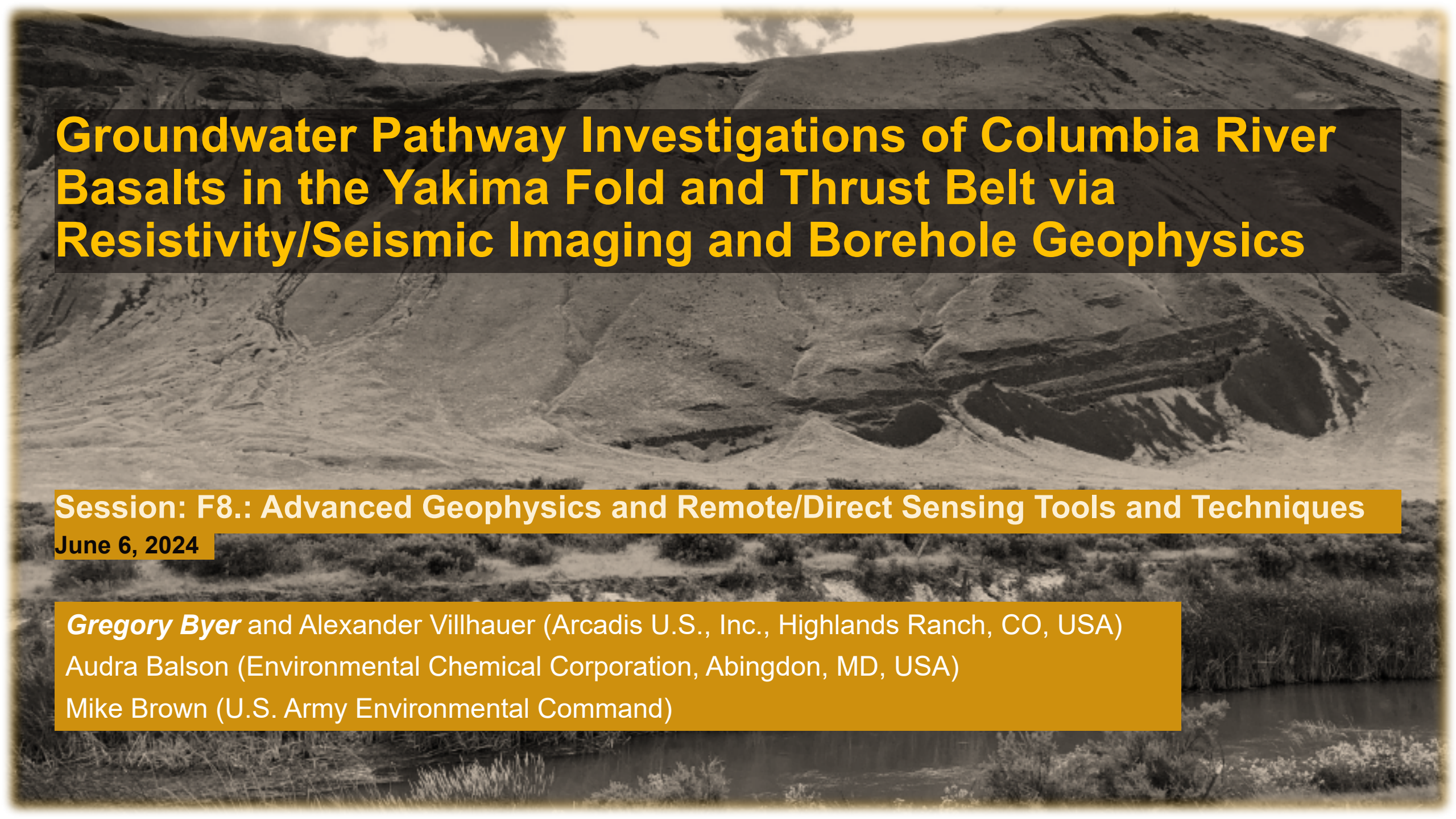

Groundwater Pathway Investigations of Columbia River Basalts in the Yakima Fold and Thrust Belt via Resistivity/Seismic Imaging and Borehole Geophysics

Session: F8.: Advanced Geophysics and Remote/Direct Sensing Tools and Techniques

June 6, 2024

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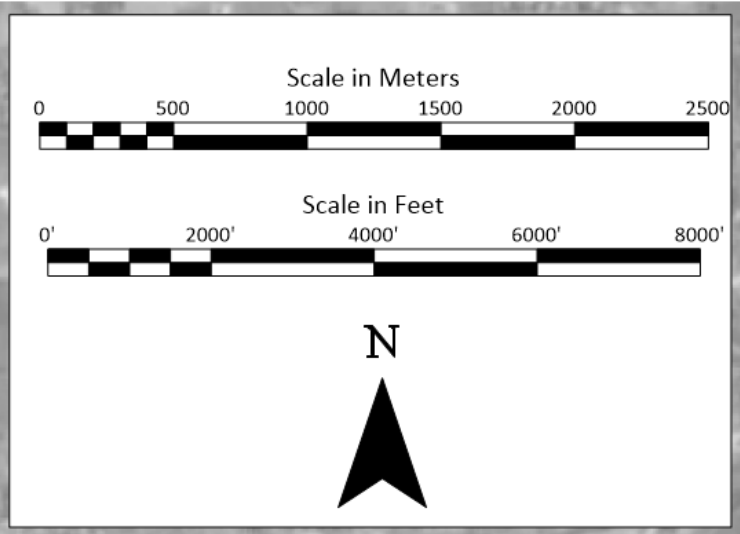
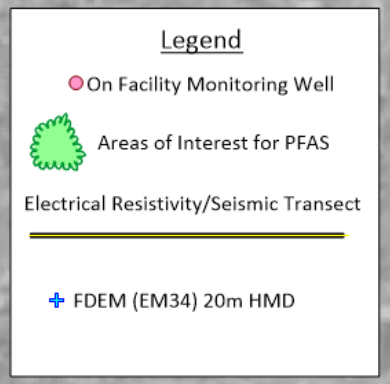
Audra Balson (Environmental Chemical Corporation, Abingdon, MD, USA)

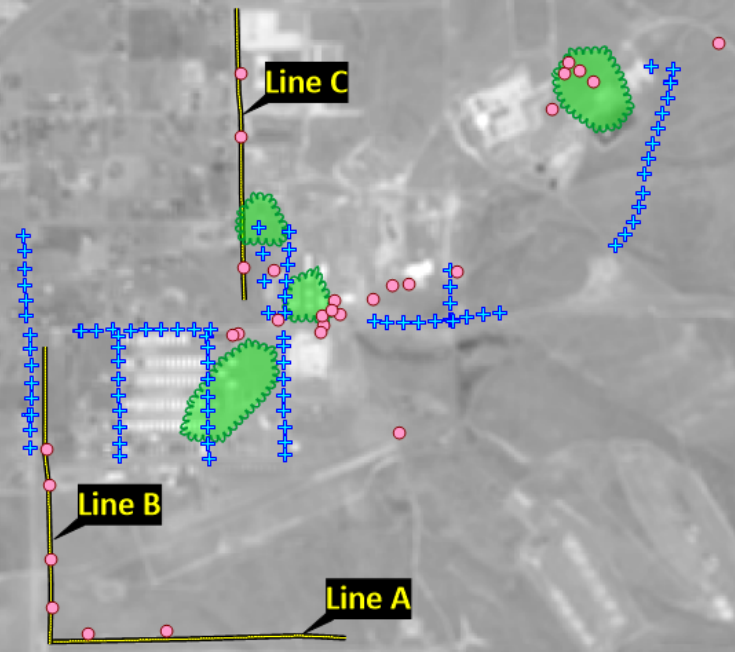
Mike Brown (U.S. Army Environmental Command)

Objective





Over 350 residential and water supply wells are located between the facility and the river to the north, west and south



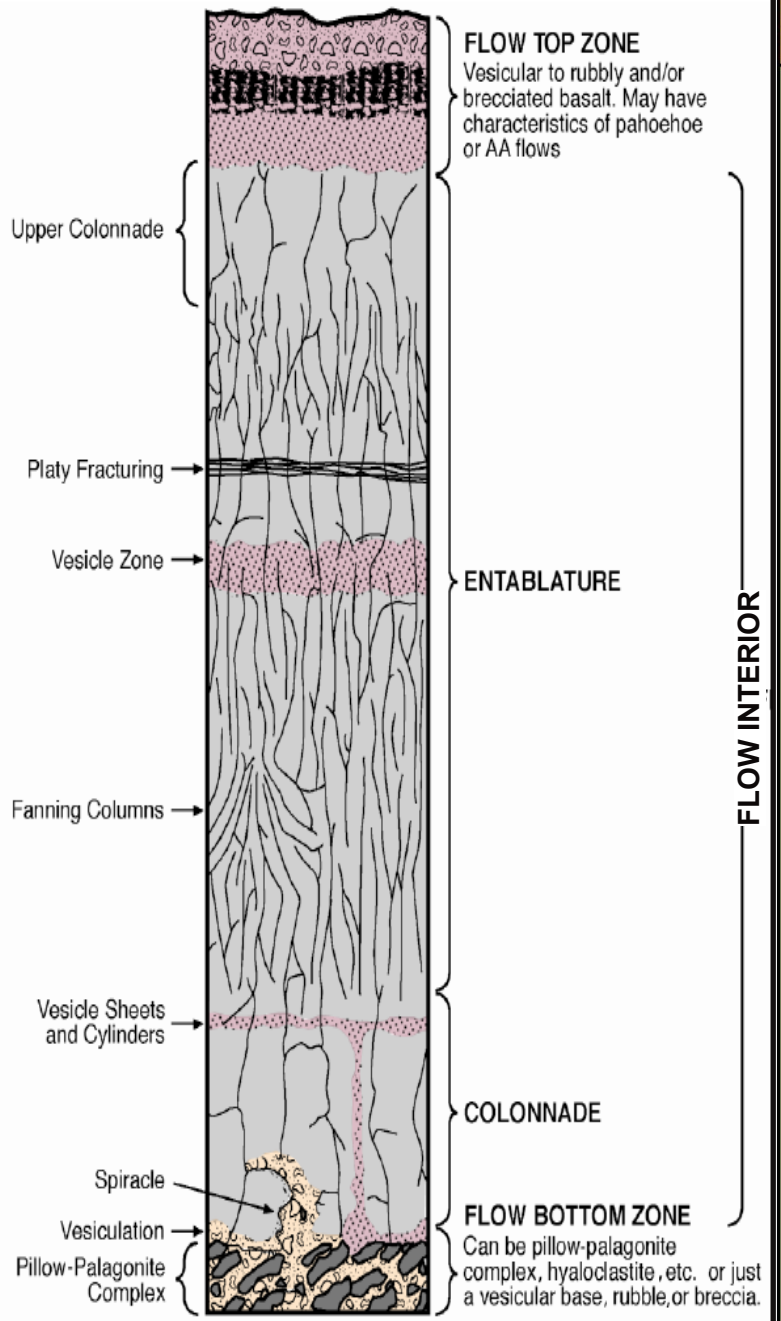
The key objective of the environmental contaminant and groundwater investigation activities was to identify and test the groundwater migrating towards of the outer boundary of the project site (Site) located in south-central Washington State.

