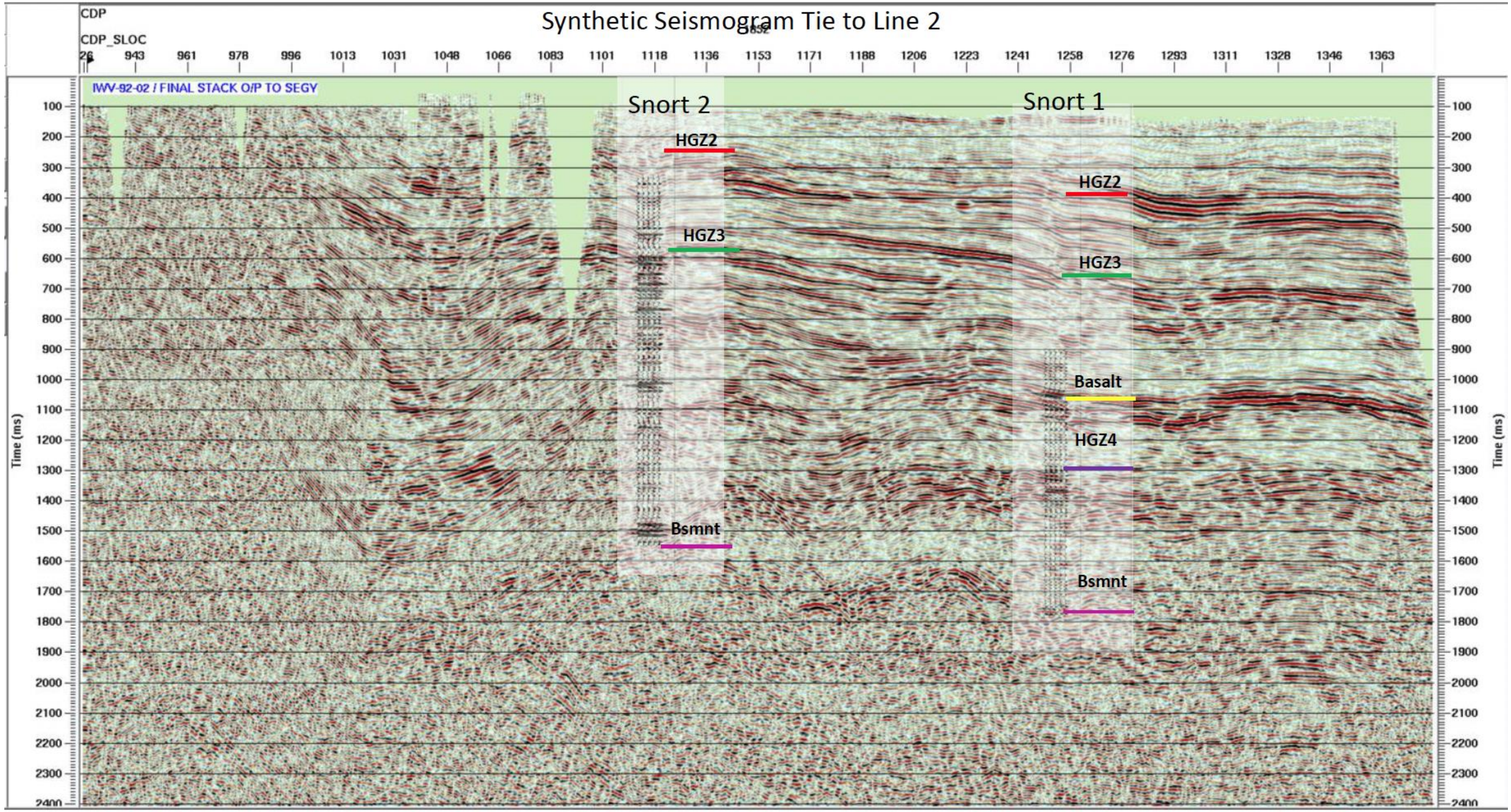
Basin Scale Mapping: Indian Wells Valley, CA
Acquired 104 Miles of 1980s & 1990s Vintage Seismic Data



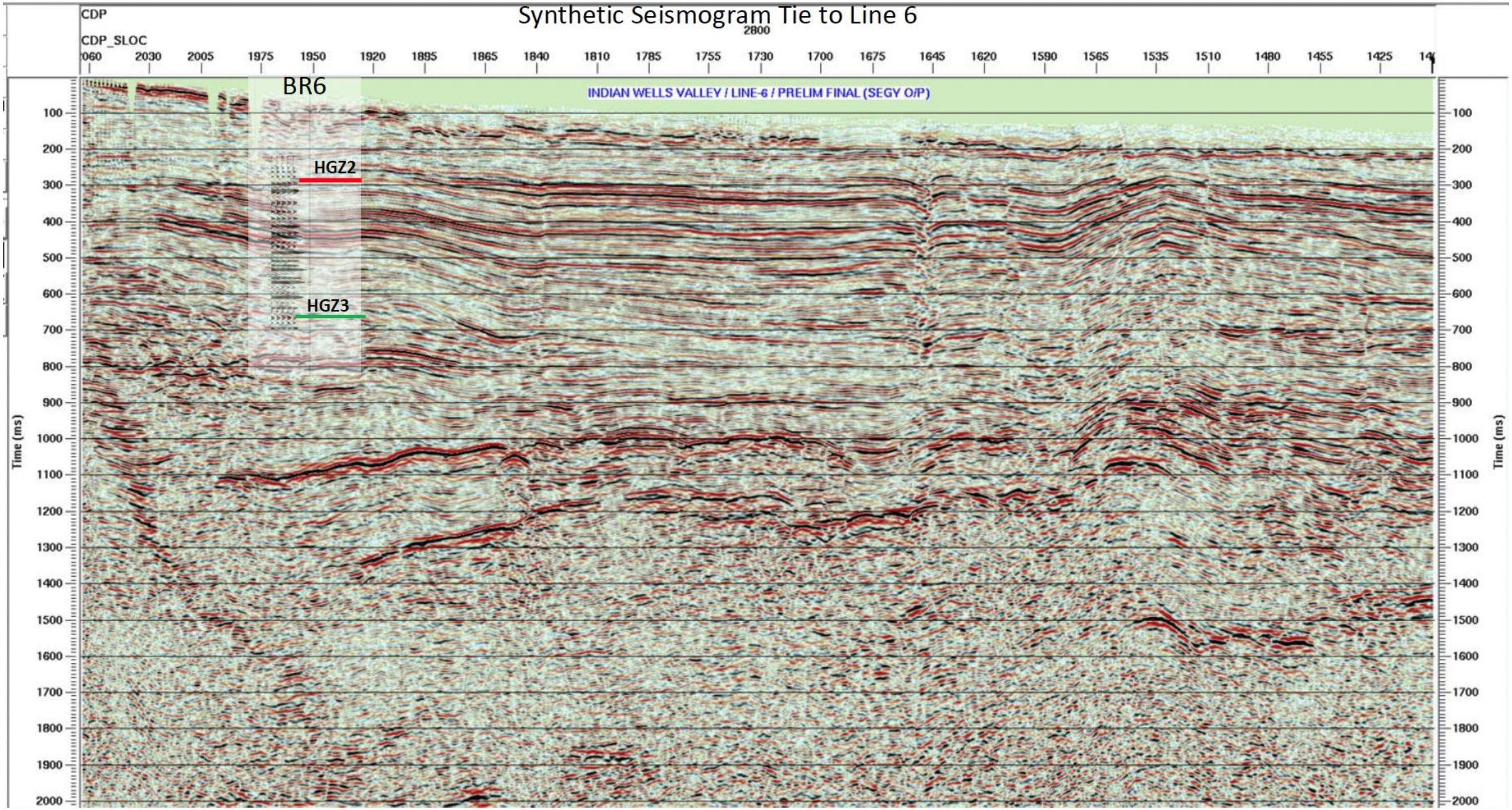


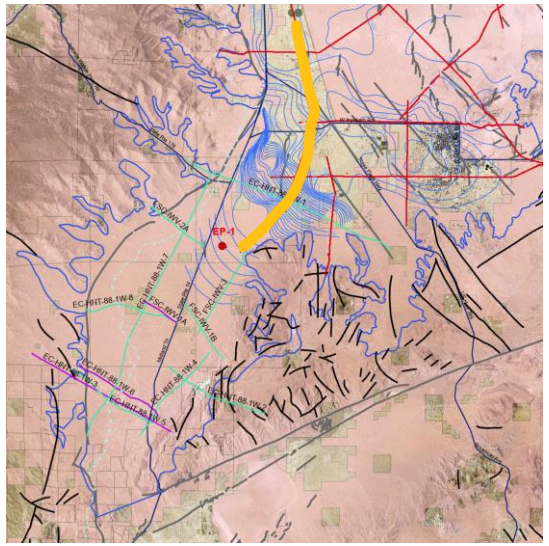
- Data reprocessed
- Imported into OpendTect 3D interpretation software
- Mapped major geologic units
- Mapped structure and faults
- Mapped net sand and clay units

