Combining land and lake bottom magnetotelluric measurements to study volcanic systems in Mono Basin, California

Hannah Peterson
Project Geophysicist (Condor Consulting, Lakewood, CO)

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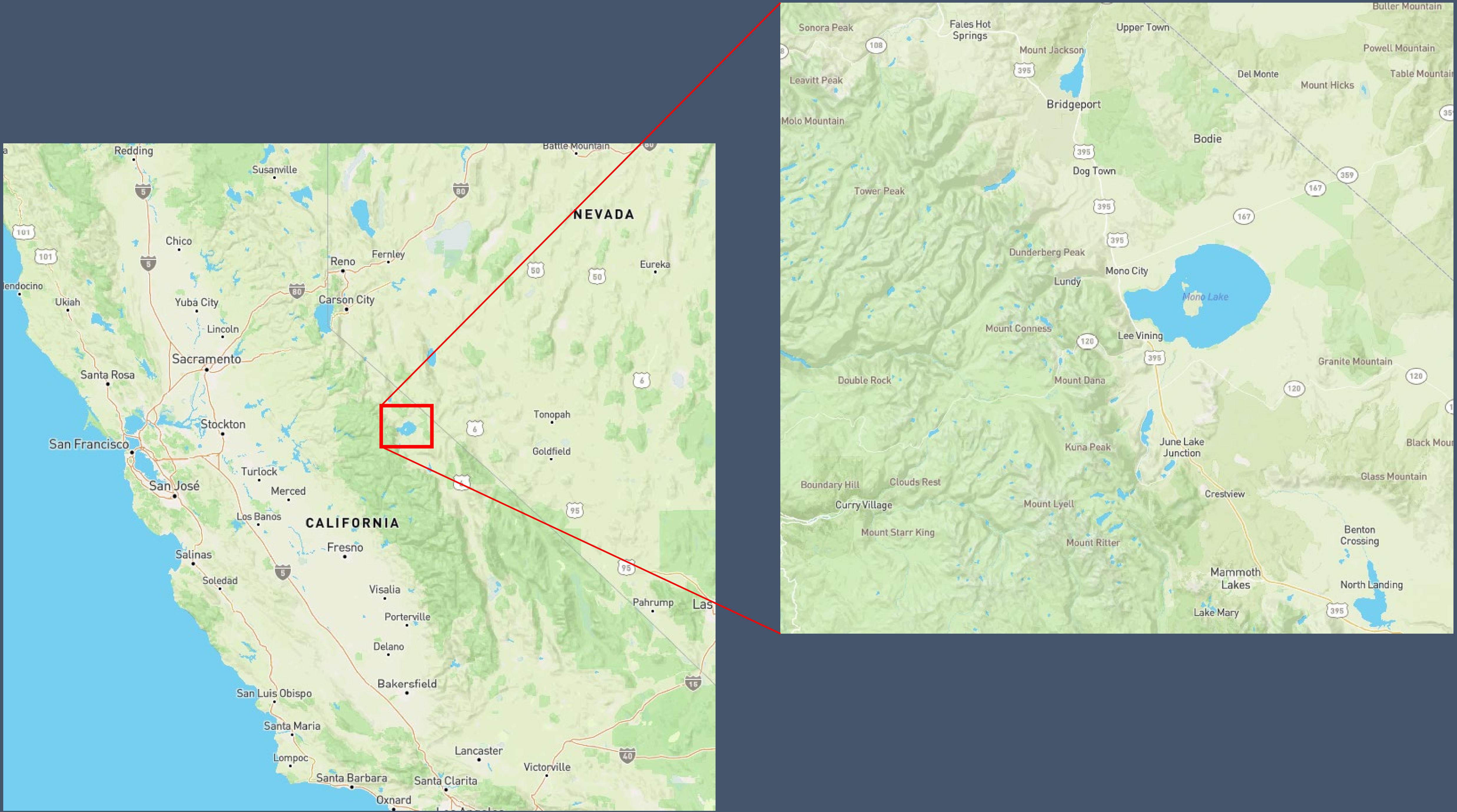
Redding
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Stockton
San Francisco
Tonopah
Goldfield
Turlock
San José
Merced
Los Banos
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Fresno
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Soledad
Visalia
Pahrump
Porterville
Delano
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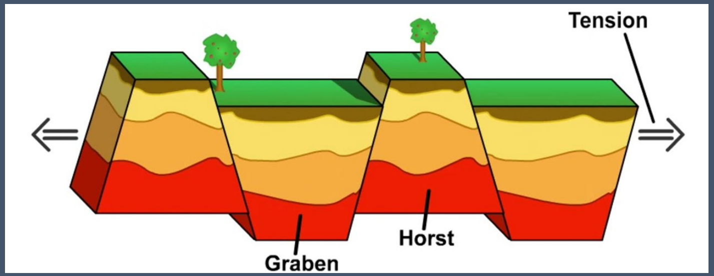
San Luis Obispo
Santa Maria
Lancaster
Lompoc
Victorville
Santa Barbara
Santa Clarita
Oxnard
Buller Mountain
Sonora Peak
Fales Hot Springs
Upper Town
Mount Jackson
Powell Mountain
Leavitt Peak
Del Monte
Mount Hicks
Bridgeport
Molo Mountain
Bodie
Dog Town
Tower Peak
Dunderberg Peak
Mono City
Lundy
Mono Lake
Mount Conness
Lee Vining
Granite Mountain
Double Rock
Mount Dana
Kuna Peak
June Lake Junction
Boundary Hill
Clouds Rest
Glass Mountain
Crestview
Curry Village
Mount Lyell
Benton Crossing
Mount Starr King
Mount Ritter
Mammoth Lakes
North Landing
Lake Mary