Geologic Setting

Columbia River Basalts

- The Columbia River Basalts (CRBs) are a series of broad lava flows known as flood basalts and cover large portions of southeast Washington, northeast Oregon and western Idaho.
- Current information indicates that the study area is underlain by members of the **Saddle Mountain Basalt.**

https://wa100.dnr.wa.gov/columbia-basin/frenchman-coulee



Barnett et al., 2007

Series	Group	Formation	Series	Isotopic Age (m.y)	Magnetic Polarity
Miocene, Upper	Columbia River Basalt Group, Yakima Basalt Subgroup	Saddle Mountains Basalt	Lower Monumental Member	6	N
			Ice-Harbor Member	8.5	
			Basalt of Goose Island		N
			Basalt of Martindale		R
			Basalt of Basin City		N
			Buford Member		R
			Elephant Mountain Member	10.5	N, T
			Pomona Member	12	R
			Esquatzel Member	?	
			Weissenfels Ridge Member		
			Basalt of Slippery Creek		N
			Basalt of Tenmile Creek		N
			Basalt of Lewiston Orchards		N
			Basalt of Cloverland		N
			Asotin Member	13	
			Basalt of Huntzinger		N
			Wilbur Creek Member		
			Basalt of Lapwai		N
			Basalt of Wahluke		N
			Umatilla Member		
			Basalt of Sillusi		N
			Basalt of Umatilla		N
Miocene, Middle	Columbia River Basalt Group, Yakima Basalt Subgroup	Wanapum Basalt	Priest Rapids Member	14.5	
			Basalt of Lolo		R
			Basalt of Rosalia		R
			Roza Member		T, R
			Shumaker Creek Member		N
			Frenchman Springs Member		
			Basalt of Lyons Ferry		N
			Basalt of Sentinel Gap		N
			Basalt of Sand Hollow	15.3	N
			Basalt of Silver Falls		N, E
			Basalt of Ginkgo	15.6	E
			Basalt of Palouse Falls		E
			Eckler Mountain Member		
			Basalt of Dodge		N
			Basalt of Robinette Mountain		N
			Vantage Horizon		
Miocene, Middle	Columbia River Basalt Group, Yakima Basalt Subgroup	Grande Ronde Basalt (Priest Rapids Member)	Member of Sentinel Bluffs	15.6	N_2
			Member of Slack Canyon		
			Member of Fields Spring		
			Member of Winter Water		
			Member of Umtanum		
			Member of Ortley		
			Member of Armstrong Canyon		
			Member of Meyer Ridge		R_2
			Member of Grouse Creek		
			Member of Wapshilla Ridge		
			Member of Mt. Horrible		
			Member of China Creek		N_1
			Member of Downy Gulch		
			Member of Center Creek		R_1
			Member of Rogersburg		
			Teepee Butte Member		
			Member of Buckhorn Springs	16.5	
		Imnaha Basalt	Martin et al., 2005	17.5	R_1, T, N_0, R_0

Sedimentary Interbeds of Ellensburg Fm.

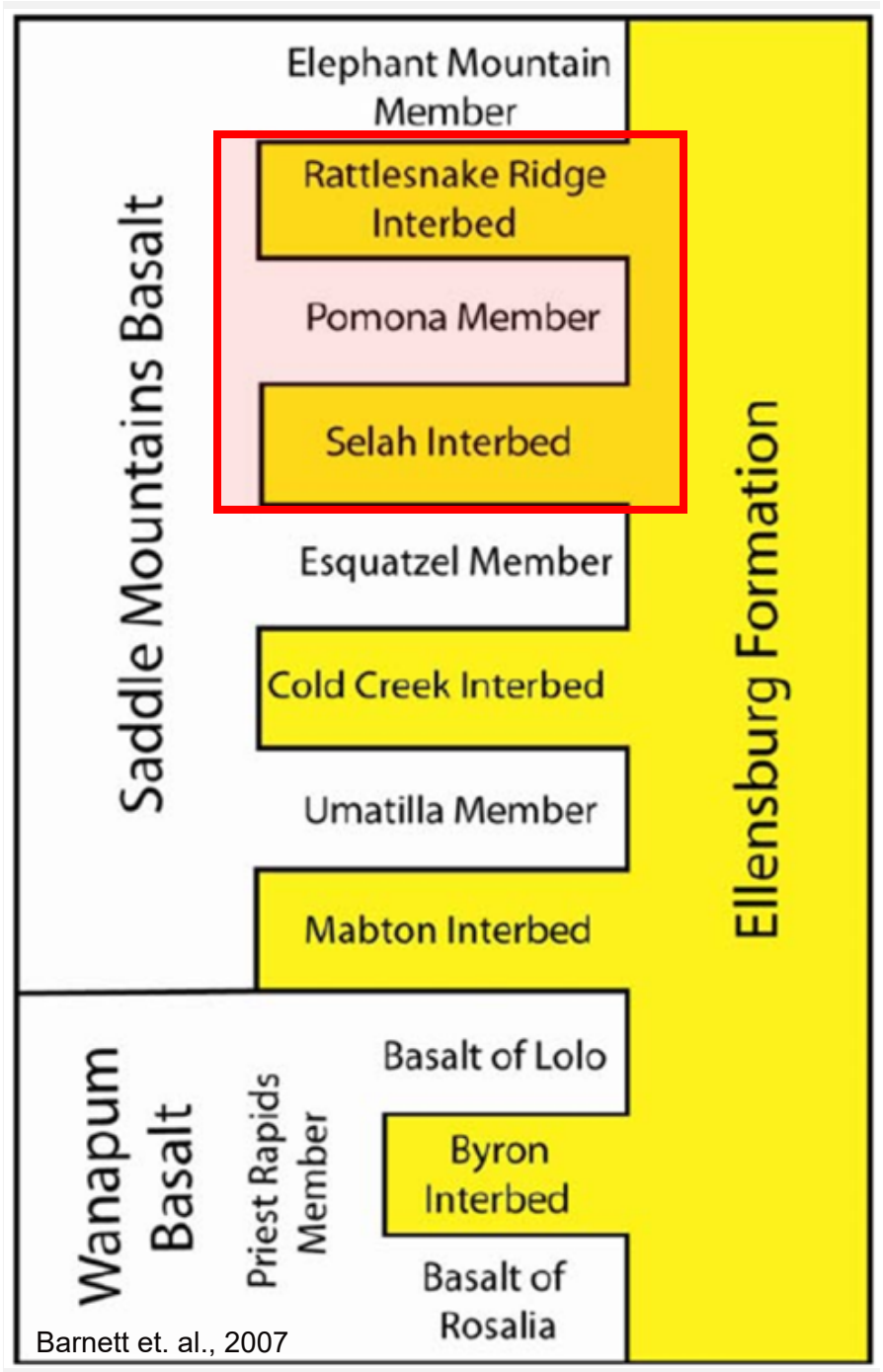
- The Ellensburg Formation is the name given to units of alluvial and volcanic material between basalt flows of the CRBs. Between individual basalt flows are the sedimentary interbeds.

- The Cascade Range was lower at the time, but there were explosive volcanoes in the south part of the range. The bulk of material from the Ellensburg Formation was derived from those ancient eruptive centers that are long gone and now replaced by the current crop of Cascade volcanoes.

- The Ellensburg Formation can be thought of as the interfingering of volcanics and **alluvial material from the west with basalts from the east with the basalt being the predominant formation.**

https://washingtonlandscape.blogspot.com/2011/05/ellensburg-formation-side-trip-off-of-i.html

Graded Lahar and Ash

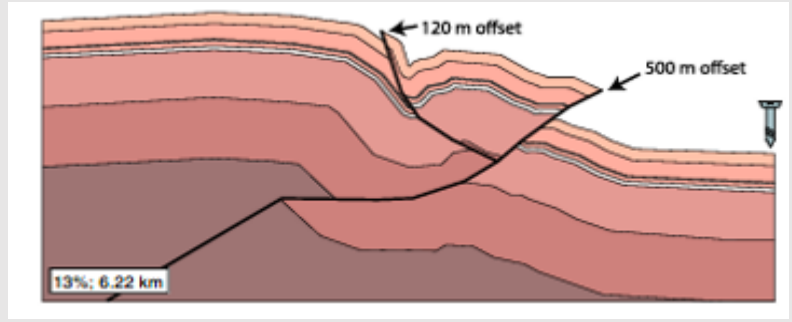


Barnett et. al., 2007

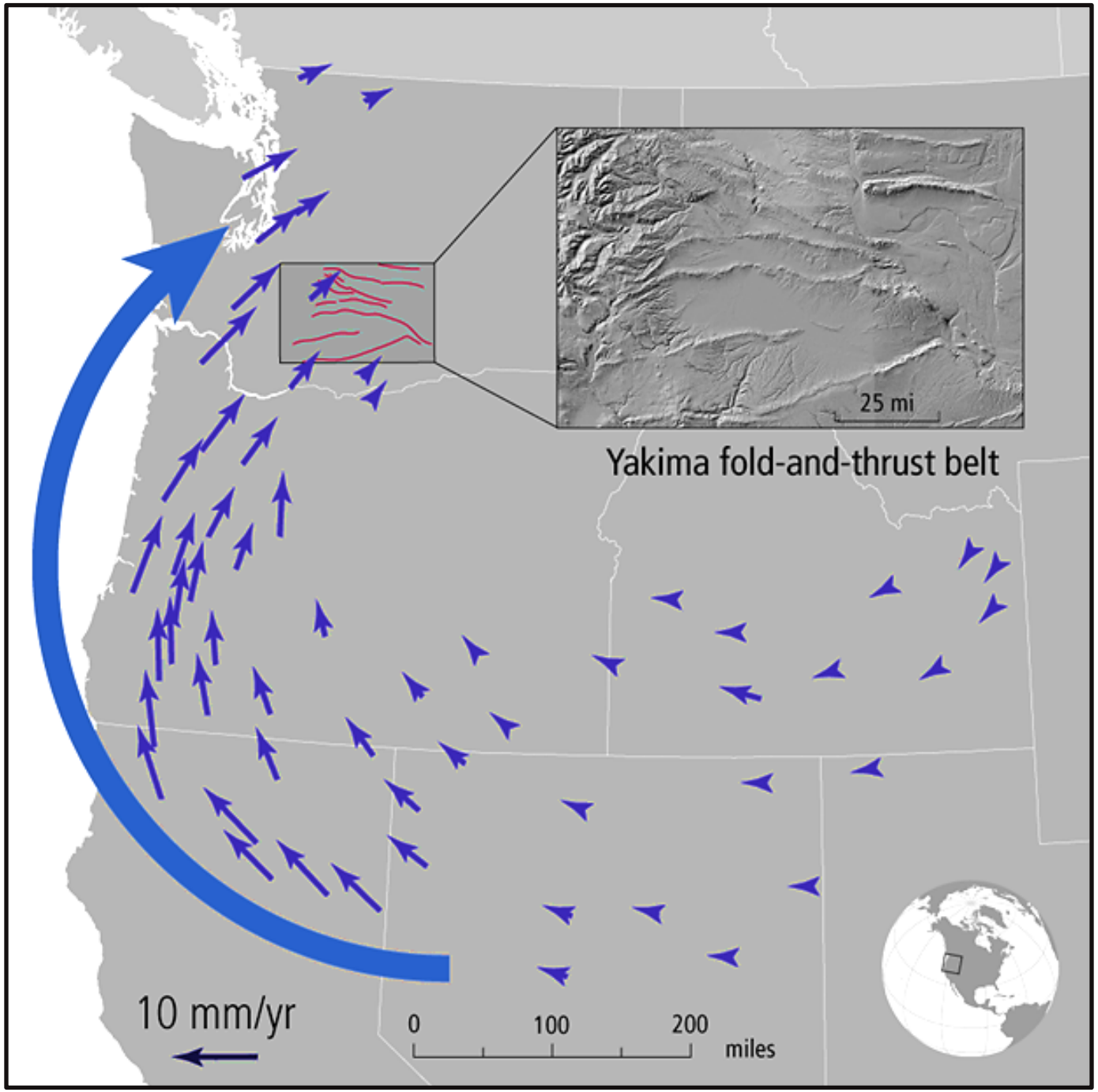
Tectonic Setting

- Present-day Pacific Northwest rotation highlighting the Yakima fold-and-thrust belt.
- **Purple arrows** are vectors showing the direction and amounts of rotation from GPS stations.
- The **big blue arrow** shows the general rotation trend.
- The small box shows **red lines** that emphasize the folds, while the large box shows lidar data of those folds.