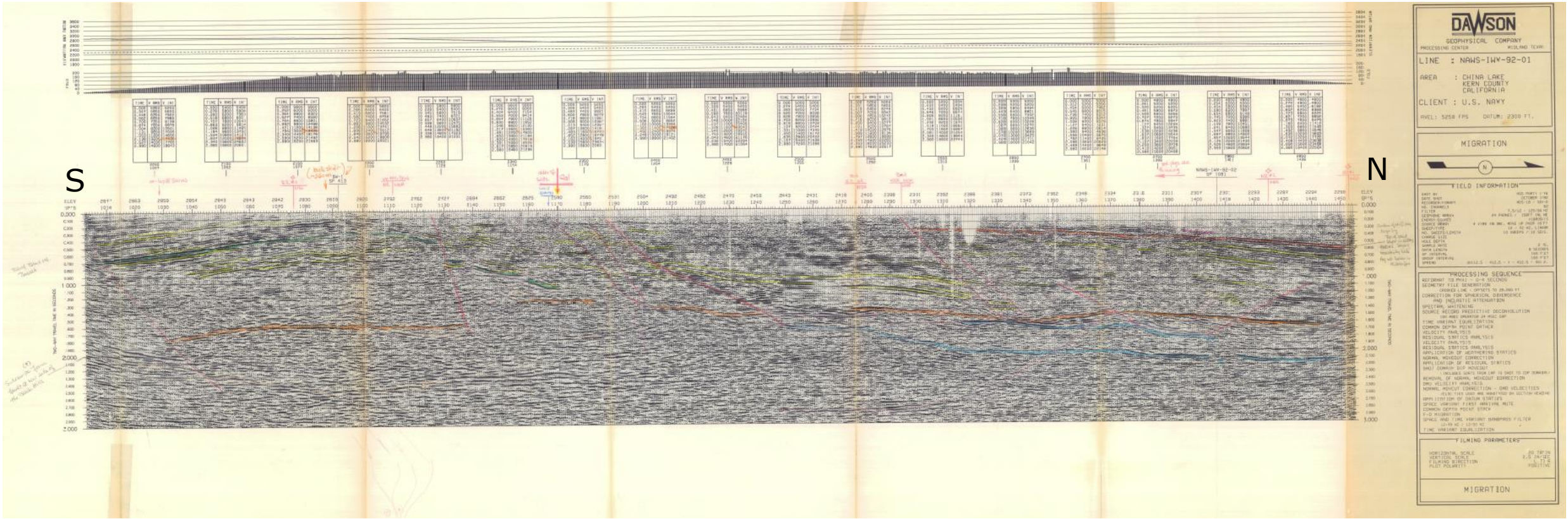
Synthetic Seismogram Tie to Line 2

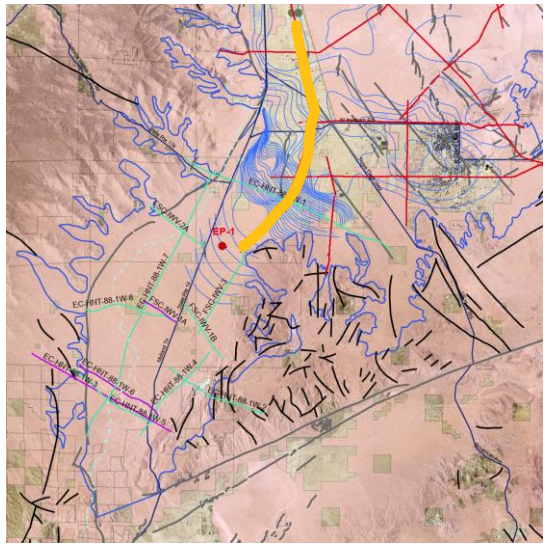


Synthetic Seismogram Tie to Line 6




EP-1
EC-INT-88-1W-2A
EC-INT-88-1W-7
EC-INT-88-1W-8
EC-INT-88-1W-1
EC-INT-88-1W-3
EC-INT-88-1W-4
EC-INT-88-1W-5
EC-INT-88-1W-6

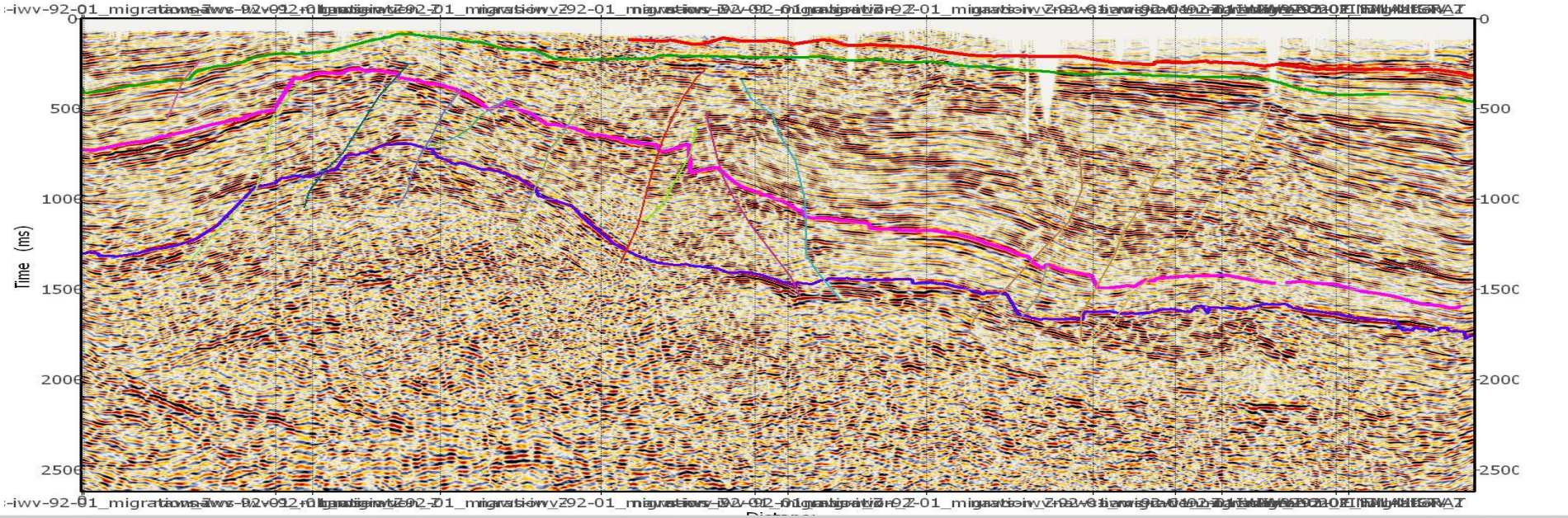

S
N
DAWSON
GEOPHYSICAL COMPANY
LINE : NAWS-IWY-92-01
AREA : CHINA LAKE
KERN COUNTY
CALIFORNIA
CLIENT : U.S. NAVY
MIGRATION
FIELD INFORMATION
PROCESSING SEQUENCE
FILMING PARAMETERS
MIGRATION

