Woodard & Curran

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From Airborne Electromagnetic (AEM) Data to Hydrogeologic Conceptual Models (HCMs)

PRESENTED BY

Jack Baer, P.G.

Sercan Ceyhan

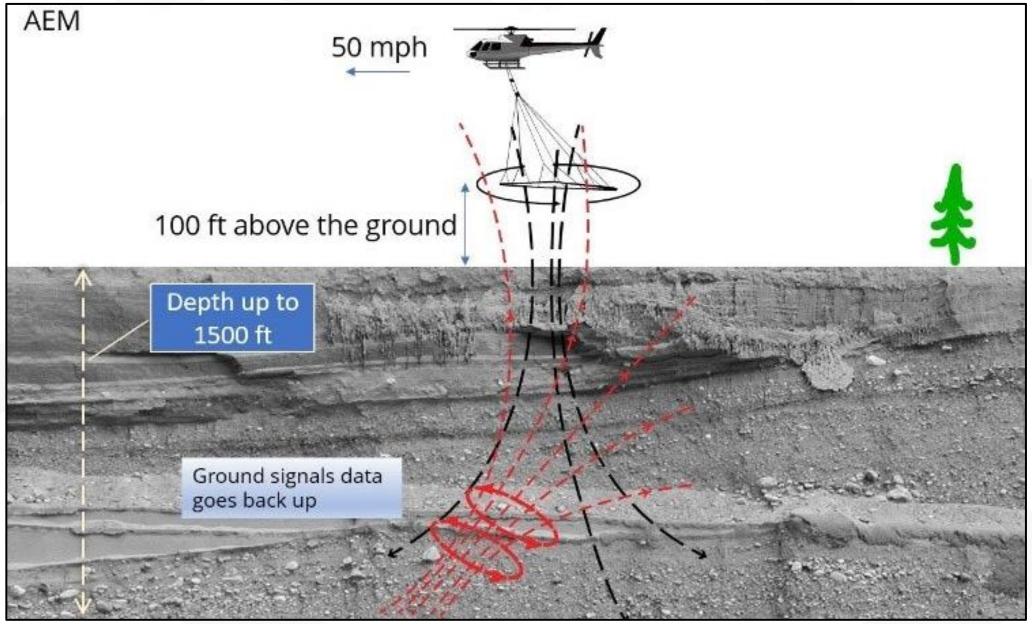
Outline

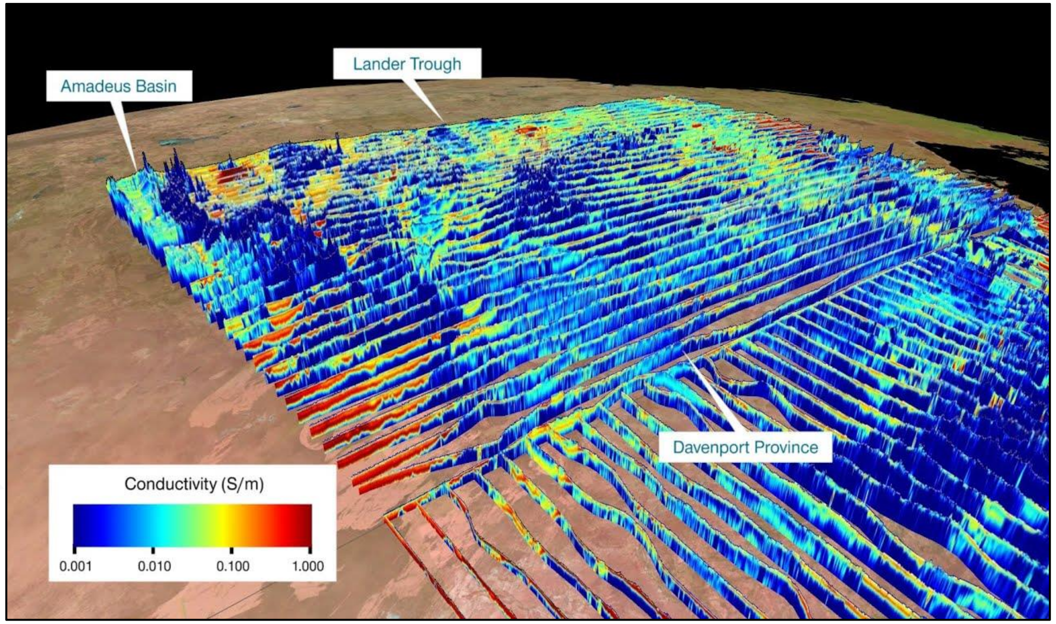
- →AEM Introduction
- →Project Overview
- →Literature Review
- →AEM2HCM Tool Development
  - Machine Learning Model Development
  - Preliminary Results
  - Sensitivity Analysis
- →Next Steps

Airborne Electromagnetic Data

→Helicopters with geophysical instruments fly along survey lines, collect data

→*Data* **+** *physics & math* → *2.5D model of subsurface electrical resistivity*





Project Overview

- **Overall Program Goals:** Technical assistance to GSAs and other local agencies in utilizing AEM data in a cost-effective and standardized manner
  - Facilitate use of AEM data by GSAs and others in improving sustainable groundwater management

- **Project Purpose:** Develop workflow and tool(s) to utilize AEM survey data in enhancing hydrogeologic conceptual models and numerical groundwater models
  - Preliminary research into existing workflows and best practices for:
    - Interpreting and using AEM data to enhance HCMs
    - Parameterizing numerical models using AEM data

Project Plan

→ **Solution:** *Build a machine learning model to aid in the development of hydrostratigraphic models from AEM data* ***– AEM2HCM Tool***

→ **Why machine learning?**

- AEM inverse models are non-unique
- Automatic interpretation enables many HCMs to be developed and tested in a groundwater model
- Enables stratigraphic calibration with a parameterization utility (e.g. PEST), stratigraphic sensitivity and uncertainty analysis

Learning Styles
Unsupervised vs. Supervised

Supervised Learning	Unsupervised Learning
Labelled	Not labelled
By Proper Guidance (Kind of Teacher)	No Guidance (Self Learning)
Explicitly learning model	It Identifies the patterns
Predicts the outcome/future	Not Predict nor find anything specific
	

- → Supervised – more robust, more control, but requires ample training data
- → Difficult to compile sufficient training data for geologic interpretation from AEM
  - Few publicly available datasets that include hydrogeologic conceptual models
  - AEM-lithology relationships highly variable locally, also dependent on equipment calibration and non-unique interpretations by contractor (often qualitative)
- → Here, used an unsupervised approach