Graphic and lidar data from WGS/DNR, GPS data from UNAVCO



Kelsey et al., 2017 ***Folded & Thrust Faulted Rocks***

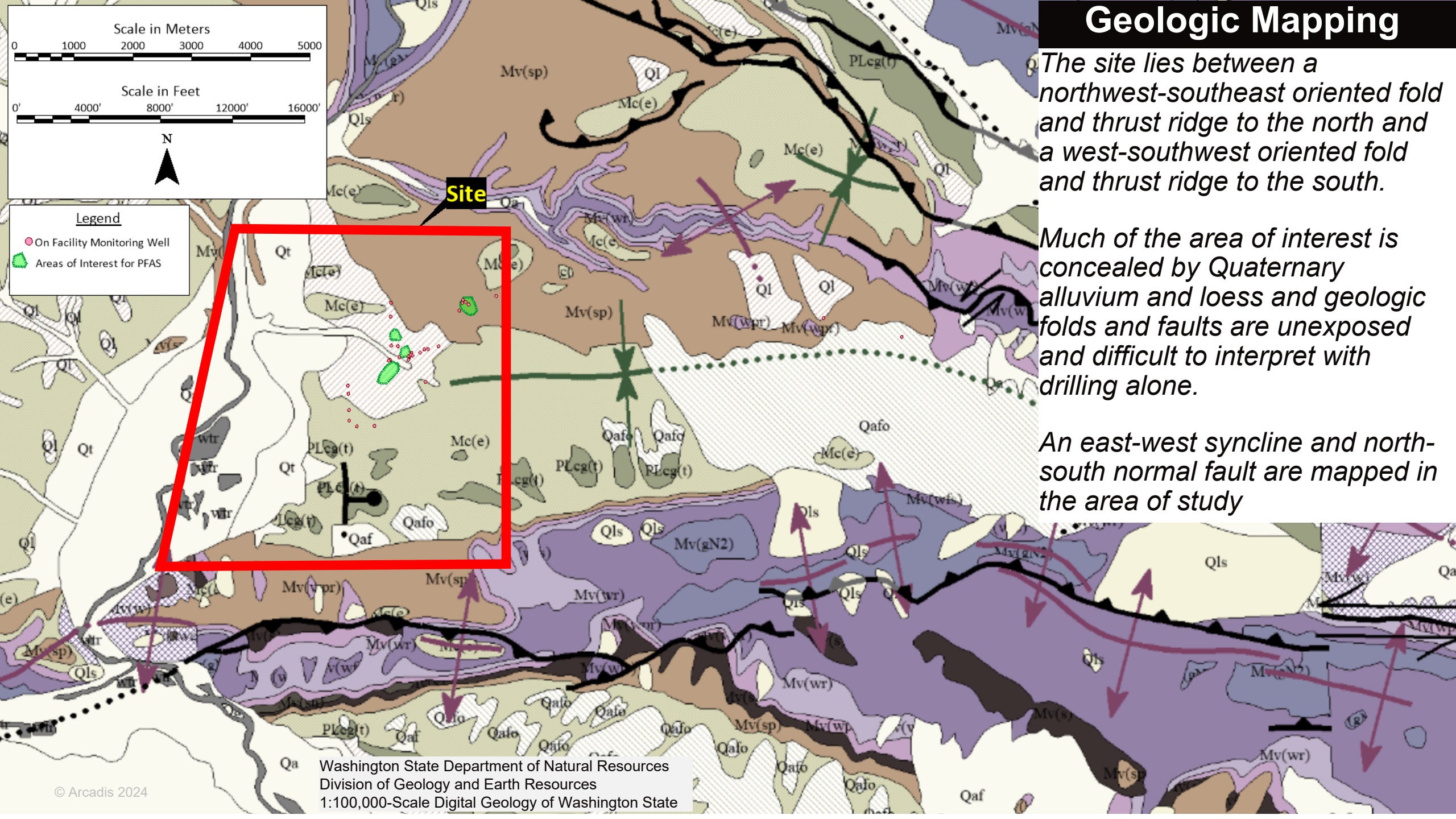


Geologic Mapping

The site lies between a northwest-southeast oriented fold and thrust ridge to the north and a west-southwest oriented fold and thrust ridge to the south.

Much of the area of interest is concealed by Quaternary alluvium and loess and geologic folds and faults are unexposed and difficult to interpret with drilling alone.

An east-west syncline and north-south normal fault are mapped in the area of study



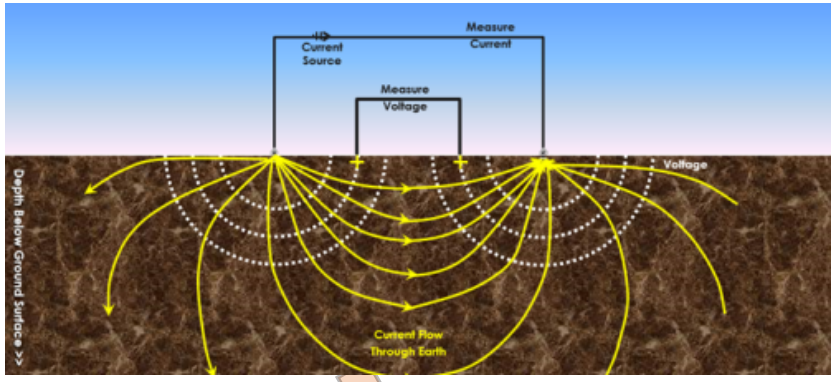
Washington State Department of Natural Resources
Division of Geology and Earth Resources
1:100,000-Scale Digital Geology of Washington State

Geophysical Technologies

Surface Geophysical Technologies

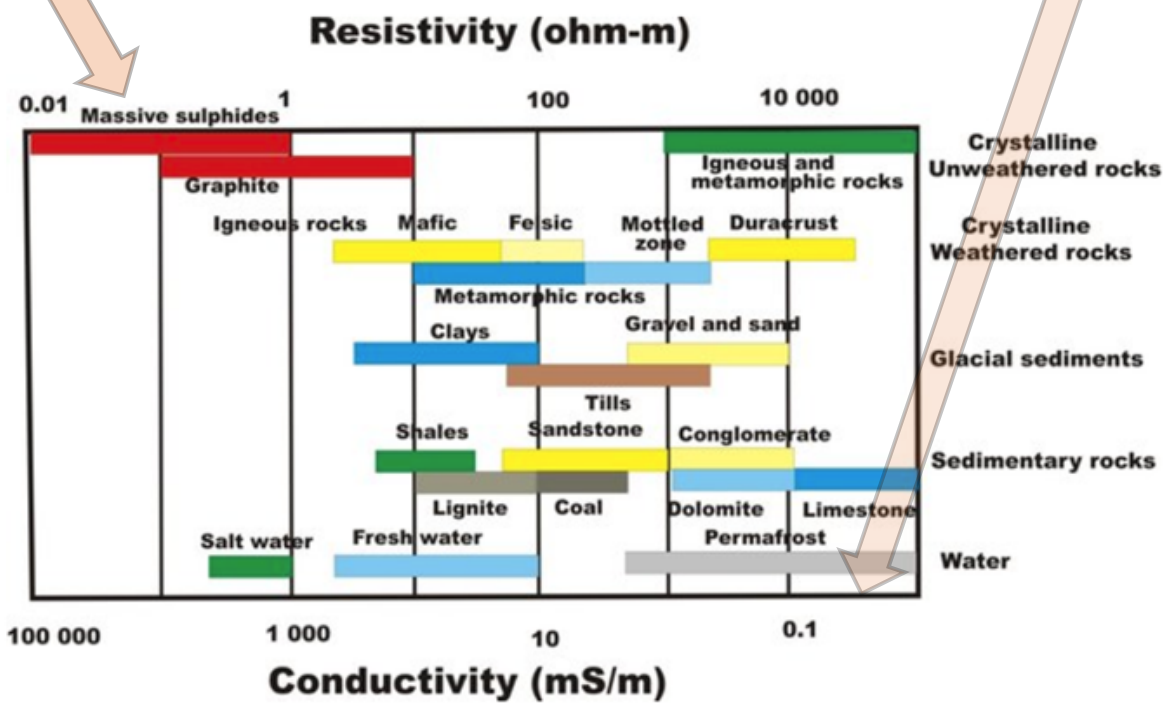
ARCADIS

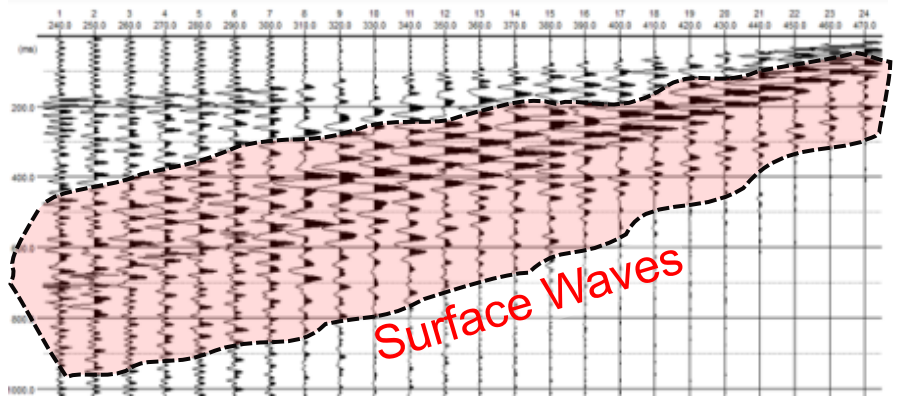
Electrical Resistivity Tomography



FDEM (EM34)