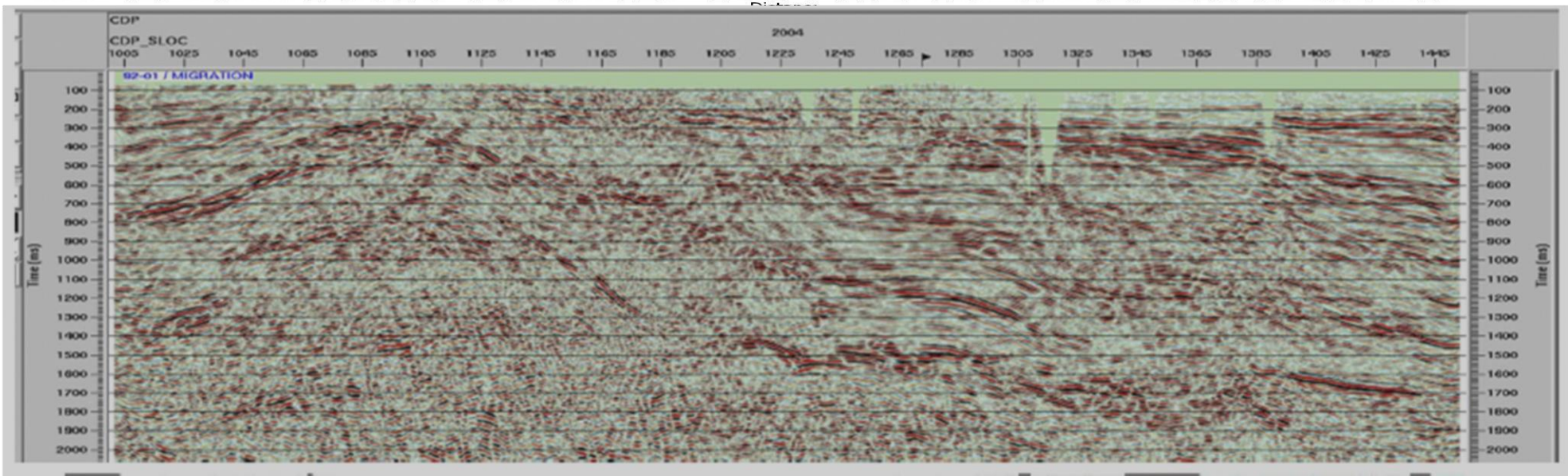


Line IWV-92-01

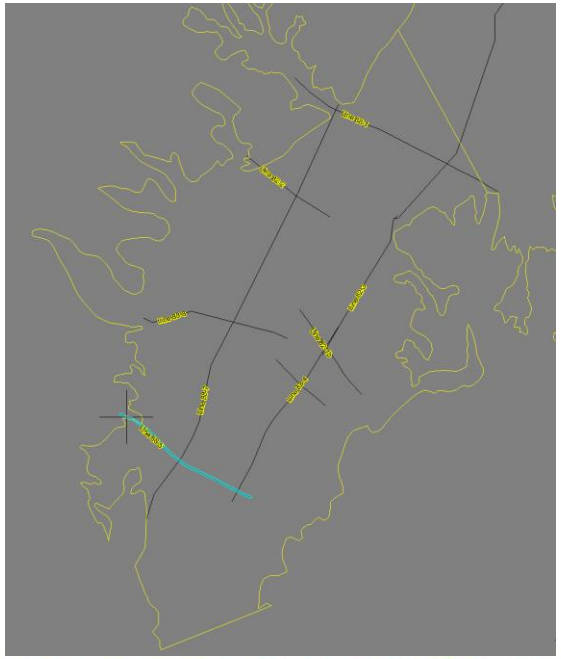
S

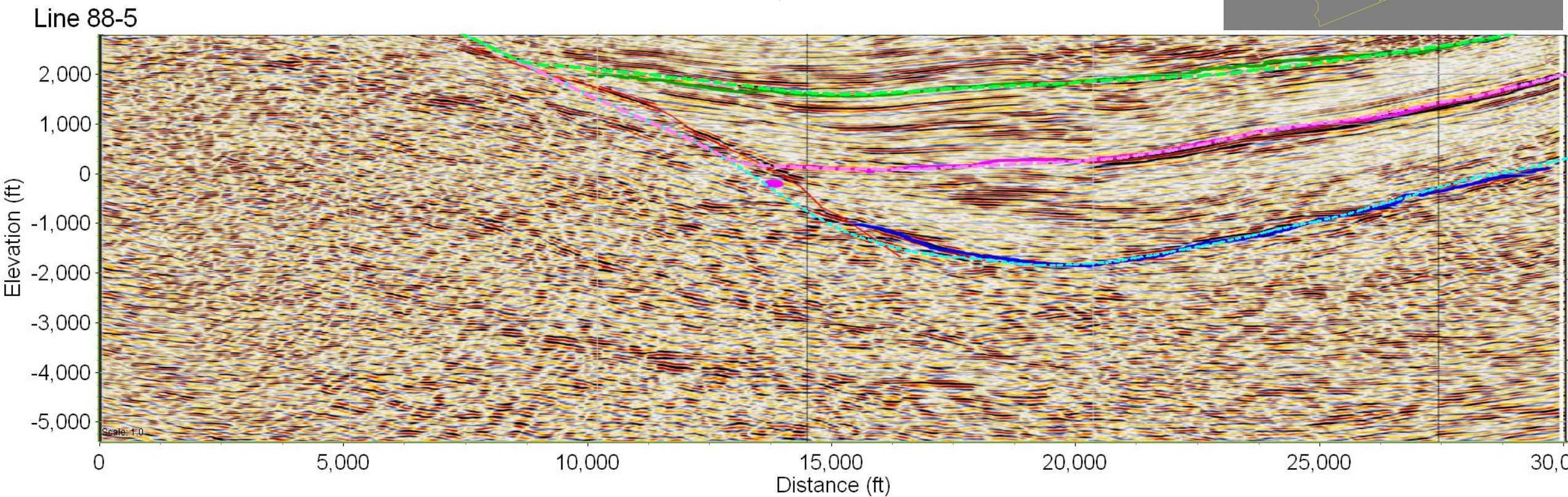
N



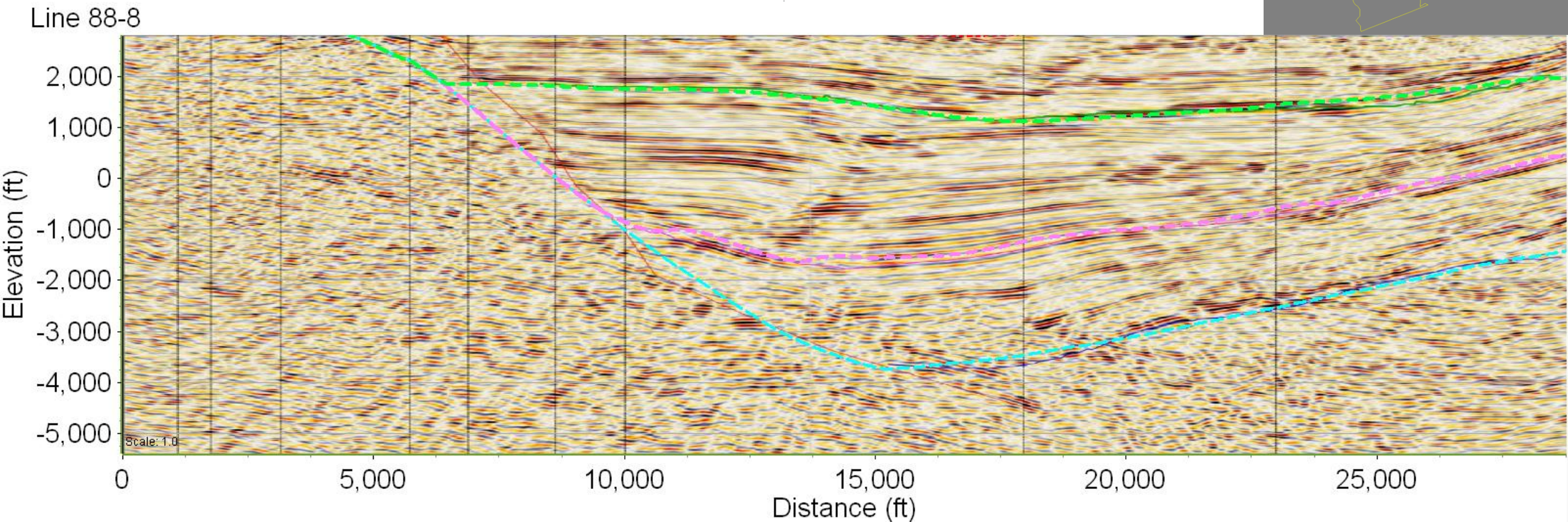


Line 88-5




Line 88-5
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
-5,000
Elevation (ft)
Scale: 1.0
0
5,000
10,000
15,000
20,000
25,000
Distance (ft)

Line 88-8


Line 88-8
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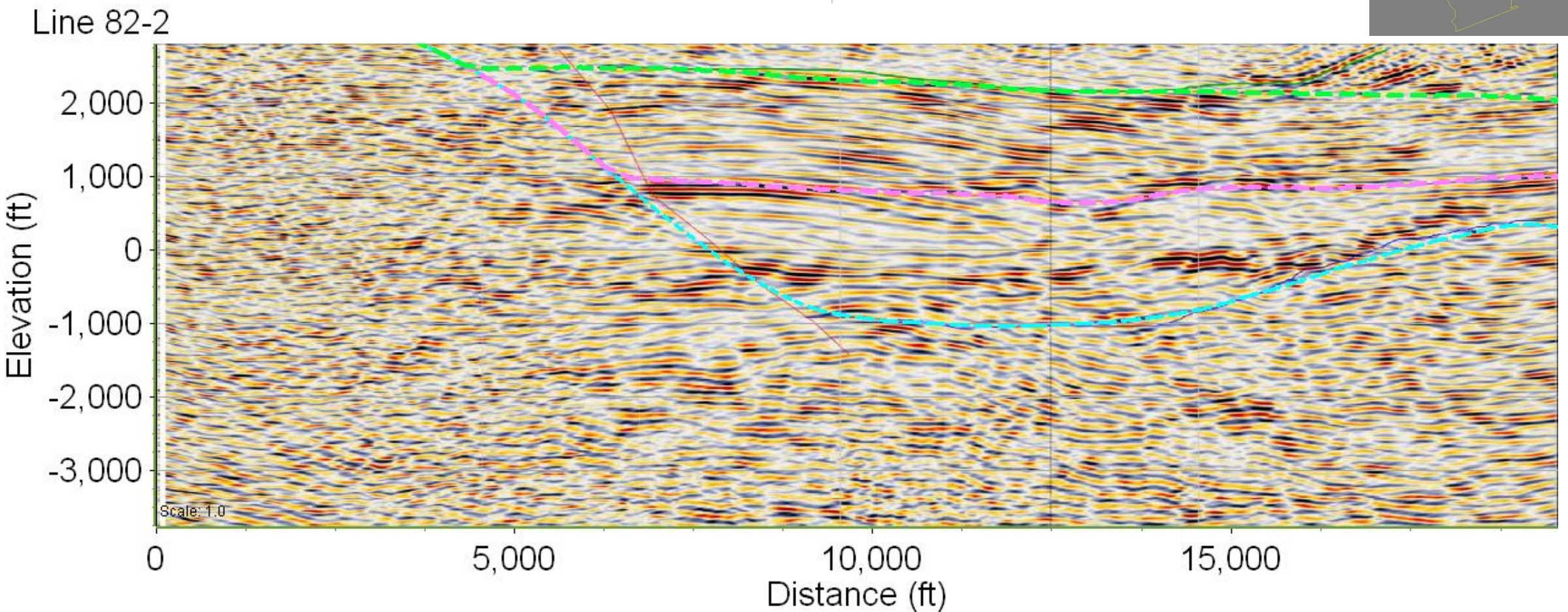
1,000
0
-1,000
-2,000
-3,000
-4,000
-5,000
Elevation (ft)
Scale: 1.0
0
5,000
10,000
15,000
20,000
25,000
Distance (ft)