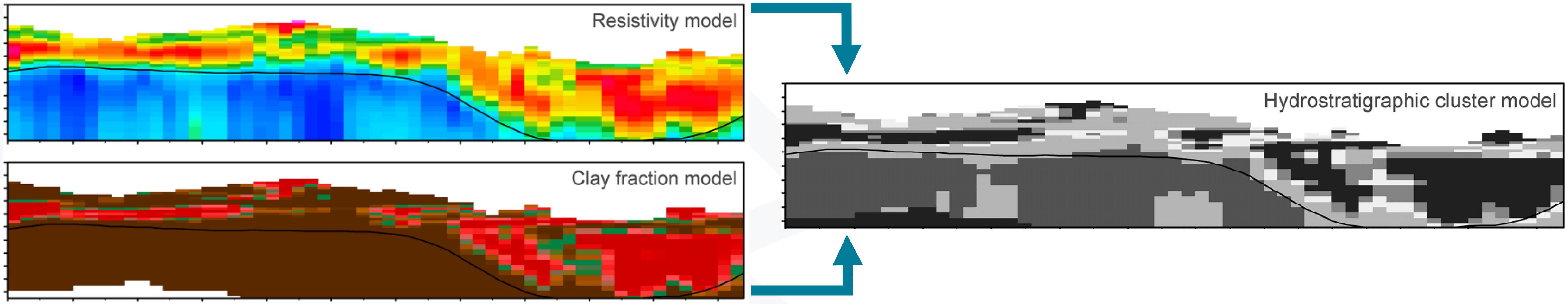
Relevant Literature
Marker et al., 2015

Identify locations with similar lithologic properties (e.g. sand, silty sand, clay)

WHAT: Unsupervised machine learning model

HOW: K-Means clustering of resistivity & clay fraction models

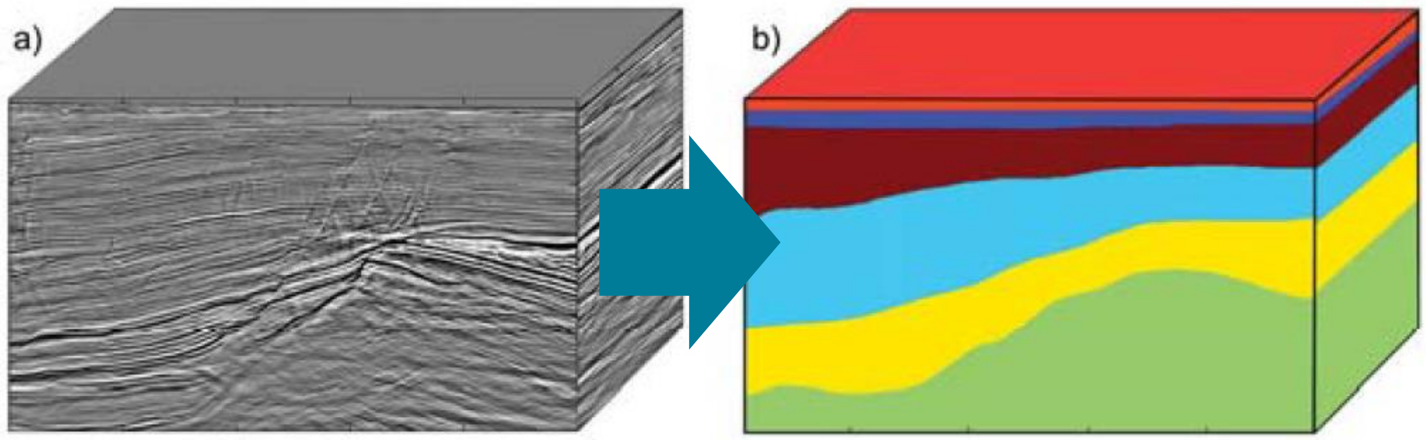
GOAL: Lithologic modeling



Relevant Literature
Bugge et al., 2020

Identify generalized strata/horizons (e.g. formations)

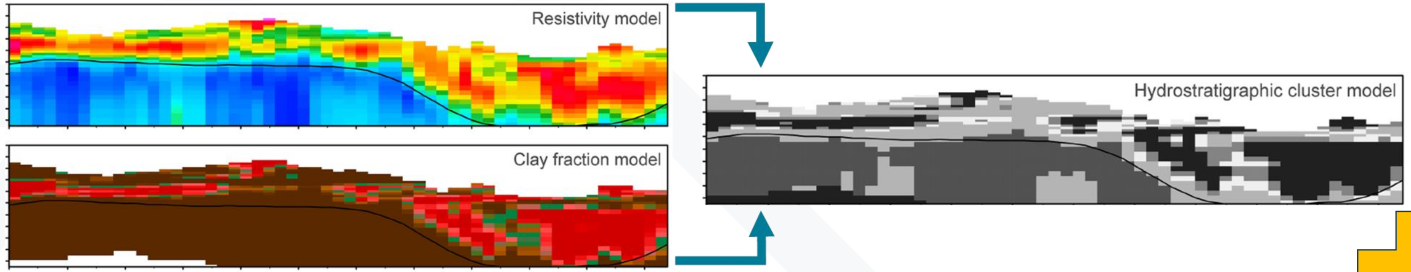
WHAT: Unsupervised machine learning model
HOW: Image processing + HDBSCAN clustering of seismic reflection data (seismic cube)
→ Features: Amplitude, Texture, Two-Way Travel Time
GOAL: Stratigraphic modeling