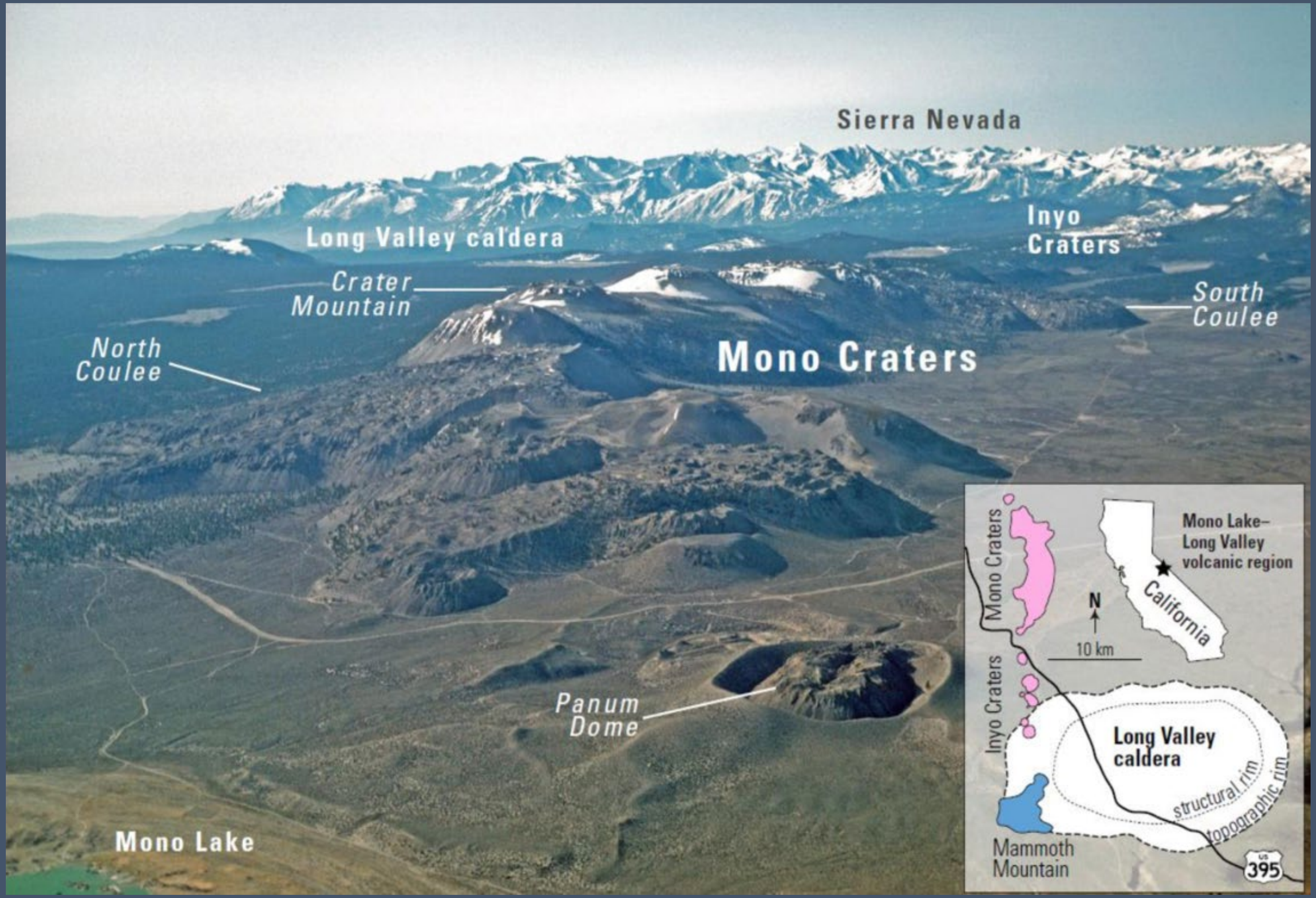
Regional Geology

The Owen Valley region consists of Owens River Gorge, Mono Basin and Long Valley Caldera