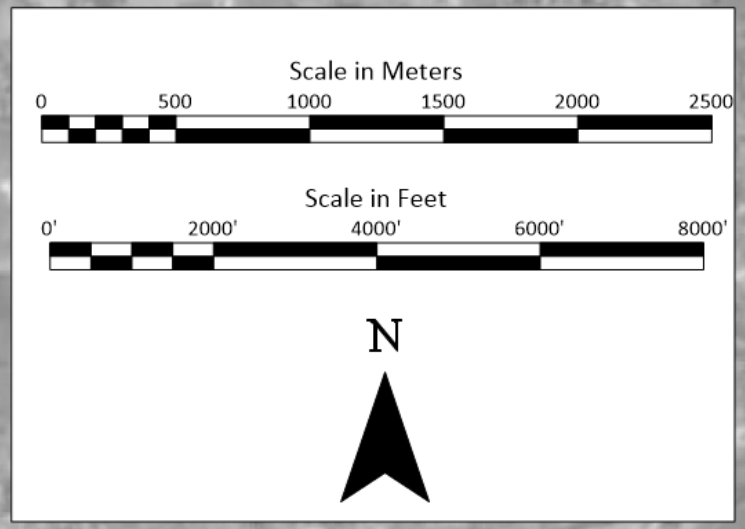
Seismic (MASW)

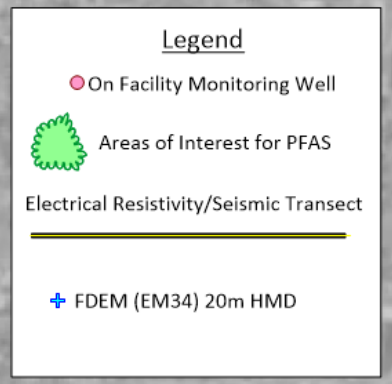




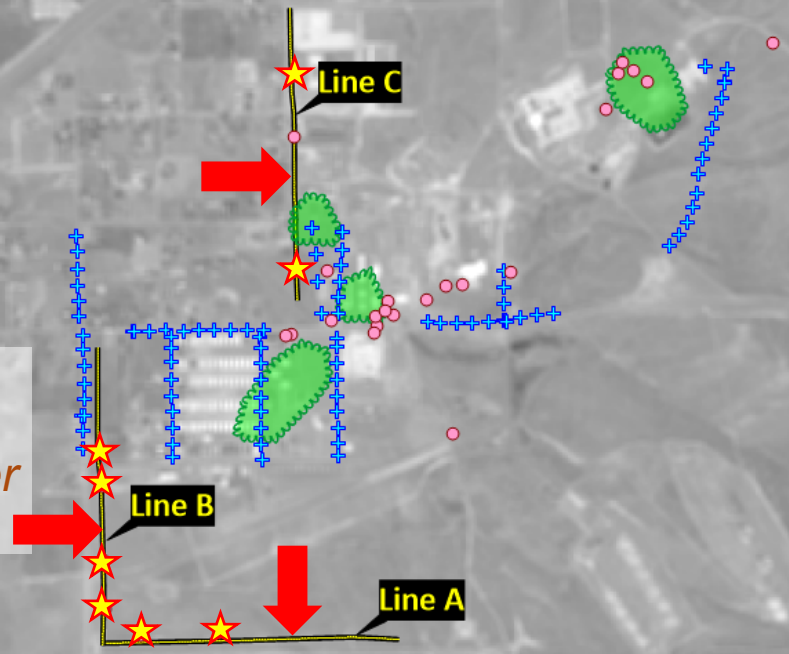
Palacky, G.V. (1987), Resistivity characteristics of geologic targets, in Electromagnetic Methods in Applied Geophysics, Vol 1, Theory, 1351

Geophysics Data Collection Areas



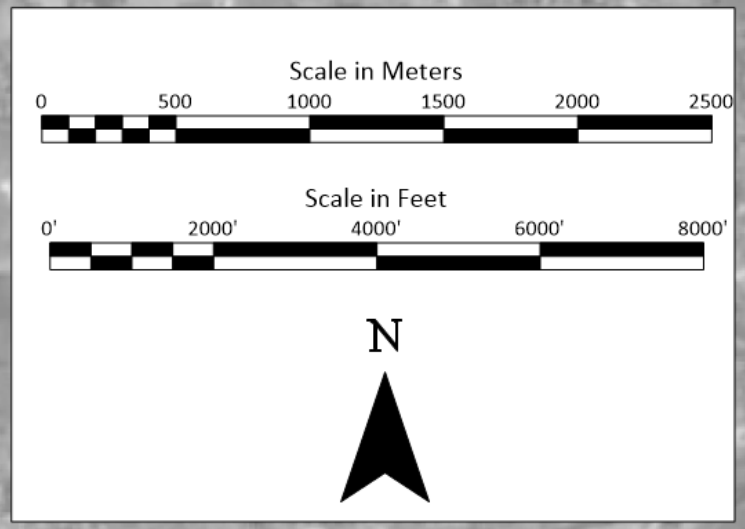


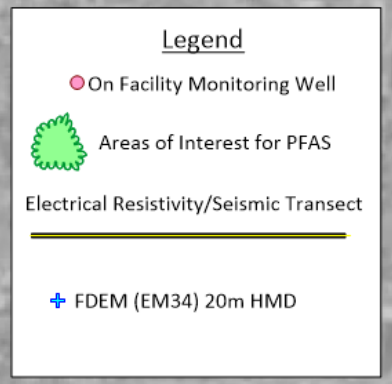
Over 350 residential and water supply wells are located between the facility and the river to the north, west and south



- *3 Resistivity/Seismic Geophysical Transects, each 1110 meters (3642 feet) in length (Lines A-C)*

Geophysics Data Collection Areas





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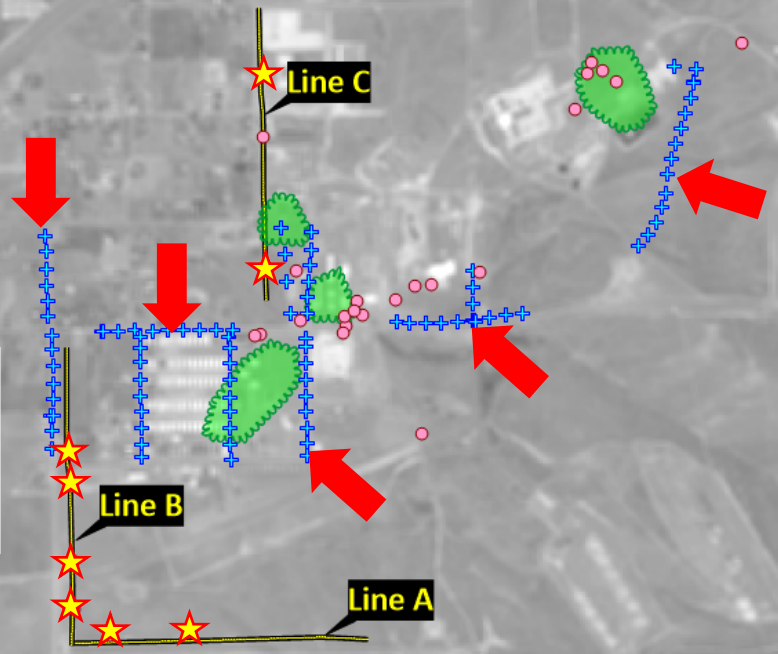
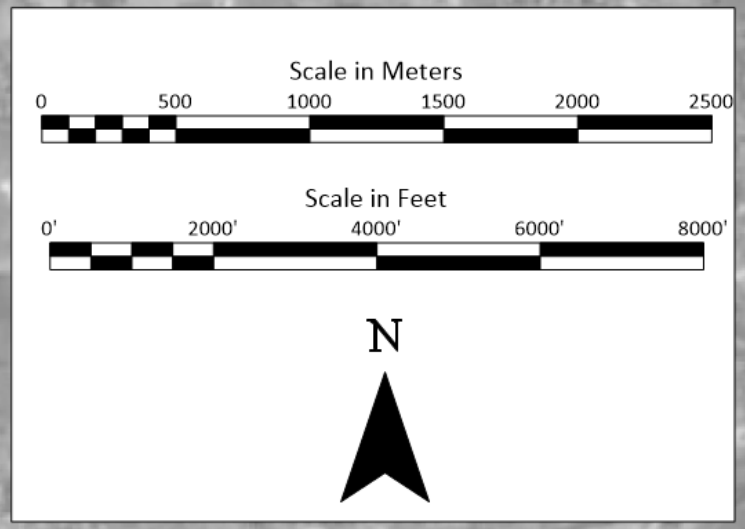
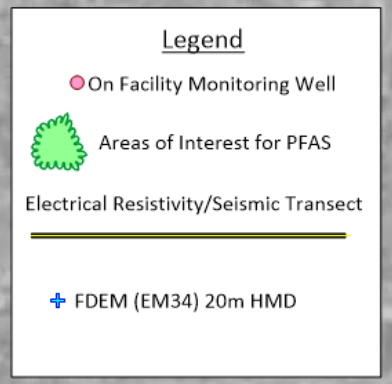


- *3 Resistivity/Seismic Geophysical Transects, each 1110 meters (3642 feet) in length (Lines A-C)*
- *85 FDEM (EM34) 20m HMD and VMD data points*

Geophysics Data Collection Areas





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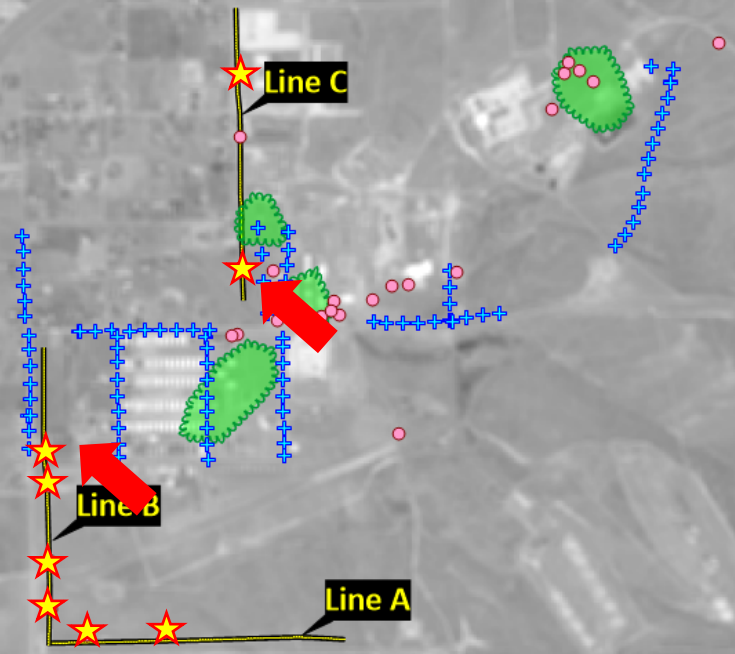
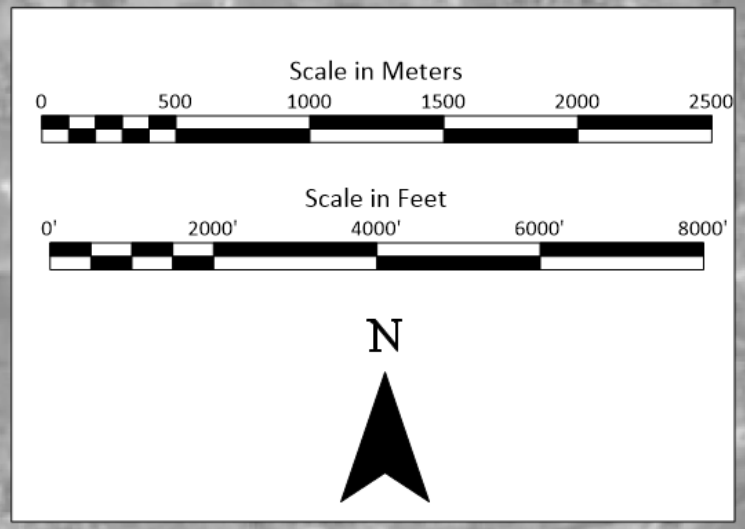
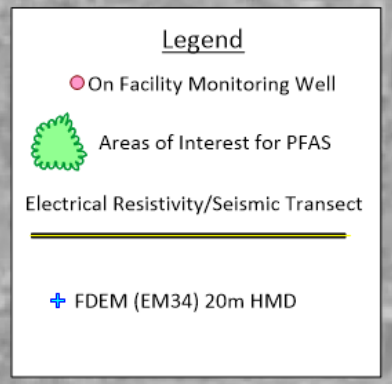