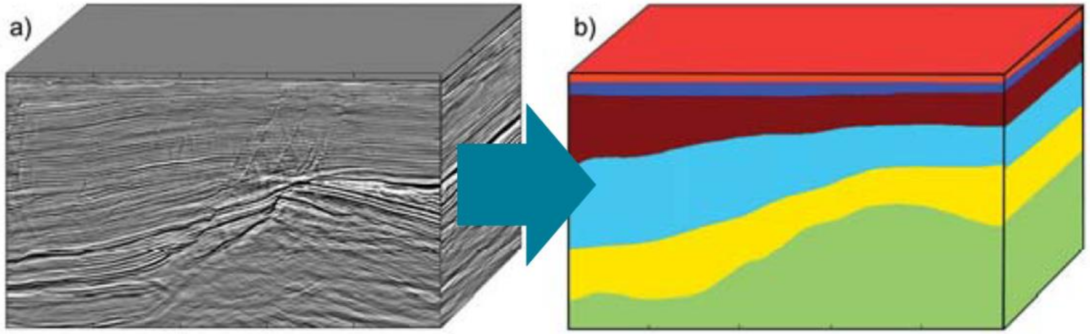
AEM2HCM Tool

Development Thought Process

→Marker et al., 2015



→Bugge et al., 2020



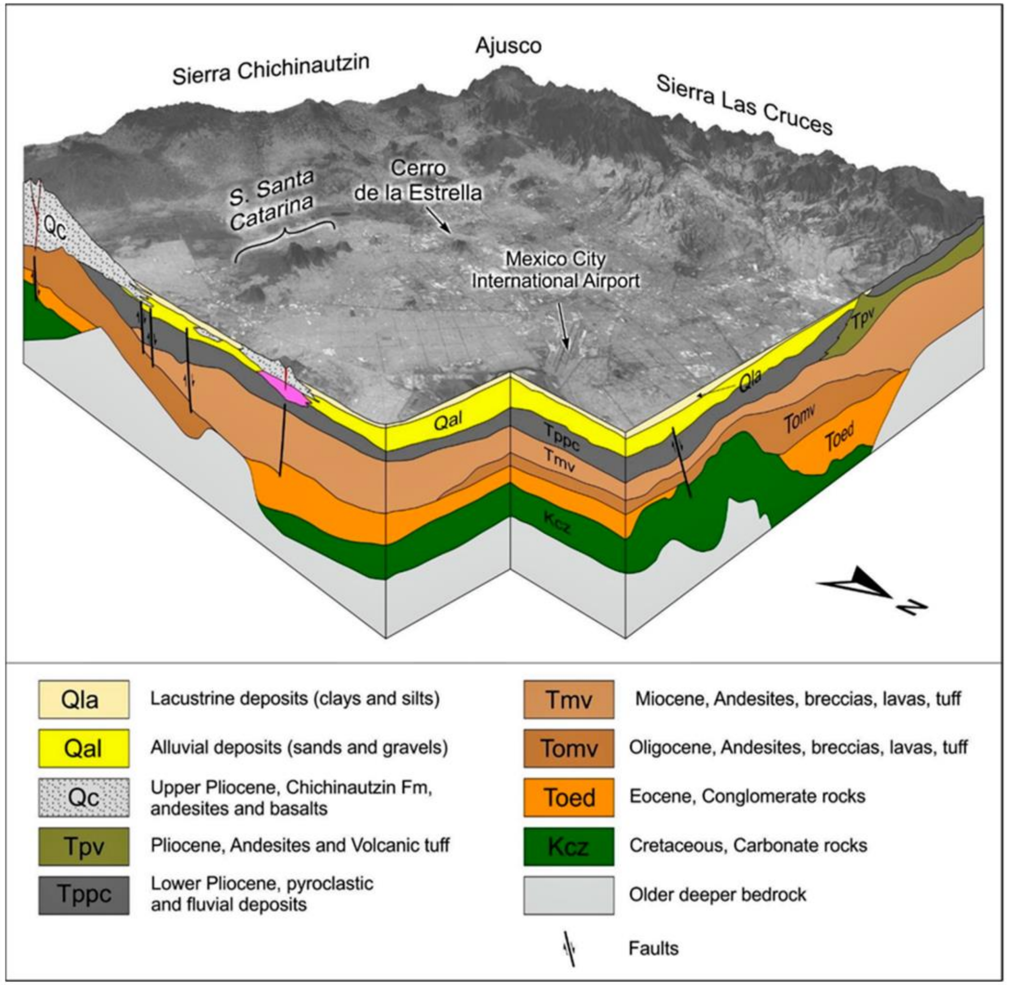
Combine

&

Modify

Feature Selection and Engineering

What Makes a Hydrostratigraphic Unit?



Goal:
Identify plausible hydrostratigraphic units from AEM data

Properties of Hydrostratigraphic Units

- Identical Geologic Superposition
- Generalized Layers with Similar Lithologic/Hydrologic Properties
- Boundaries Often Marked by Sharp Contacts with Dissimilar Units

Feature Selection and Engineering
What Makes a Hydrostratigraphic Unit?

Available Features

- Easting/Northing
- Elevation
- Depth
- Inverse Model Layer Number
- AEM Resistivity Value
- Clay Fraction Value
- Boring Logs

Goal:
Identify plausible hydrostratigraphic units from AEM data

Properties of Hydrostratigraphic Units

Identical Geologic Superposition

Generalized Layers with Similar Lithologic/Hydrologic Properties

Boundaries Often Marked by Sharp Contacts with Dissimilar Units

Feature Selection and Engineering
Selected Features

Available Features

- Easting/Northing
- Elevation
- Depth
- Inverse Model Layer Number
- AEM Resistivity Value
- Clay Fraction Value
- Boring Logs

Domain Knowledge

Statistical Analysis

Trial-Error

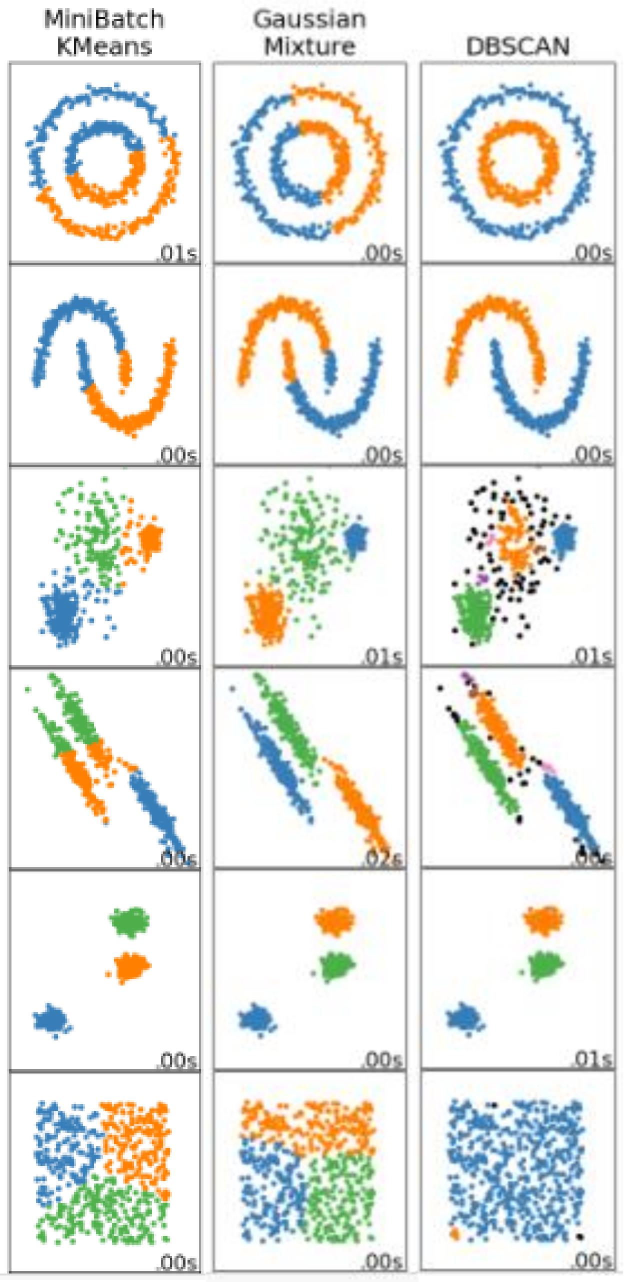
Selected Features

- Easting/Northing
- Elevation
- Depth
- **Inverse Model Layer Number**
- **AEM Resistivity Value**
- **Clay Fraction Value**
- Boring Logs