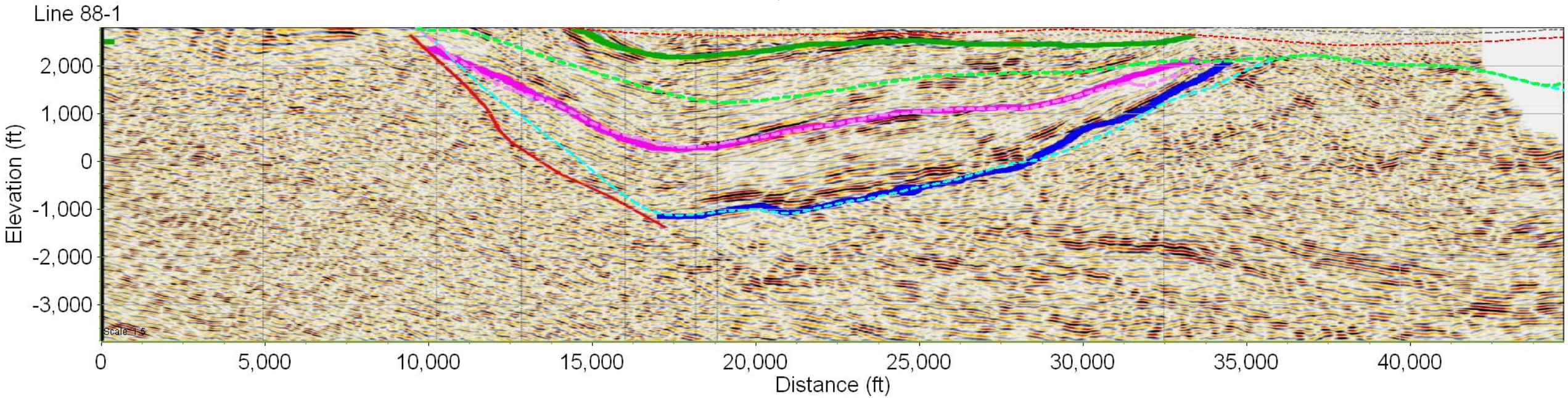
Line 82-2


Line 88-1
Line 82-2
Line 88-8
Line 82-3
Line 88-4
Line 88-7
Line 88-5


Line 82-2
2,000
1,000
0
-1,000
-2,000
-3,000
Elevation (ft)
Scale: 1.0
0
5,000
10,000
15,000
Distance (ft)

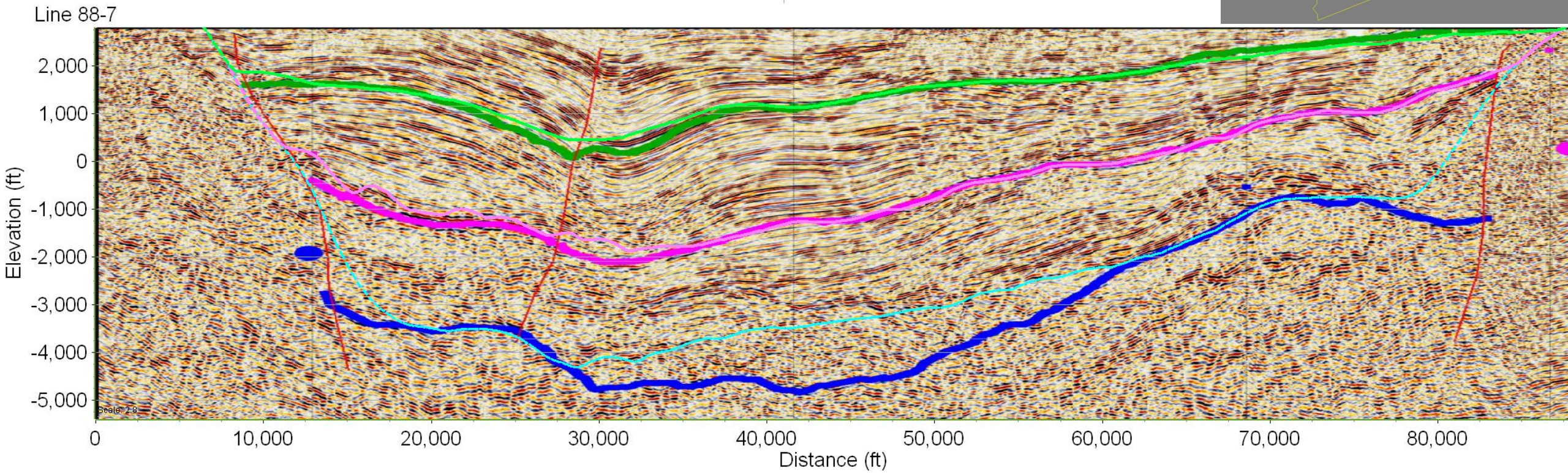
Line 88-1


Line 88-1
Line 82-2
Line 88-8
Line 82-3
Line 88-4
Line 88-7
Line 88-5


Line 88-1
2,000
1,000
0
-1,000
-2,000
-3,000
Elevation (ft)
Scale 1:5
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Distance (ft)

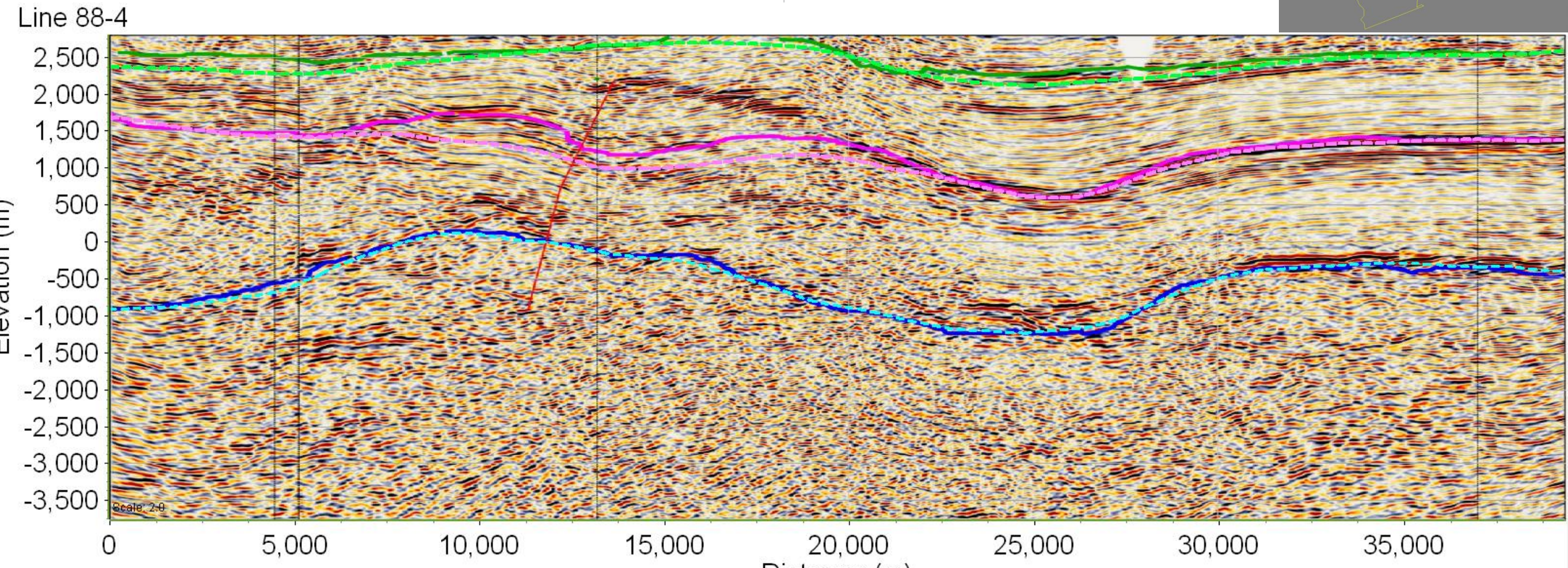
Line 88-7


Line 88-1
Line 82-2
Line 82-3
Line 88-8
Line 88-4
Line 88-7
Line 88-5


Line 88-7
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
-5,000
Elevation (ft)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Distance (ft)