- *3 Resistivity/Seismic Geophysical Transects, each 1110 meters (3642 feet) in length (Lines A-C)*
- *85 FDEM (EM34) 20m HMD and VMD data points*
- *2 Bi-Directional EM34 Soundings using all spacings and orientations*

Geophysics Data Collection Areas





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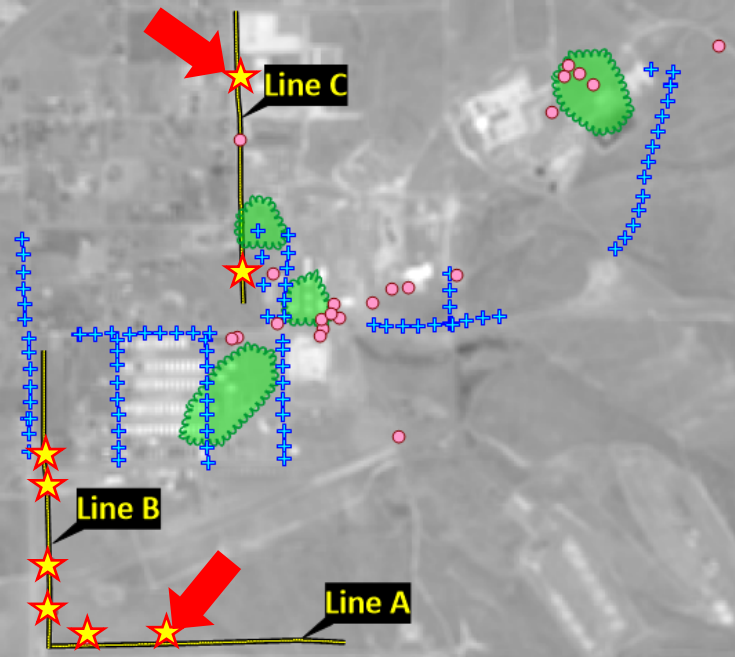


- *3 Resistivity/Seismic Geophysical Transects, each 1110 meters (3642 feet) in length (Lines A-C)*
- *85 FDEM (EM34) 20m HMD and VMD data points*
- *2 Bi-Directional EM34 Soundings using all spacings and orientations*
- *Borehole Geophysics including natural gamma, single point resistance, 3-arm caliper and acoustic televiewer*