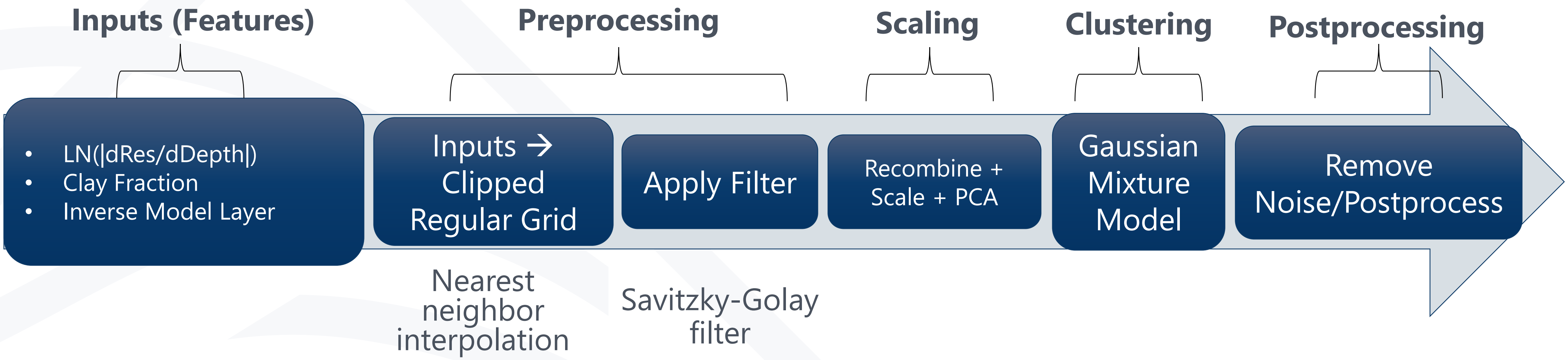
Selecting a Clustering Algorithm

K-Means vs. GMM vs. (H)DBSCAN

Property	K-Means	Gaussian Mixture Model	(H)DBSCAN
Class Probabilities (Soft Clustering)	No	Yes	Yes
Cluster Geometries	Simple	Relatively Complex	Very Complex
Speed (Large Datasets)	Fast	Medium	Slow
Memory Efficiency	Good	Medium	Poor
User-Specified K Clusters	Yes	Yes	No

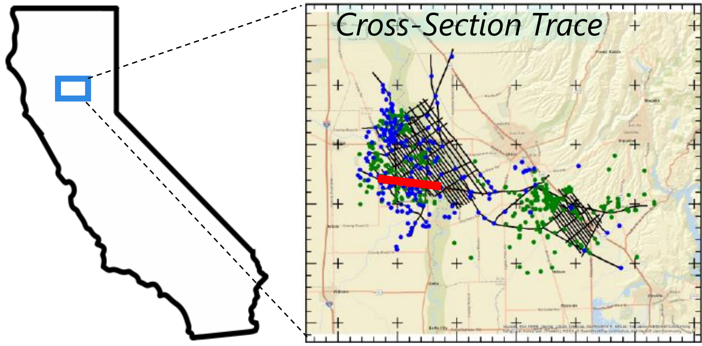


AEM2HCM Tool
Putting It All Together

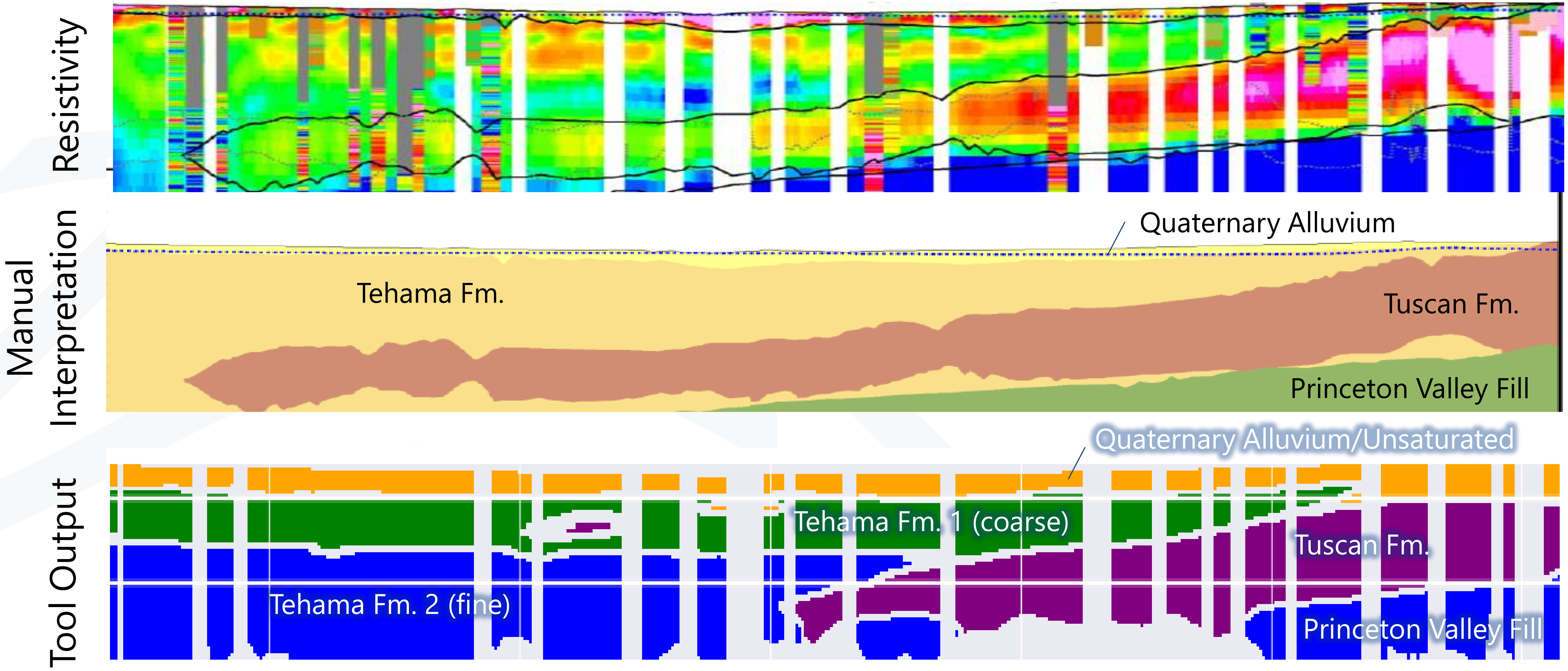


AEM2HCM Examples

Butte/Glenn

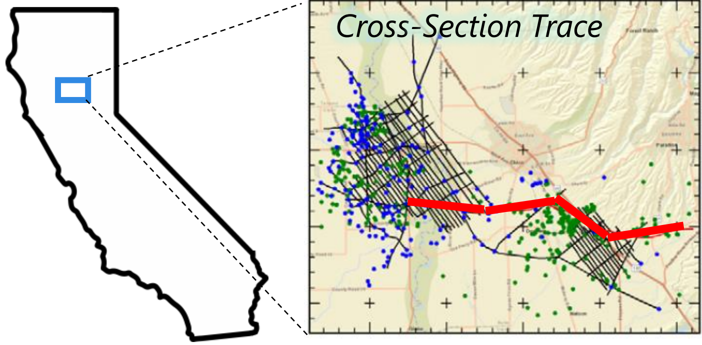


Line 710601



Note – layers in this example were clipped to class probability > 0.5; n_layers was manually set to 4; CF is a pseudo-CF