Line 88-4


Line 88-1
Lyric 92-2
Line 88-8
Line 92-3
Line 88-4
Line 88-7
Line 88-5


Line 88-4
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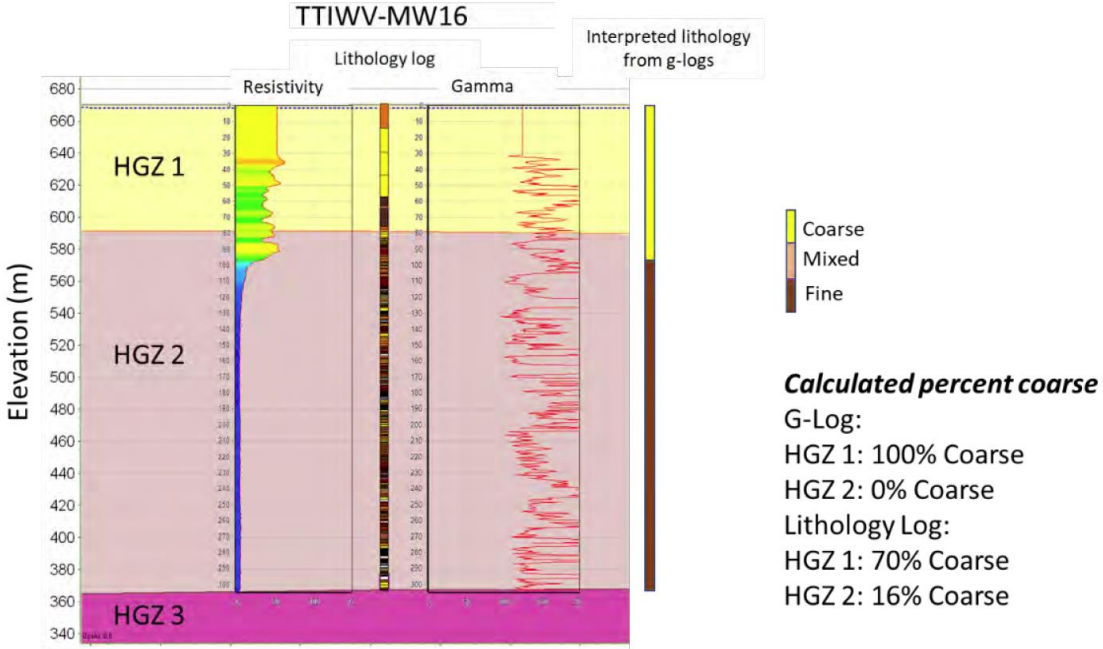
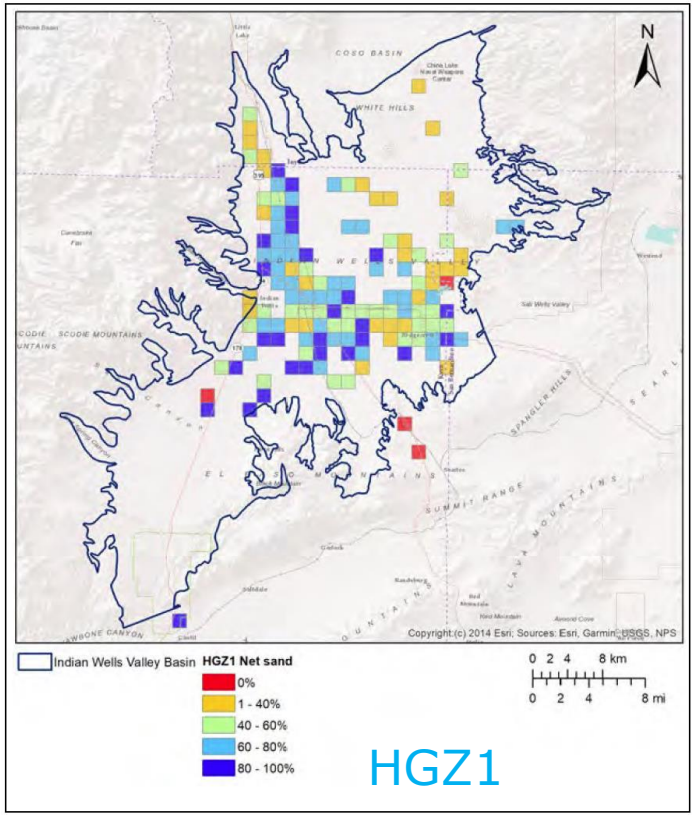
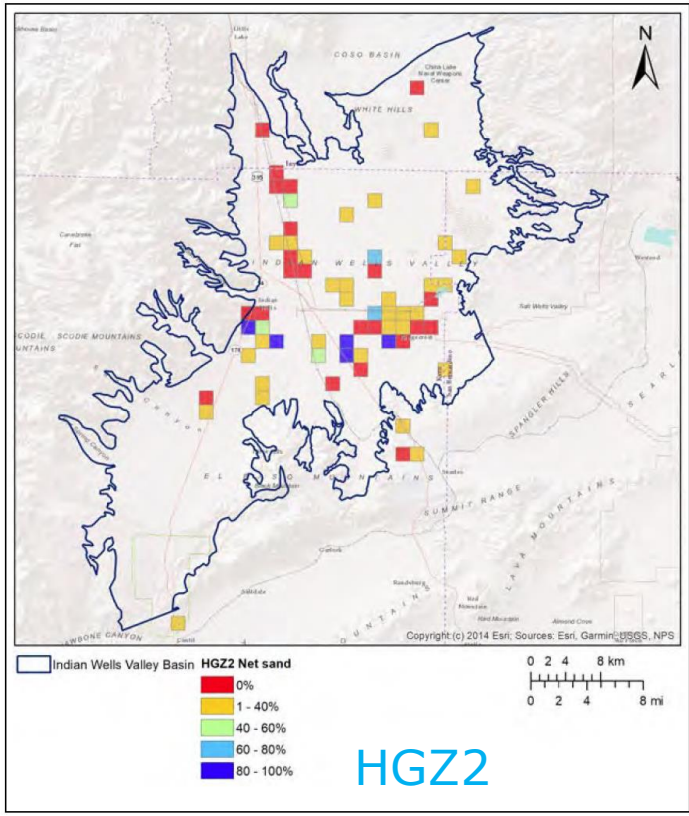
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
-2,500
-3,000
-3,500
Scale: 2:0
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000

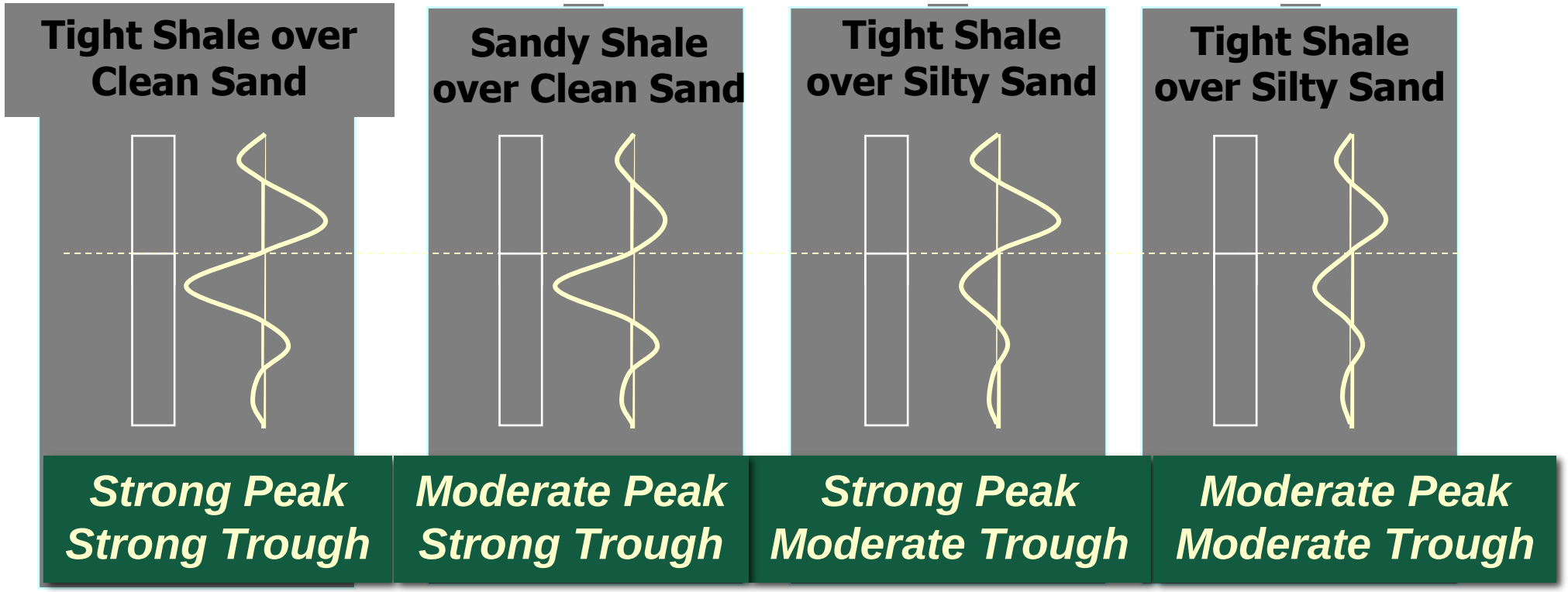
Groundwater in Storage Estimate
HGZ1 & 2 Sand, Mixed and Clay