Results

Line A

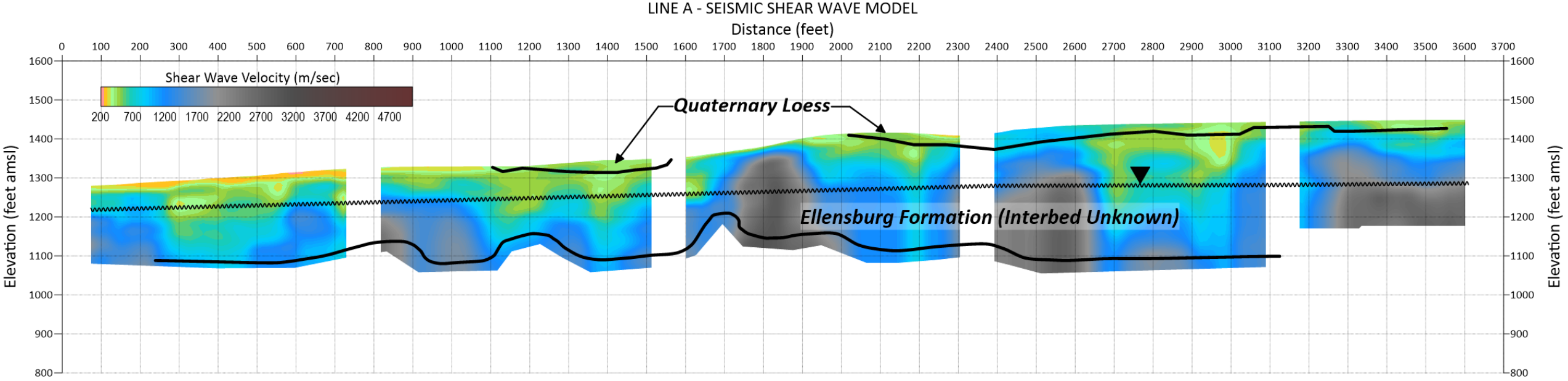
Resistivity & Seismic

ARCADIS

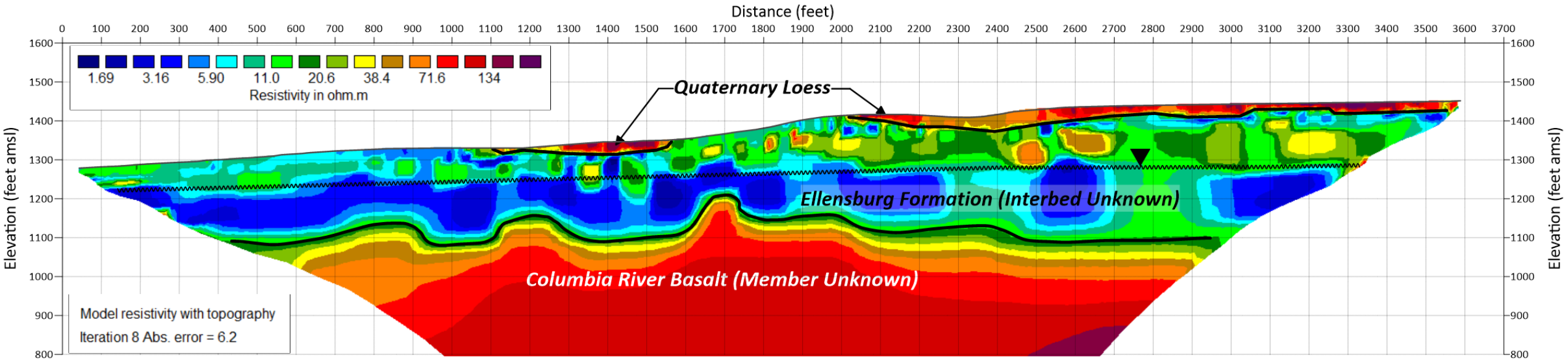
WEST

EAST

LINE A - SEISMIC SHEAR WAVE MODEL



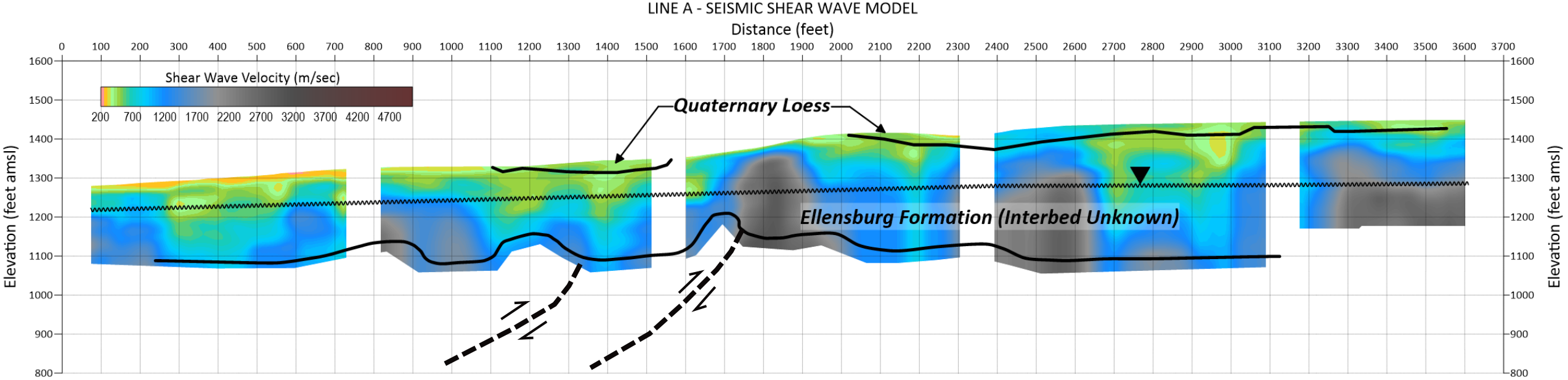
LINE A - ELECTRICAL RESISTIVITY MODEL



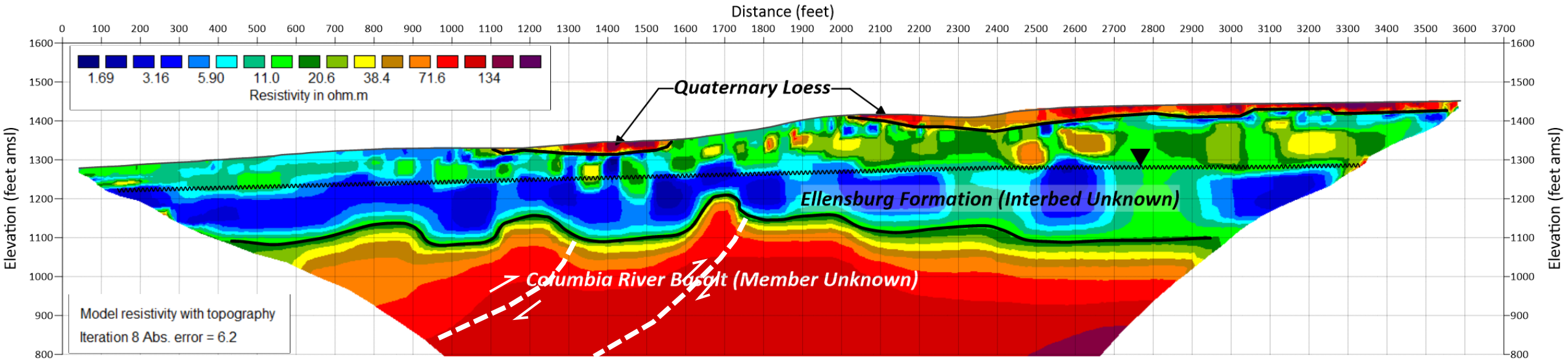
WEST

EAST

LINE A - SEISMIC SHEAR WAVE MODEL



LINE A - ELECTRICAL RESISTIVITY MODEL

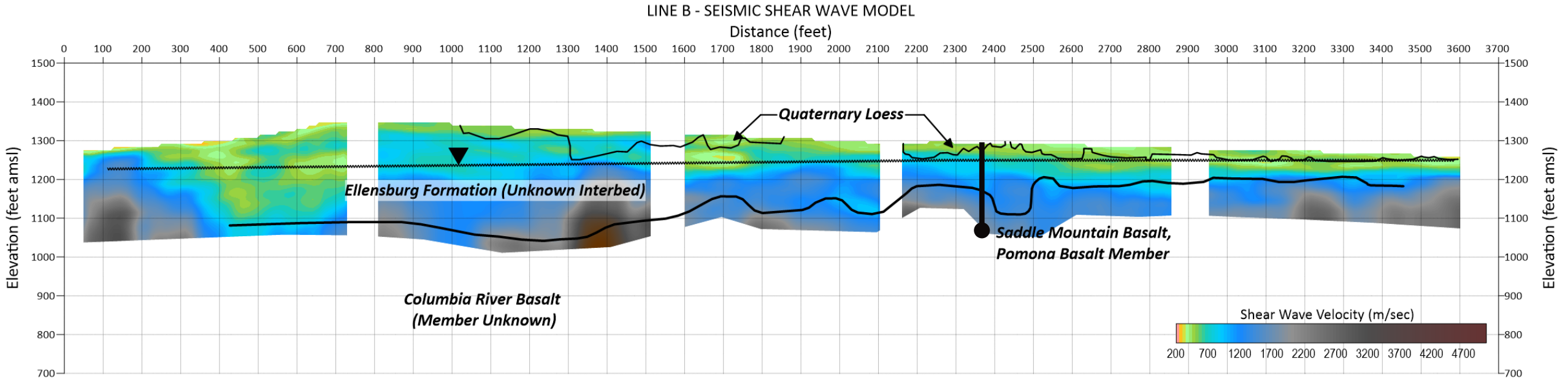


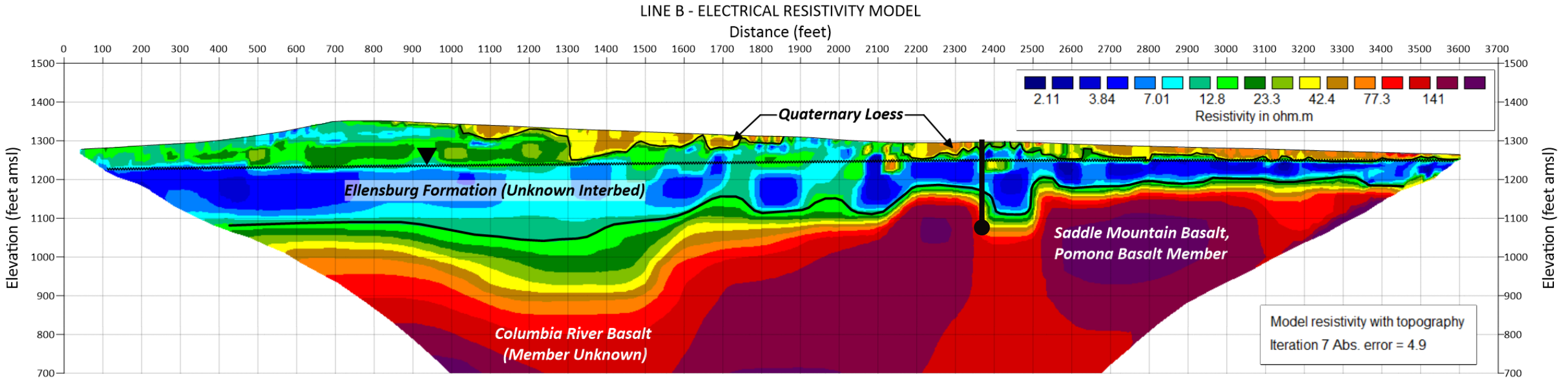
Line B

Resistivity & Seismic

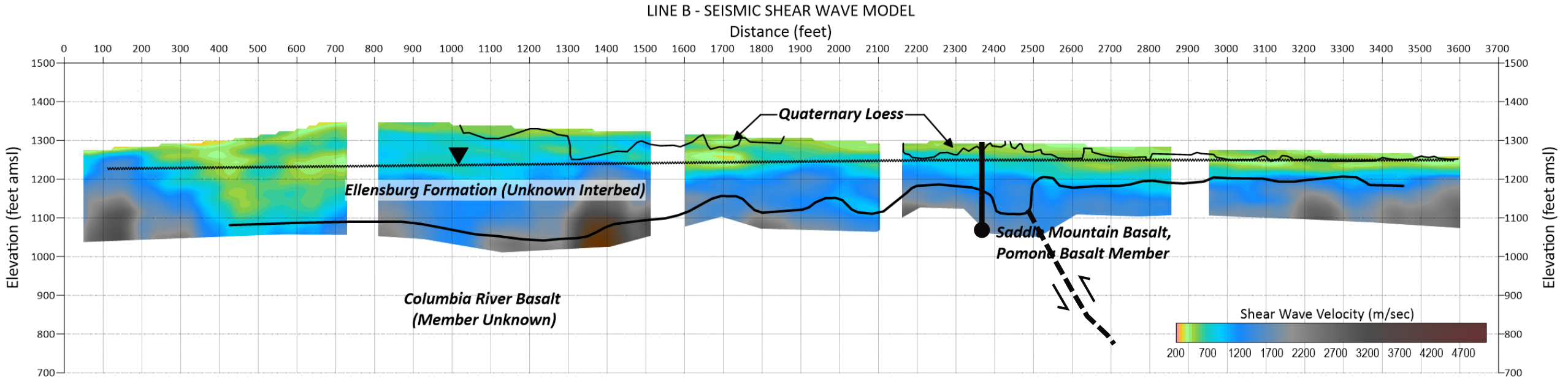
ARCADIS