AEM2HCM Examples
Butte/Glenn



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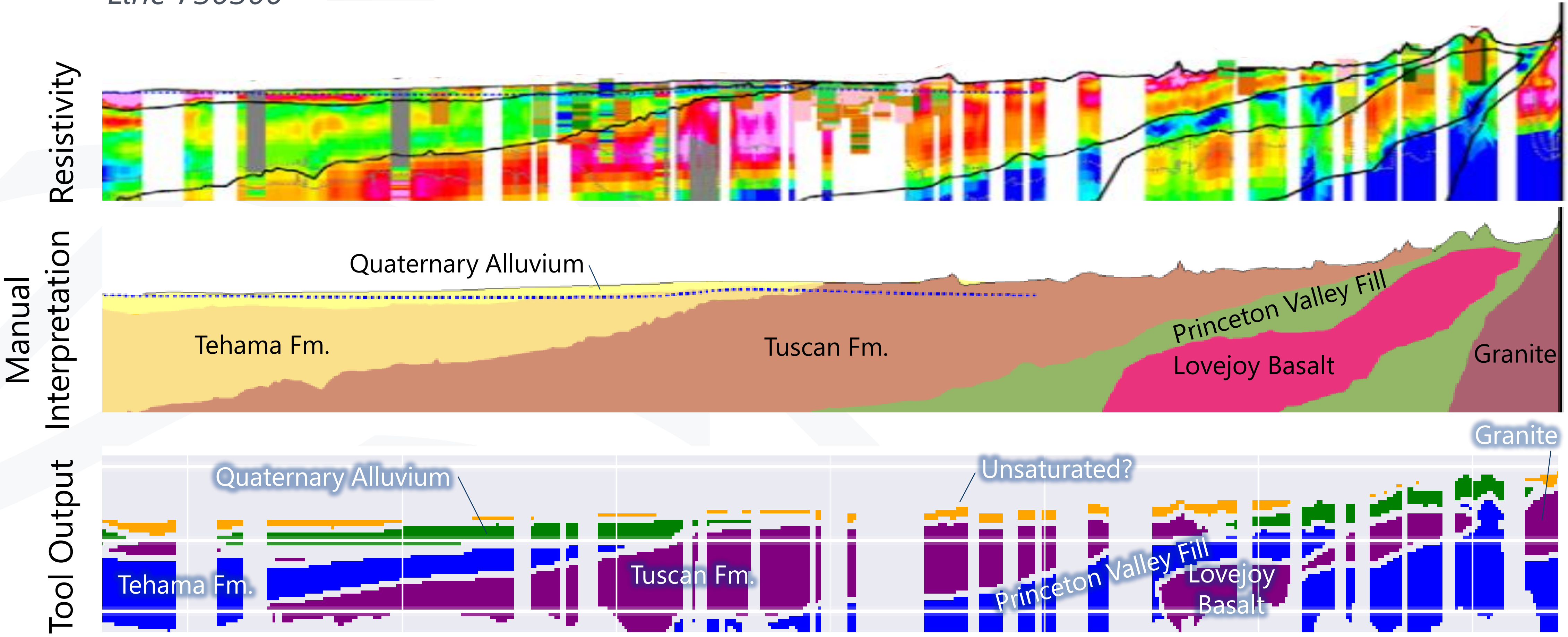

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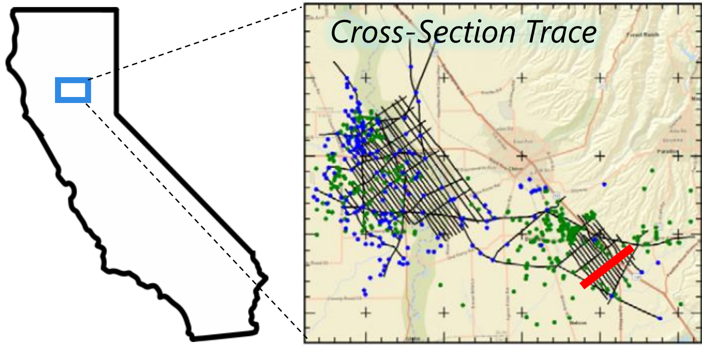
AEM2HCM Examples

Butte/Glenn



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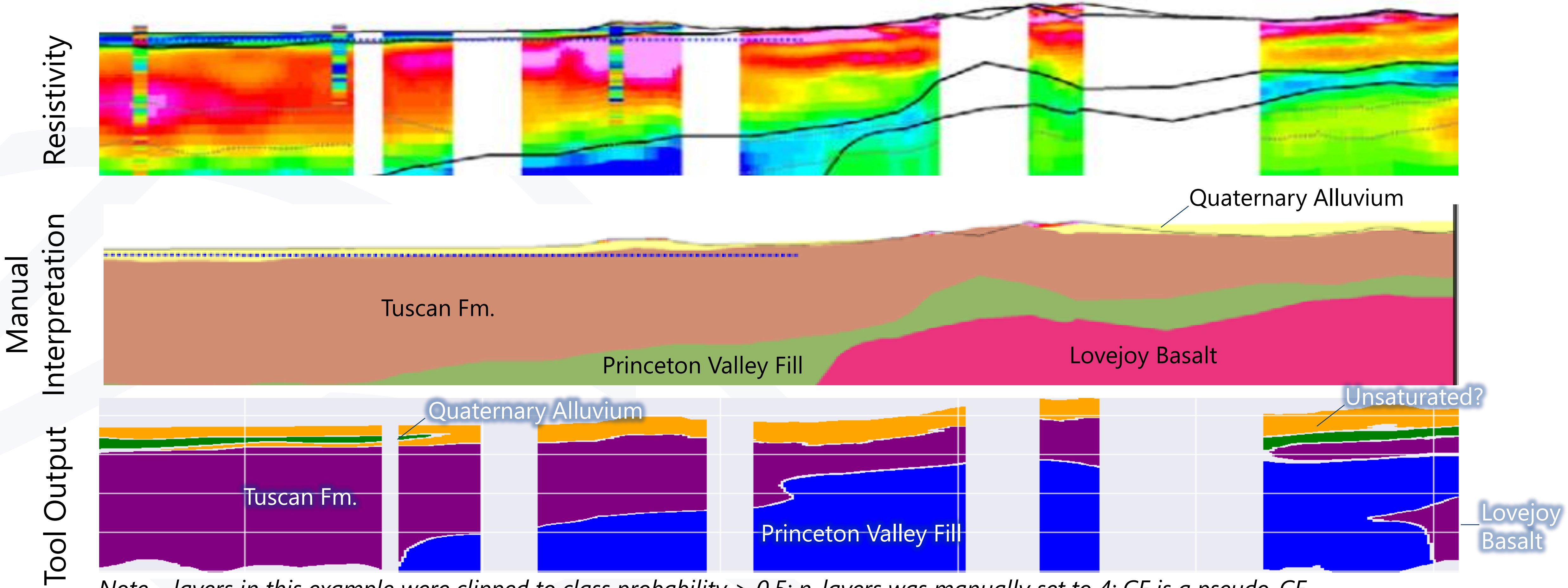