Attribute Processing:
Mapping Rock Properties from Seismic Data

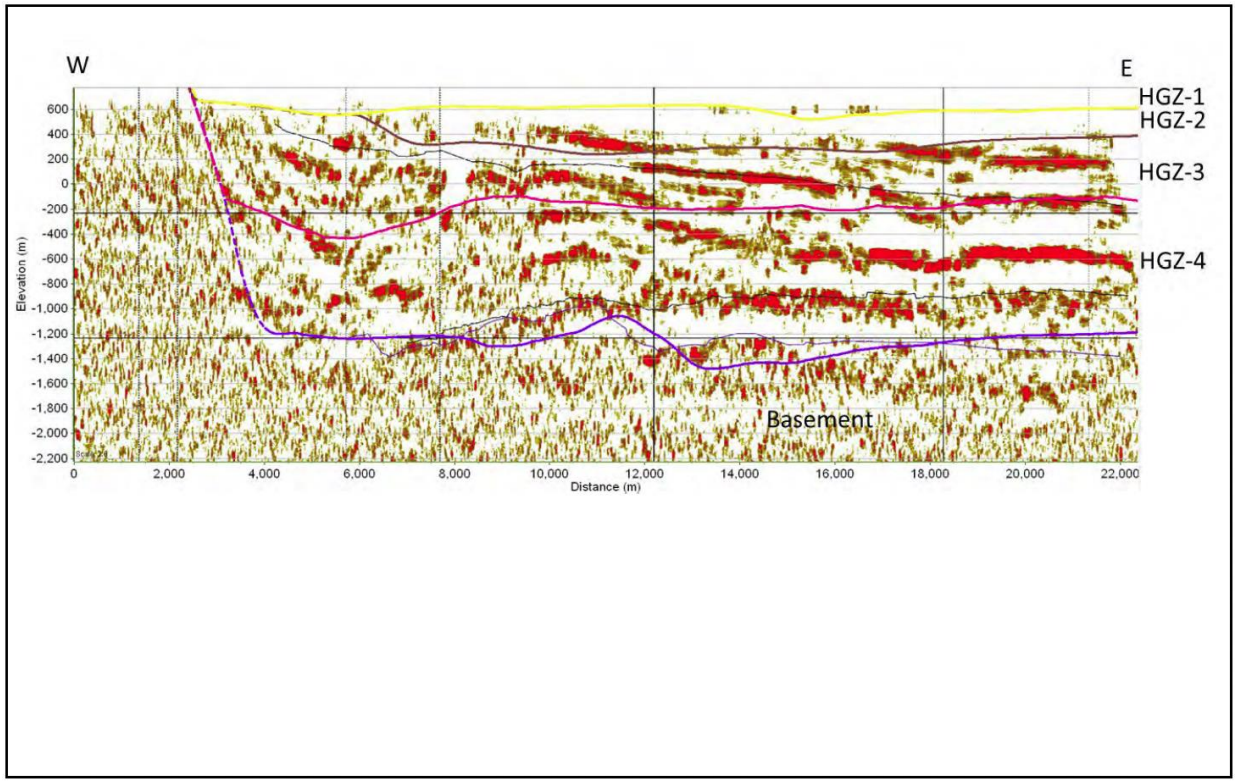


http://archives.aapg.org/slide_resources/schroeder/13/index.cfm

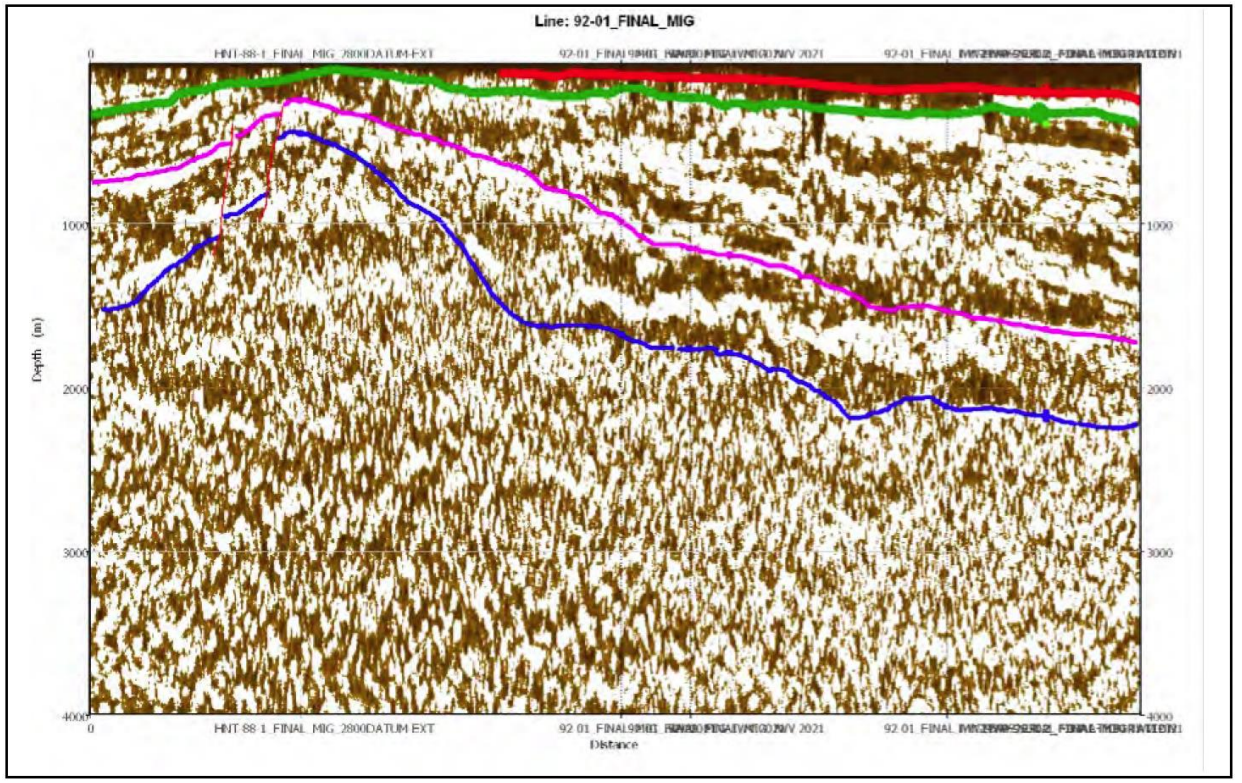
Seismic Wavelet Changes With Rock Properties

Groundwater in Storage Estimate
Net HGZ3 & 4 Sand and Net Clay

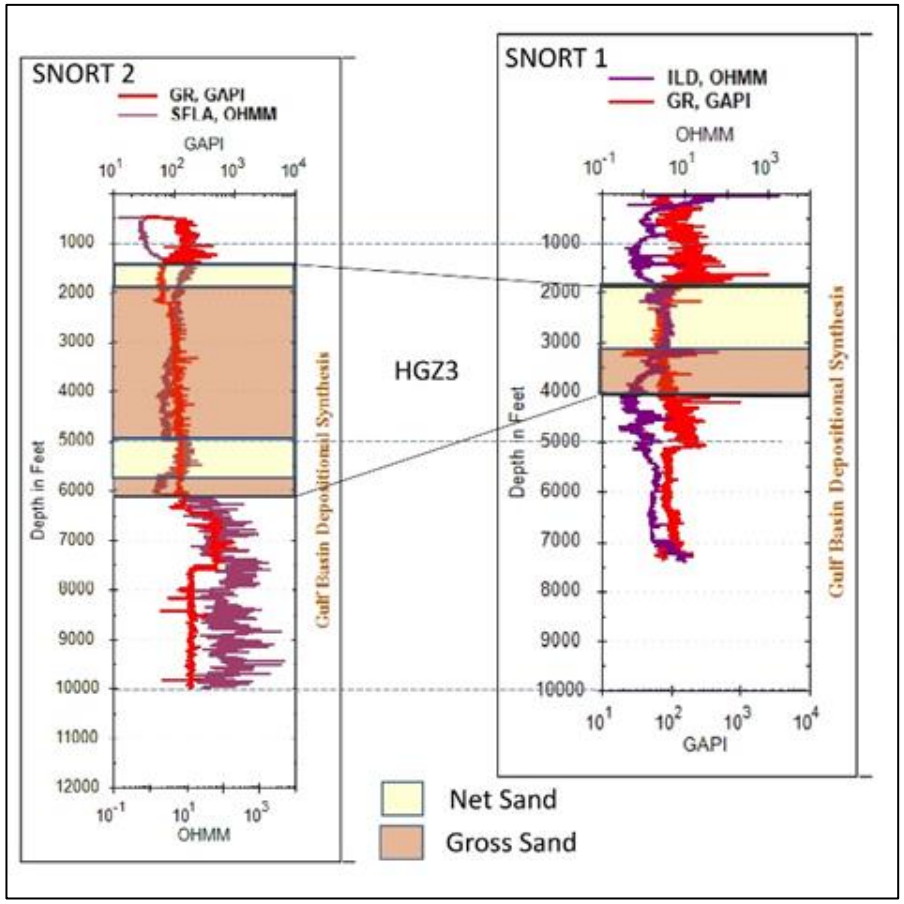
Net Sand (92-02)