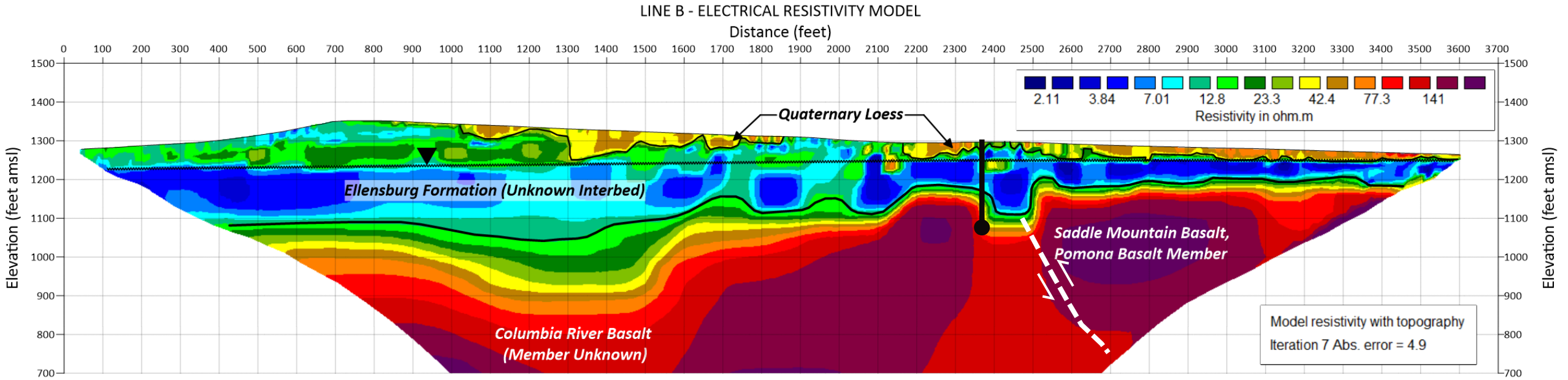
SOUTH NORTH





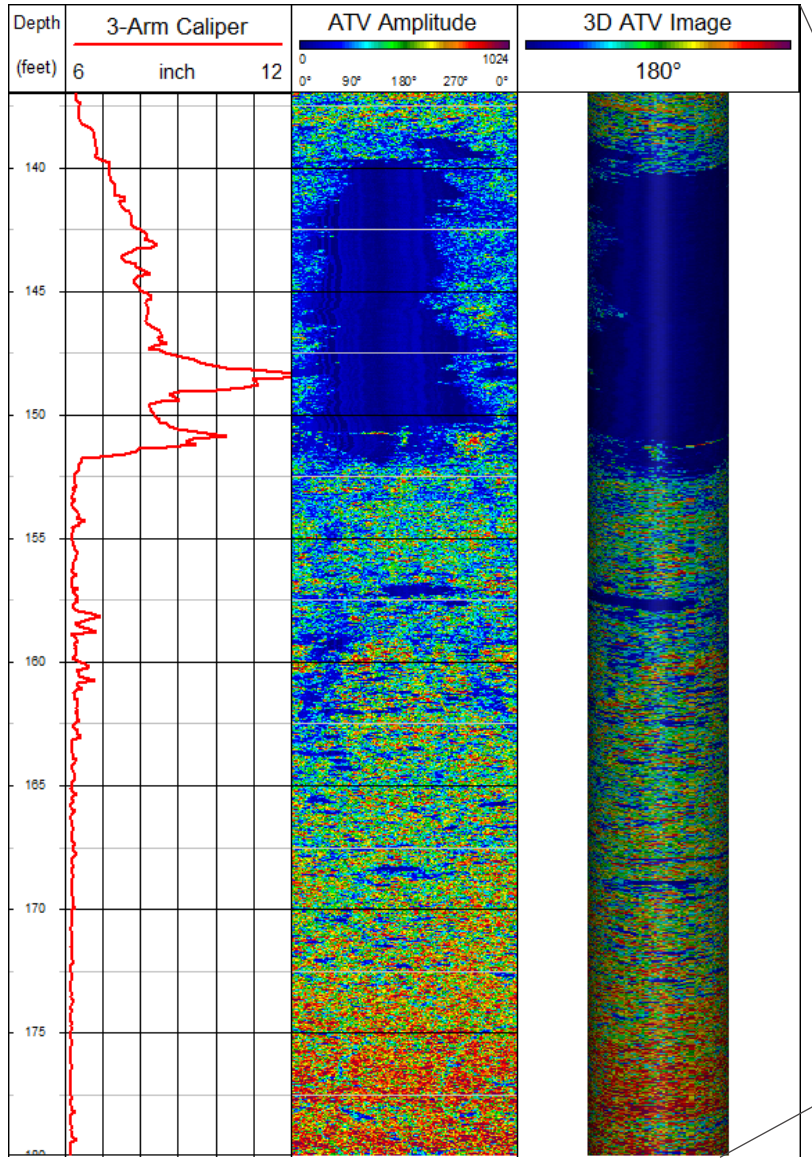
SOUTH NORTH

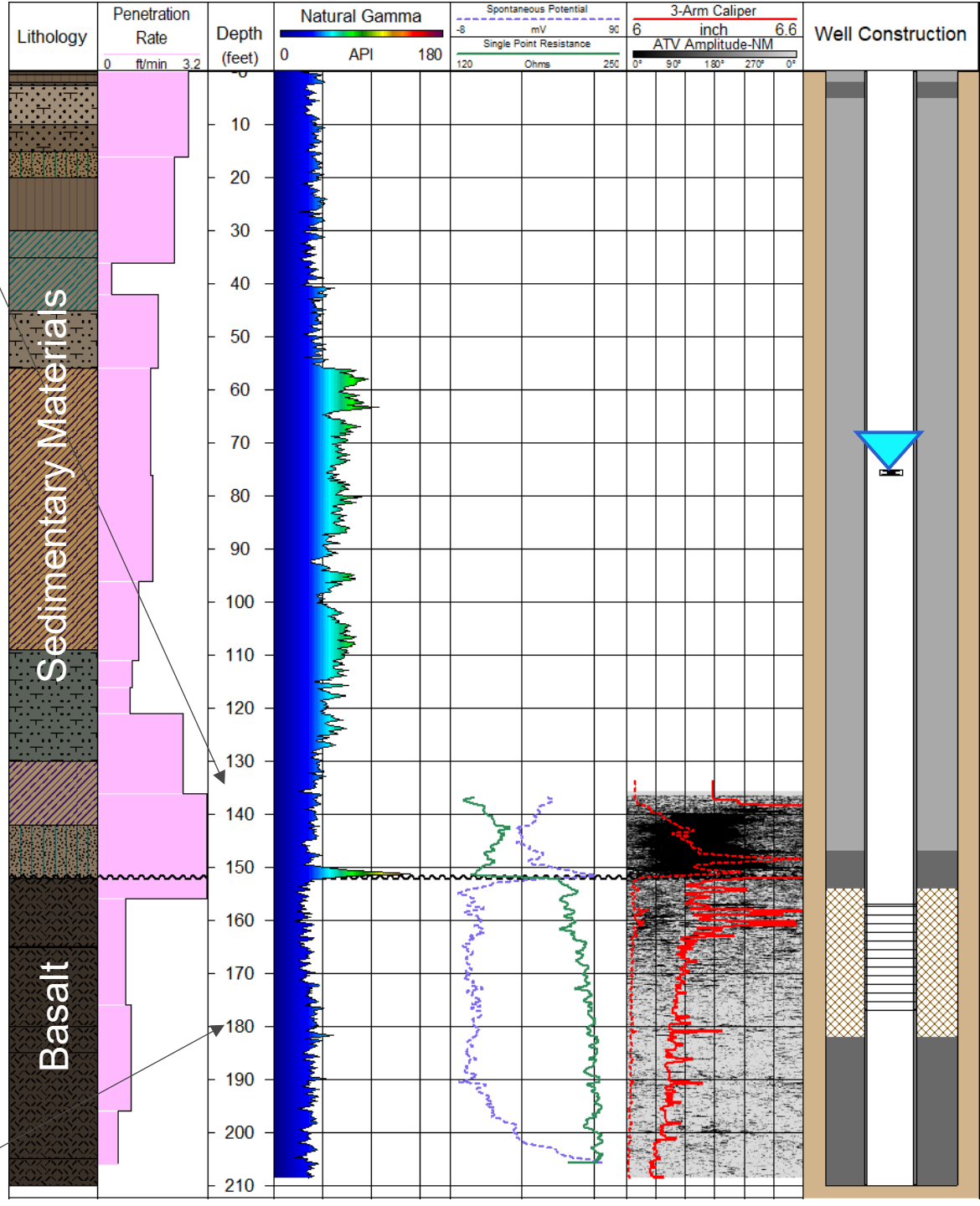




Example Geologic/ Geophysical Log in Thick Sediment Area

- Air-Rotary chip samples visually logged.
- Sediments contain some high natural gamma strata whereas basalt is generally uniformly low natural gamma
- SP/SPR respond with indication of basalt by increased resistance.
- Caliper reveals hole increase at top of basalt.
- Acoustic Televiewer shows vesicular basalt flow top, grow more massive with depth