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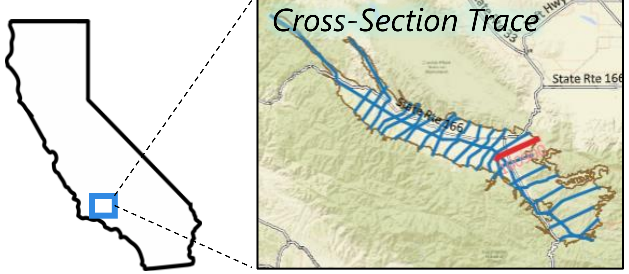
Tool is hit or miss at identifying Lovejoy Basalt – may perform better w/ n_layers=5

AEM2HCM Examples
Cuyama Valley



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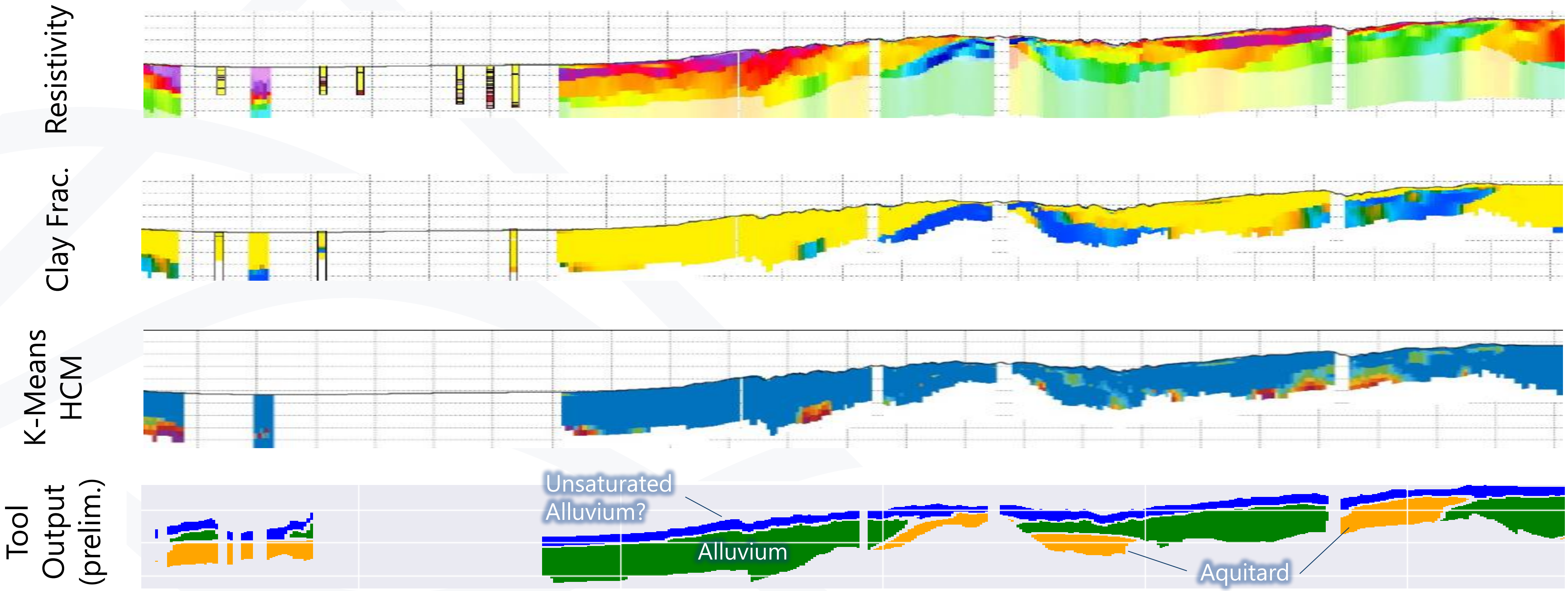


Note – layers in this example were clipped to class probability > 0.5; n_layers was manually set to 3

HCM Tool Development
Key Takeaways

- →Tool-informed HCM development will be crucial to maximizing the effectiveness of AEM data
  - Will allow for numerous uncertainty analyses
  - Will allow for optimum calibration
  - Will enable non-geophysicists to make optimum use of data
- →AEM2HCM has shown great promise to date
  - Some challenges remain with enforcing stratigraphic principles