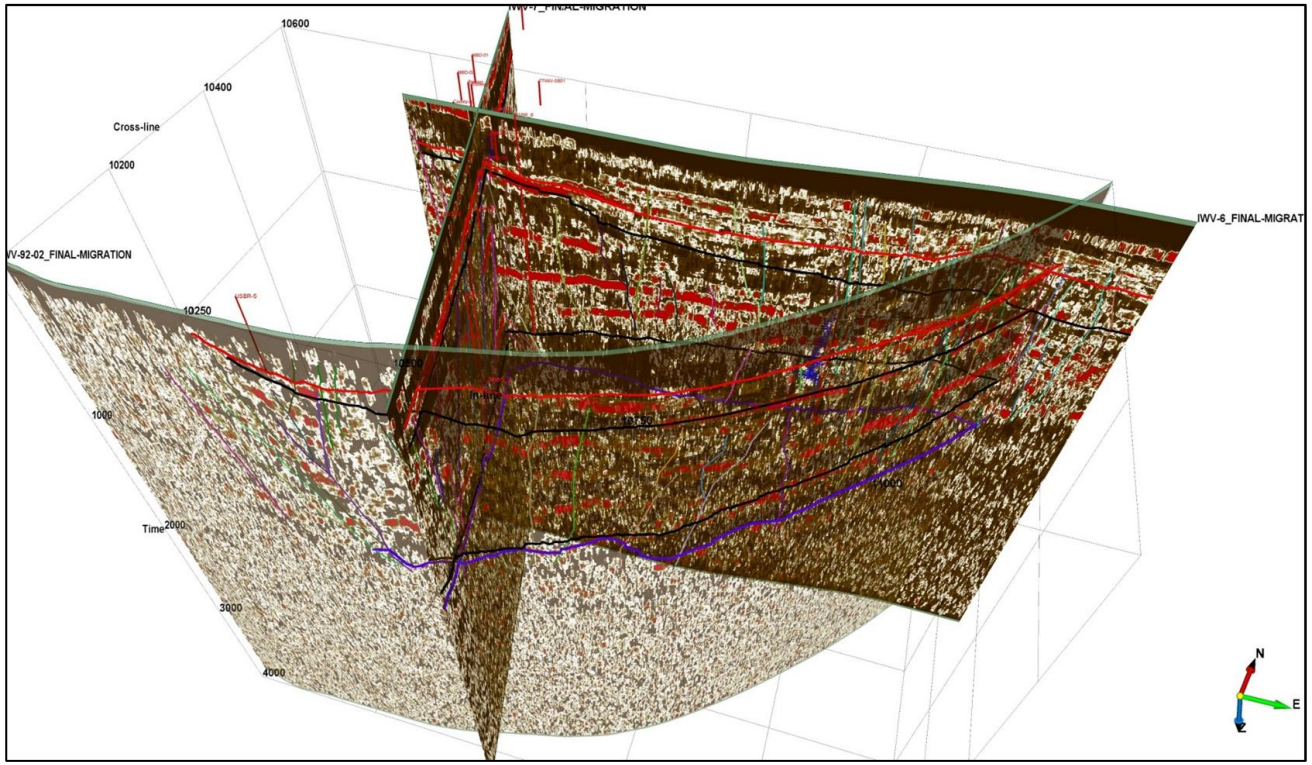
Net Clay (92-01)



Attribute Processing to Map Net Sand and Net Clay

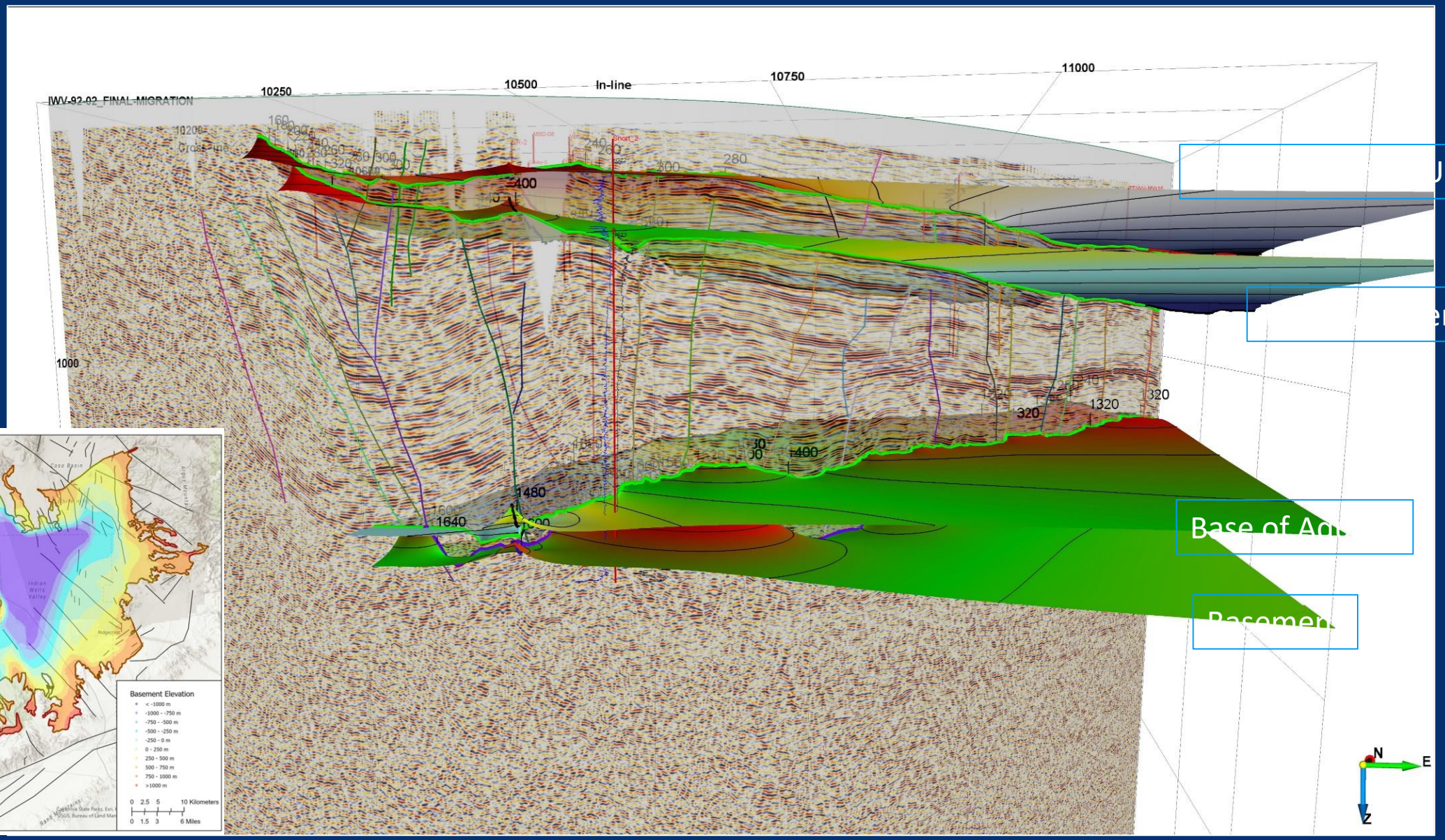


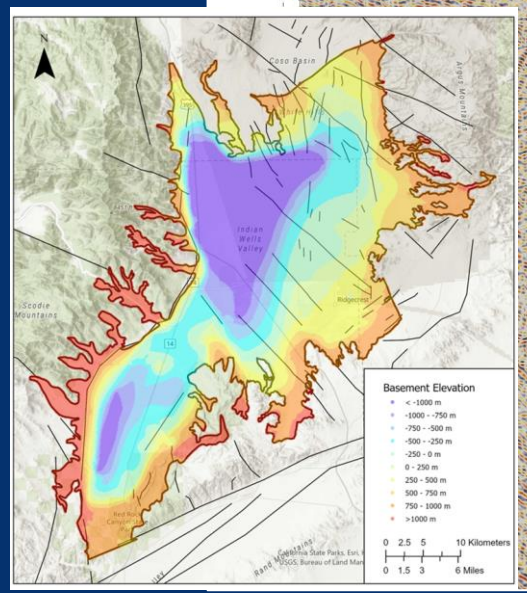
- Net sand and clay units identified on well logs