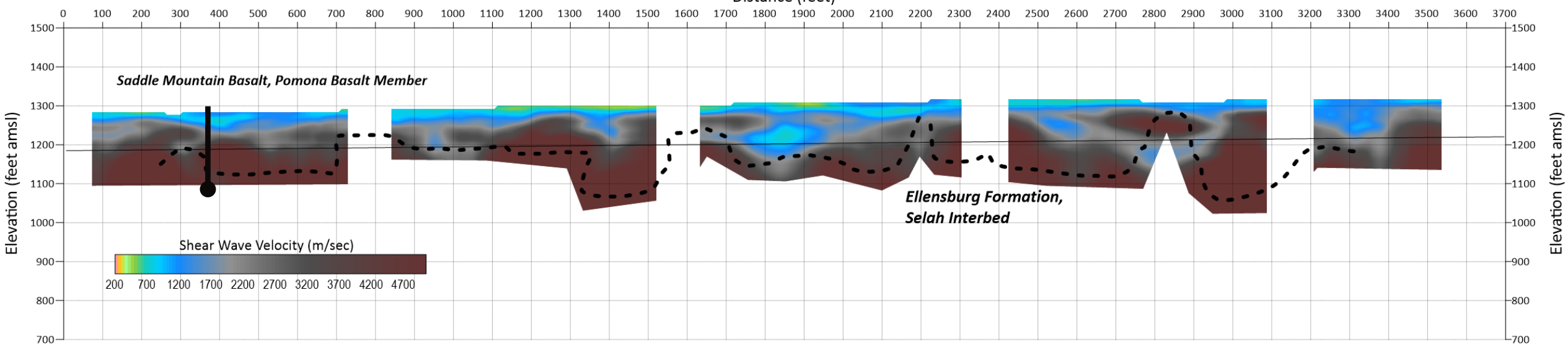
Line C

Resistivity & Seismic

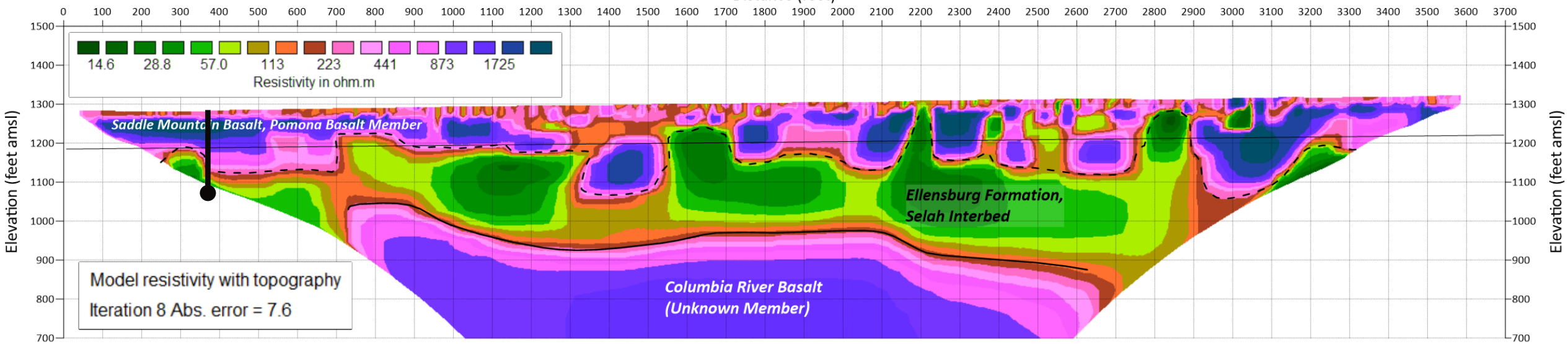
ARCADIS

SOUTH NORTH

LINE C - SEISMIC SHEAR WAVE MODEL

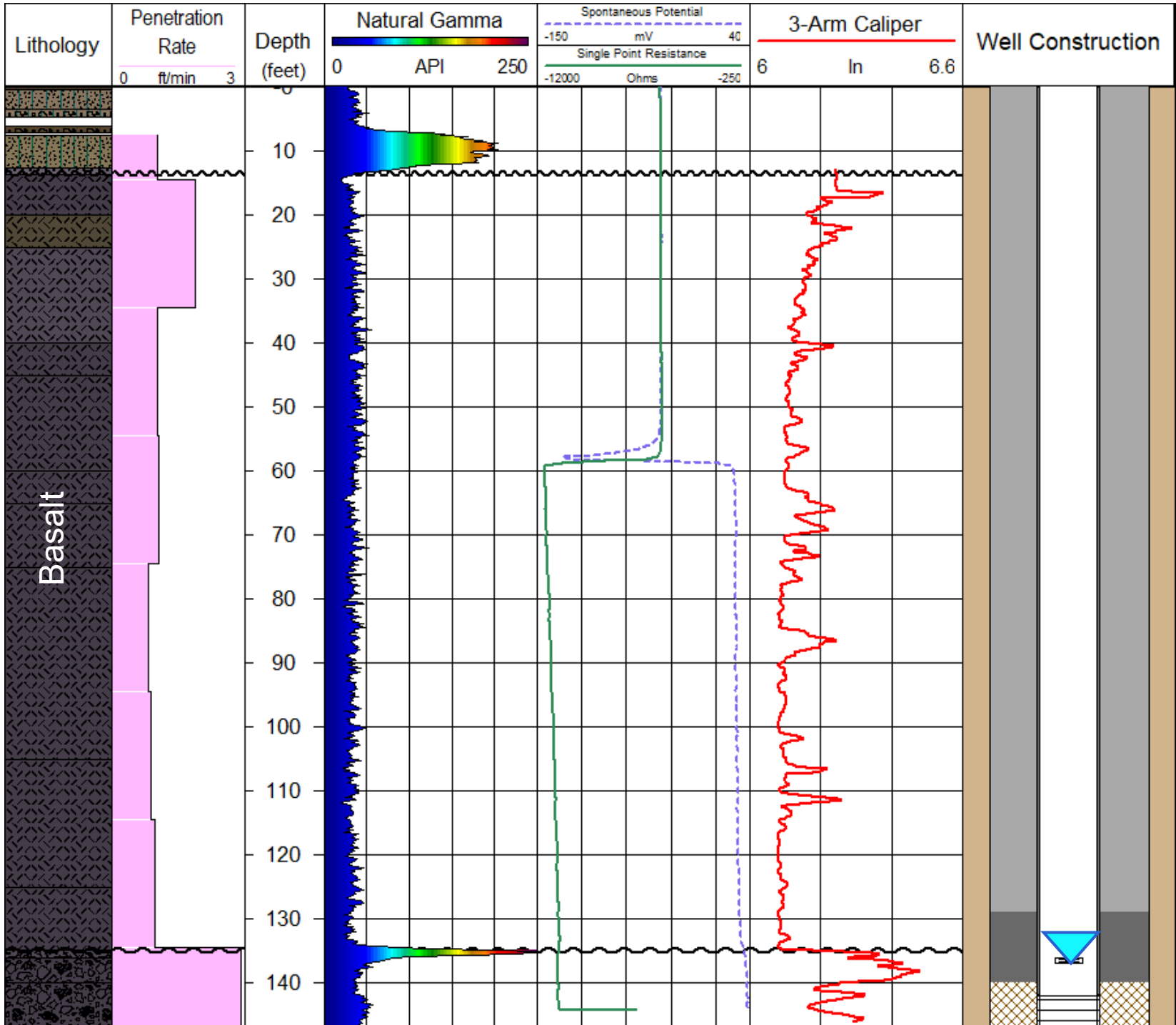


LINE B - ELECTRICAL RESISTIVITY MODEL



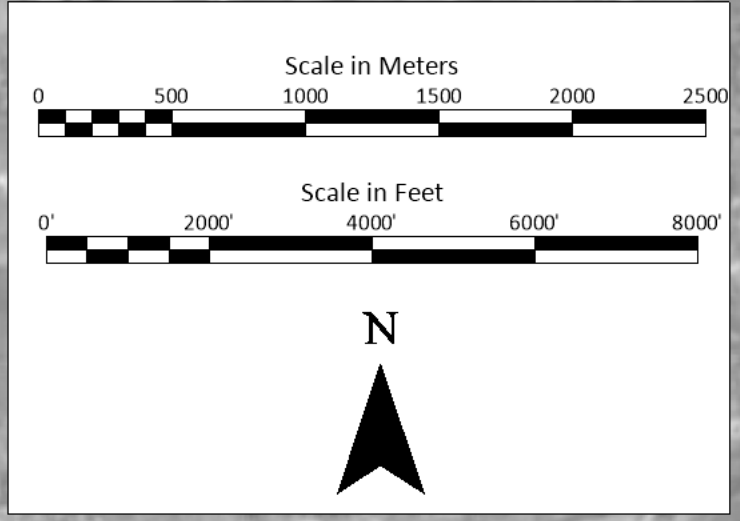
Example Geologic/ Geophysical Log in Shallow Basalt Area

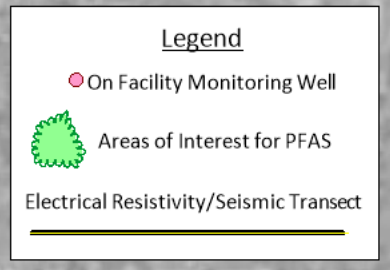
- Air-Rotary chip samples visually logged.
- Sediments contain high natural gamma strata whereas basalt is generally uniformly low natural gamma
- SP/SPR poor response due to electrical isolation between surface and saturated zone.
- Caliper reveals hole increase at base of basalt.

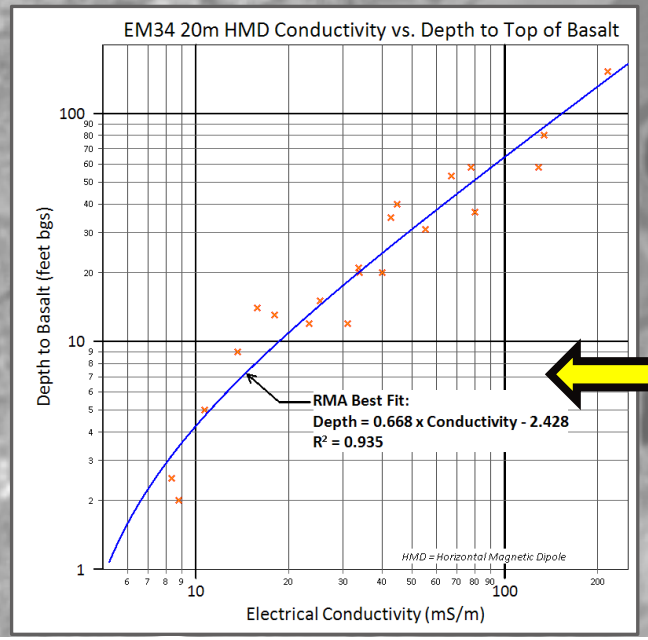


Phase 2
EM34

ARCADIS



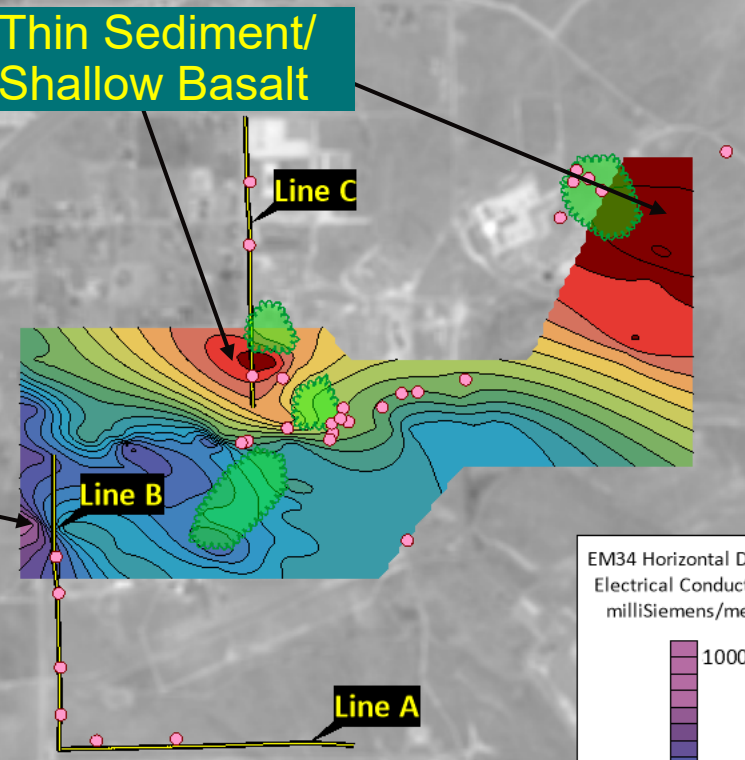


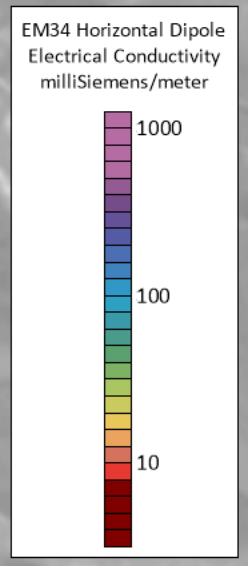


Correlation of EM34 HMD Conductivity with Well-Based Depth to Basalt

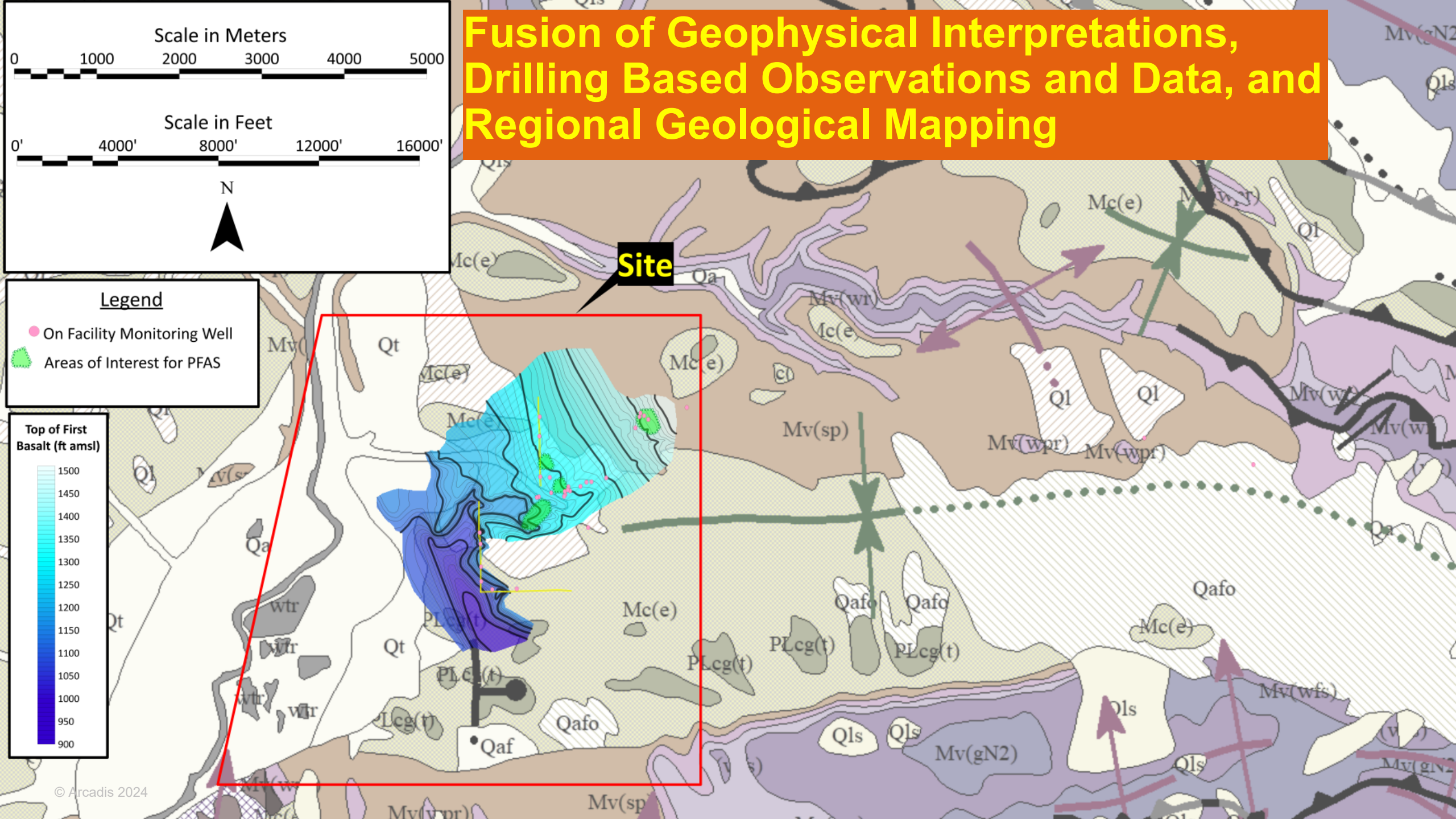
Thin Sediment/ Shallow Basalt

Thick Sediment/ Deep Basalt





Fusion of Geophysical Interpretations, Drilling Based Observations and Data, and Regional Geological Mapping



Closing Thoughts

- Applicability of Geophysics
  - **Knowledge of the geology** is essential – lithologies, hydrogeology, structure
  - Method Choices: good **physical property contrast** to create meaningful results – and don't forget to consider **site conditions and noise sources**.
  - Understanding limitations/assumptions, resolution and **pitfalls** of methods
  - **Ground-Truthing** of results using sampling and geophysical methods which can be related to the surface geophysics
- Value of Geophysics
  - Provides a means for **directing the decision making** for drilling locations
  - **Reduces uncertainty** between boreholes and **improves confidence**
  - CSM: enhances knowledge of **"big picture"** for large scale geologic problems
  - Helps to maximize return on investment - but is **not a substitute for drilling**.

Thank you

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