Testing/Sensitivity Analysis

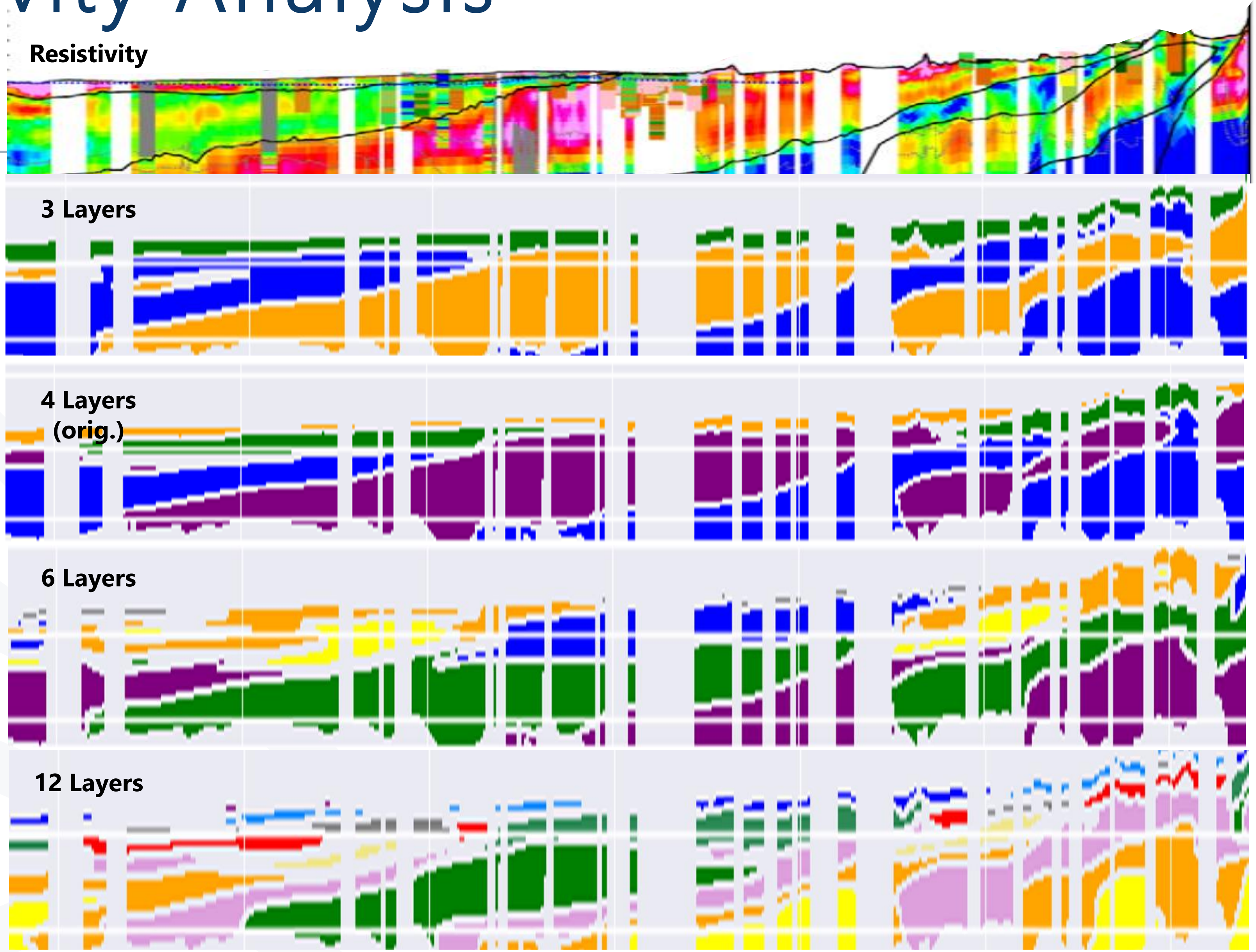
- →Initial assessment of the tool's capabilities, strengths, and weaknesses
- →Looking at changes resulting from:
  - **Number of layers**
  - **Elevation weighting**
  - Covariance type
  - Filter settings

Testing/Sensitivity Analysis

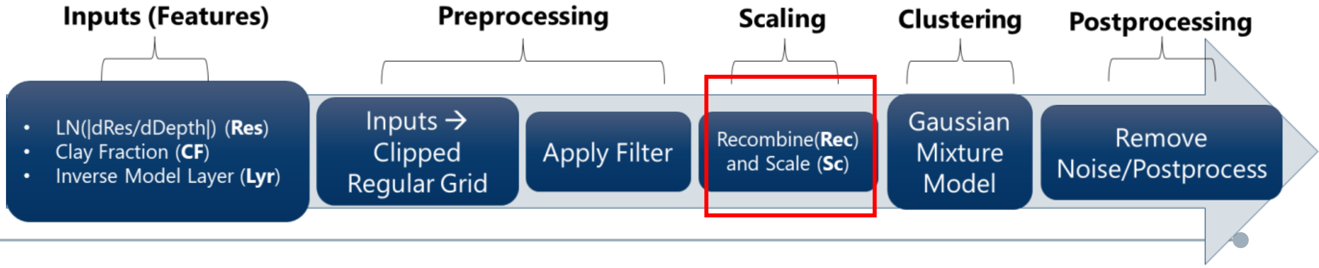
Layer Testing

- Line 730300

- → Very sensitive to the number of layers (clusters)
- → Number of layers corresponds to the number of distinct lithologic types to be identified, **not** the actual number of hydrostratigraphic units it will find
- → Both test datasets responded best to 3-4 layers, beyond that overfit to elevation