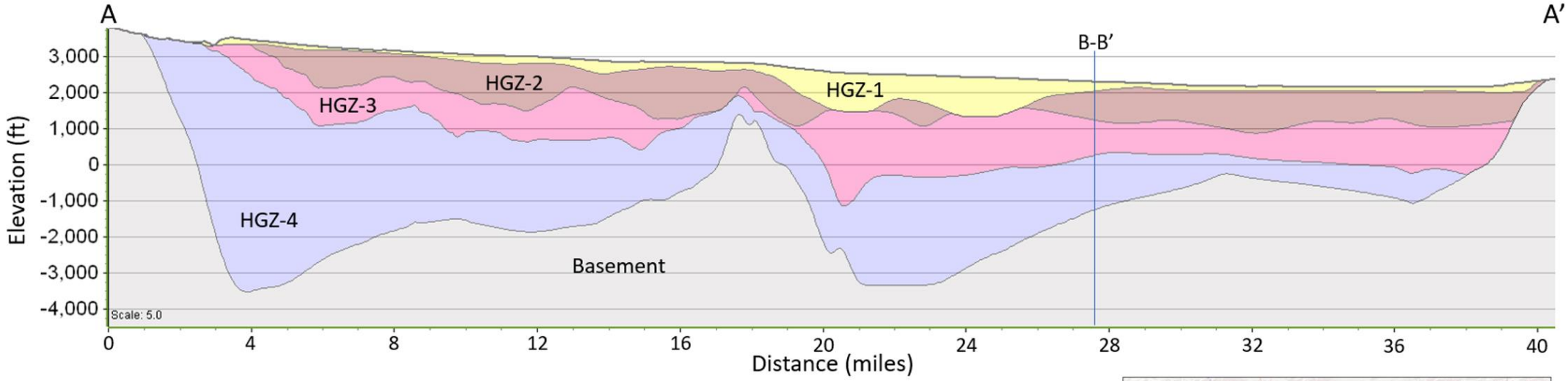
- Attribute processing of seismic lines
- Calibrated to well log data
- Net sand shown in red
- Clay units in Brown
- Can be used to select drilling targets and refine model

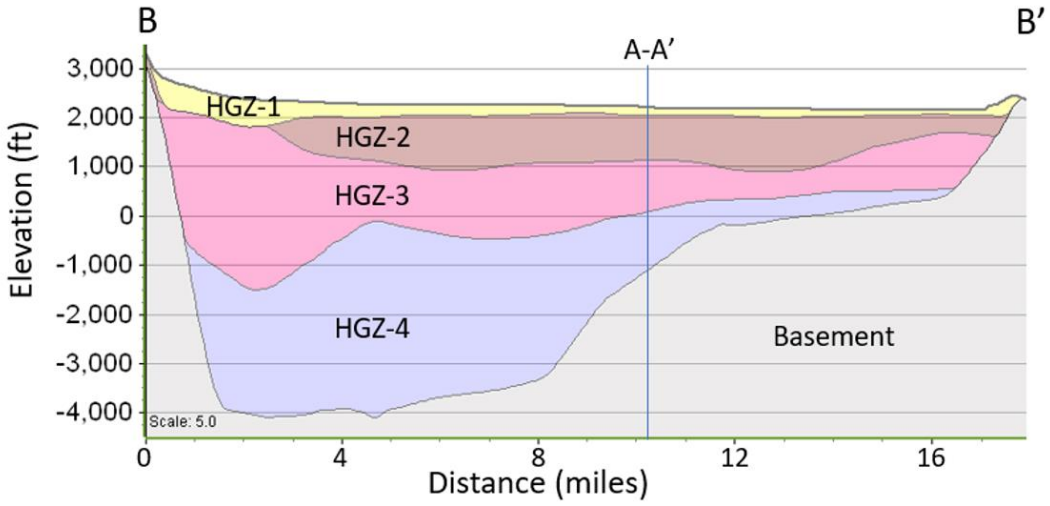
Hydrogeologic Units Horizons and Faults Mapped From Seismic Sections

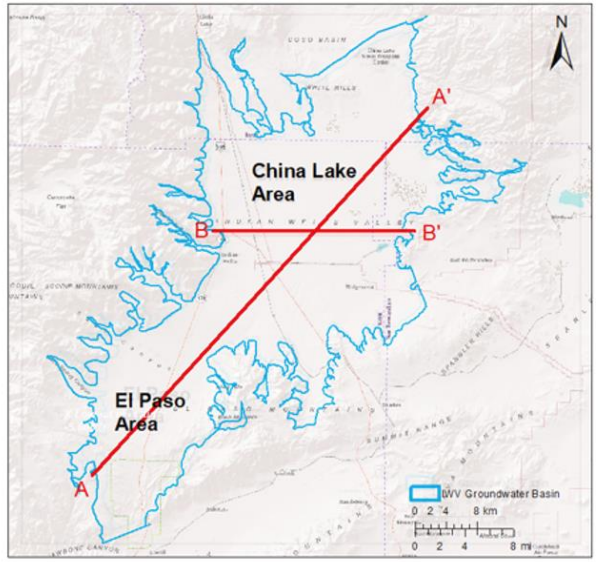




Ramboll 3D Hydrogeologic Conceptual Model

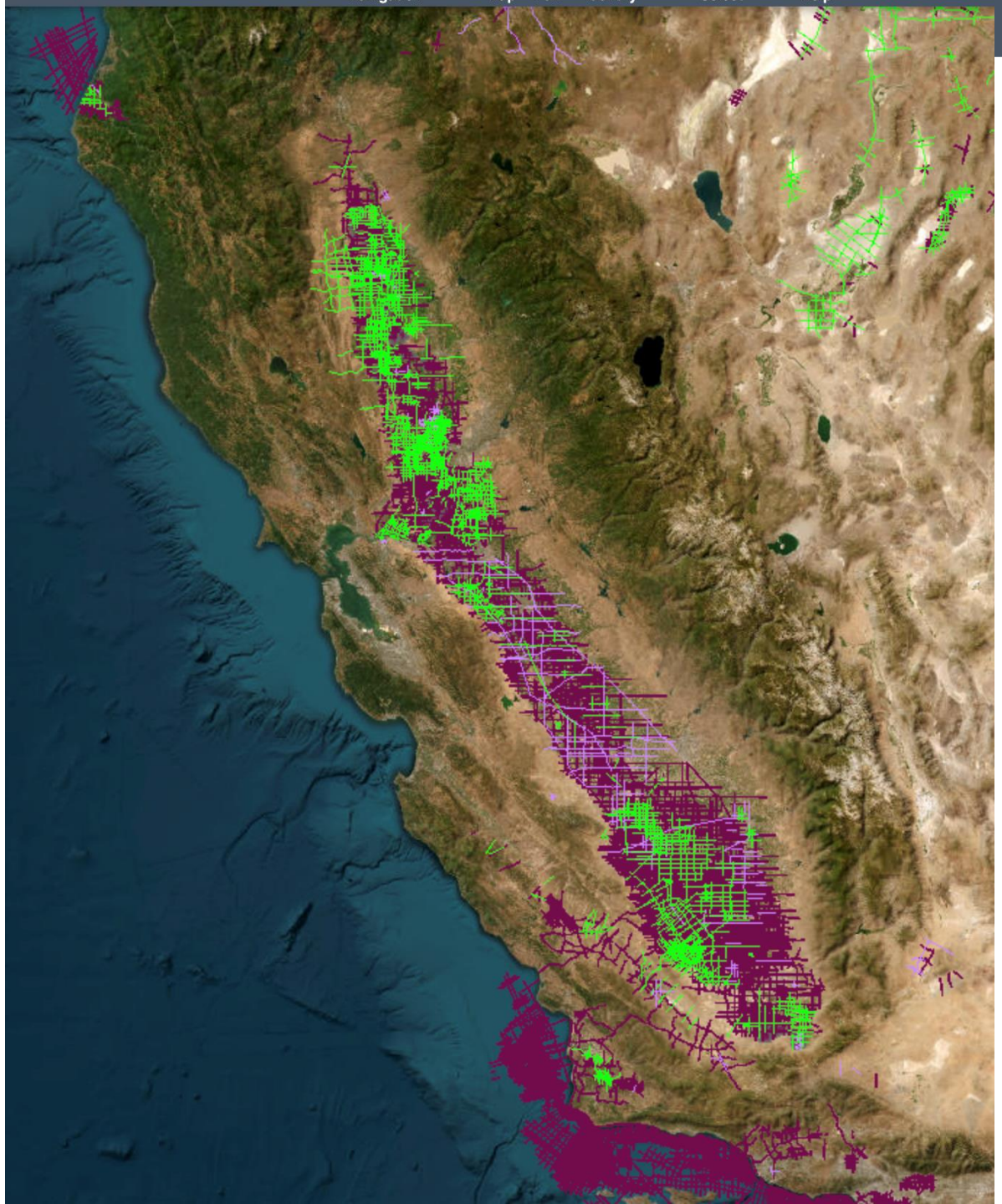






Reference: Storage Estimate, Indian Wells Valley, Ramboll, 2019, Revised 2024.

2D Seismic Data Availability



Legend

2D Reprocess 2008+

2D Reprocess

Lines

2D Reprocess 1999-2007

2D Reprocess

Lines

2D Processed before 1999

2D Lines

Lines

2D Swath Cached

2D Swath

Lines

2D Partner Operated Cached

2D Partner Operated Cached

Oil & Gas Facilities

O&G Injection Disposal Wells ~55,000

Layer List

Layers

- [ ] Notice & Permit
- [x] Well
- [x] Facility
- [ ] Underground Gas Storage
- [ ] Well Stimulation
- [ ] TR26 Onshore Seep Count
- [x] CalGEM District
- [x] CalGEM Oil & Gas Field
- [ ] City, Island, Offshore Lease, and Platform
- [ ] Public Land Survey System
- [ ] Legislative District
- [ ] County
- [ ] Geologic Map of California