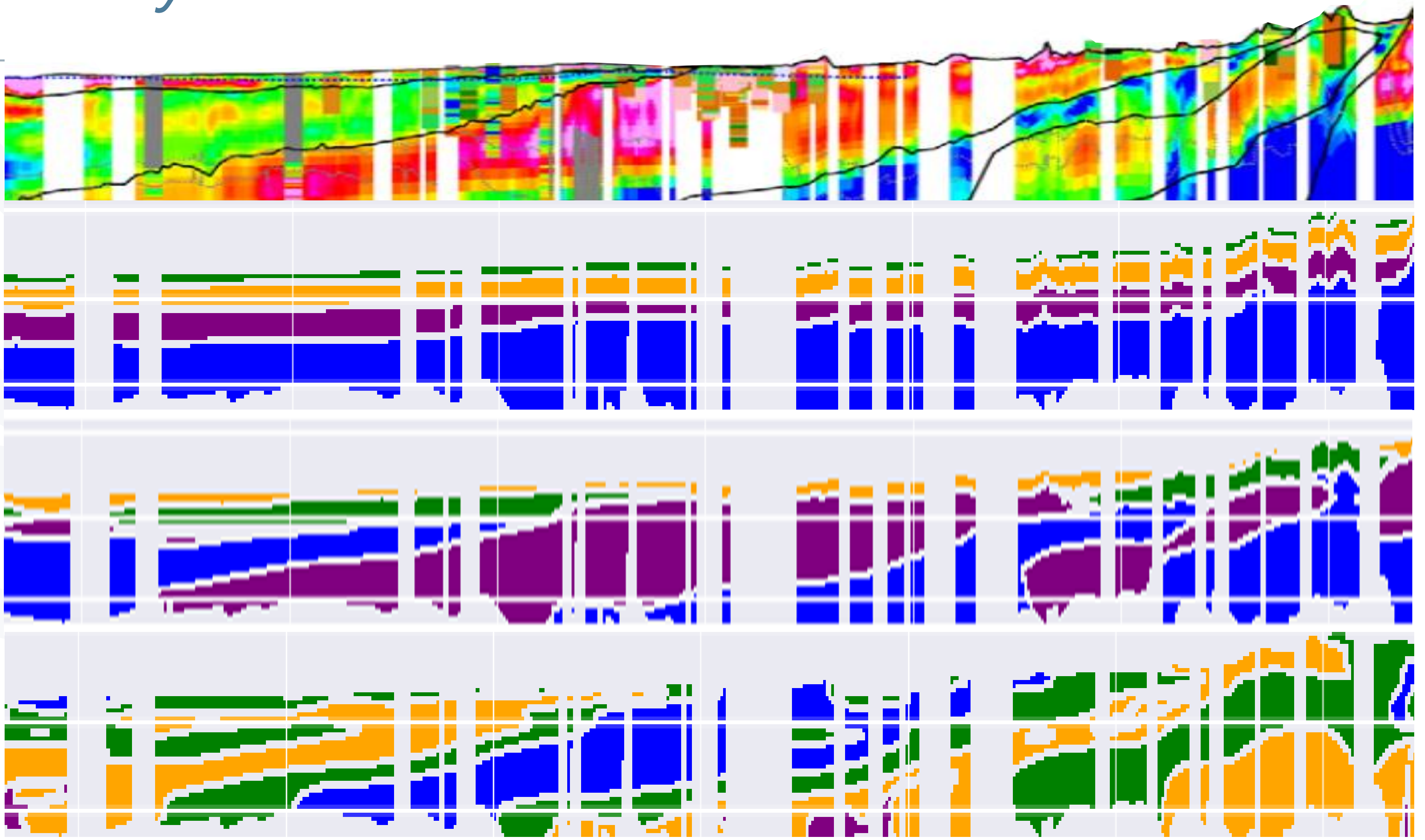
Elevation Weighting
Notes



- → Weighting features is generally **not** considered best practice in ML, but does offer some interesting possibilities here
- → Currently only testing weights on *elevation* feature
  - *Very high weight* → pancake-style layers loosely based on material types
    - » May be useful for GW modelers
  - *Very low weight* → lithologic-style model
    - » May be useful for geologists
  - *Weight of 1* → can approximate stratigraphic units
    - » May be useful for modelers and geologists alike
- → Weighting may also help prevent overfitting to depth when the desired number of layers is large

Effects of Elevation Weighting

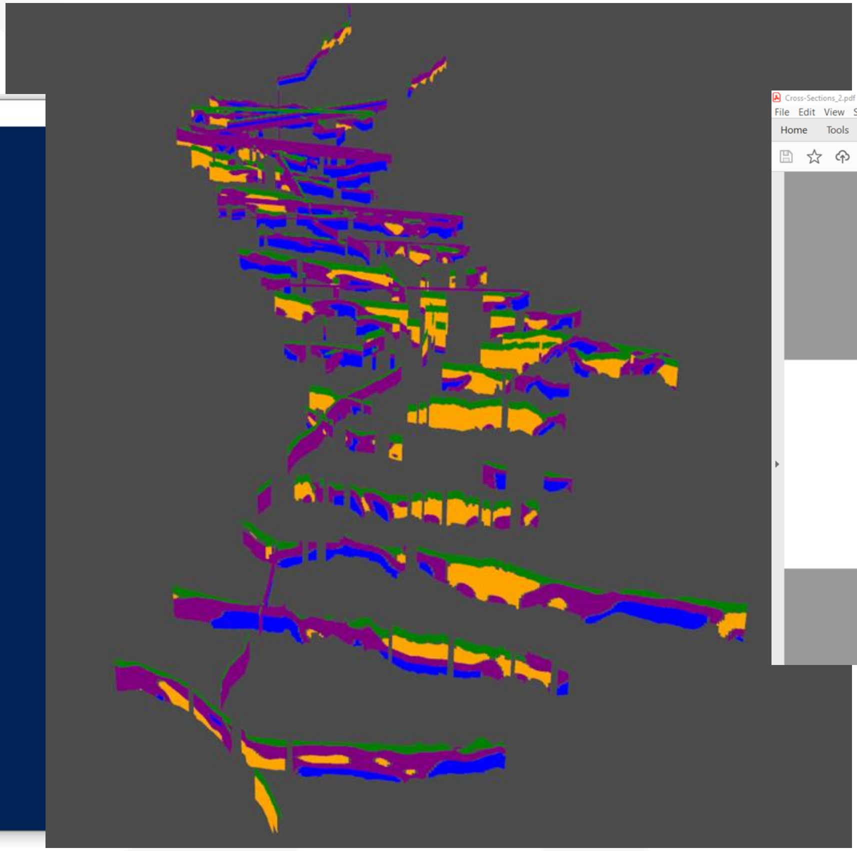
Line 730300 – Layers = 4



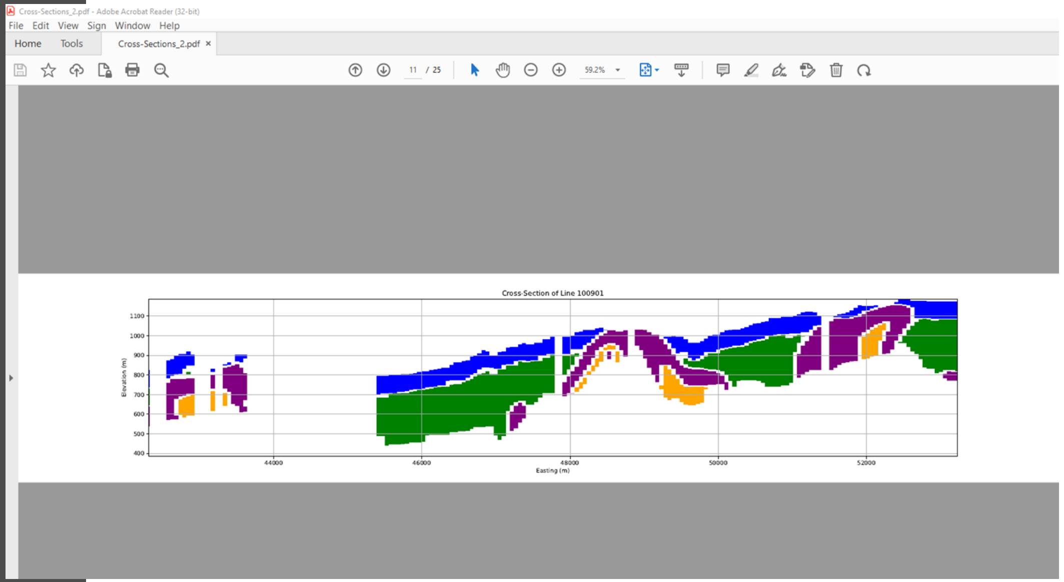
AEM2HCM
Preliminary Tool Development

Monitor Execution

Interactive fence diagrams of interpretations



Export interpreted cross-sections to PDF reports



Next Steps

- →Refine user interface and 3D visualization tools
- →Interpolation from fence diagram to 3D model
- →Allow incorporation of additional features by the user
  - Borehole data? Challenge – variable spatial resolution
- →Design algorithm to split clusters that contain distinct but lithologically similar units; enforce geologic principals
- →Generate input files for IWFM and MODFLOW
- →Test resulting stratigraphy in existing groundwater model; assess effects on model water budgets and calibration
- →Implement a workflow for quantifying the uncertainty of the resulting model

Thank you!

Woodard & Curran

Jack Baer, PG
Hydrogeologist

jbaer@woodardcurran.com
916.583.8917

801 T Street
Sacramento, CA 95811

Woodard & Curran

woodardcurran.com