Located in the Basin and Range province east of the Sierra Nevada Mountain range (California/Nevada)

Extensional tectonics = stretching/thinning of crust, which allows hot mantle to rise to the surface and causes uplift/downdrop of blocks





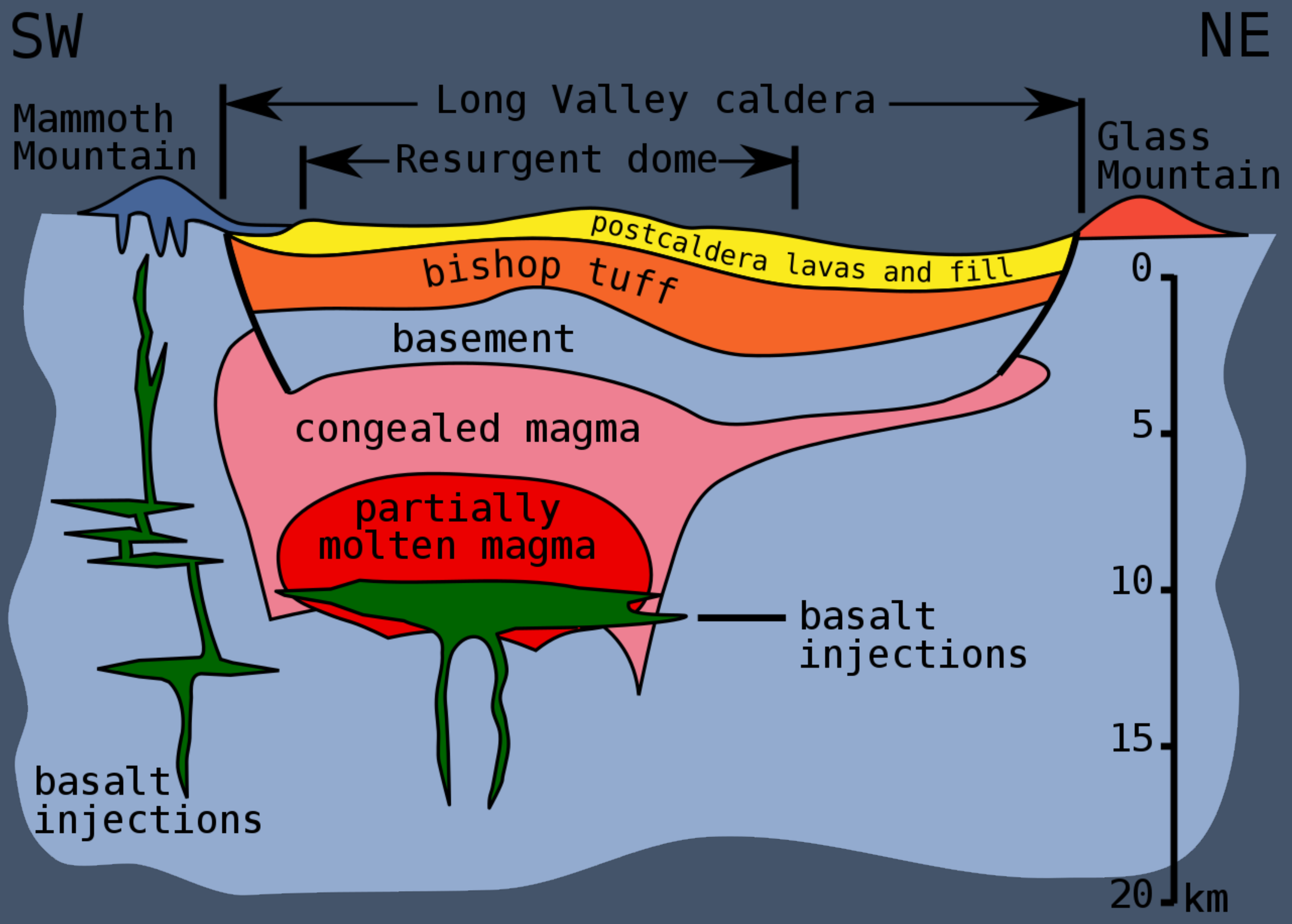
Long Valley Caldera

0.76 Ma

Bishop Tuff – 600 cubic km spread over more than 2000 km area

Volcanism is fed through a northwest striking dike allowed by 'basin and range' topography

Resurgent doming has occurred in the last 100 thousand years



Mono Basin

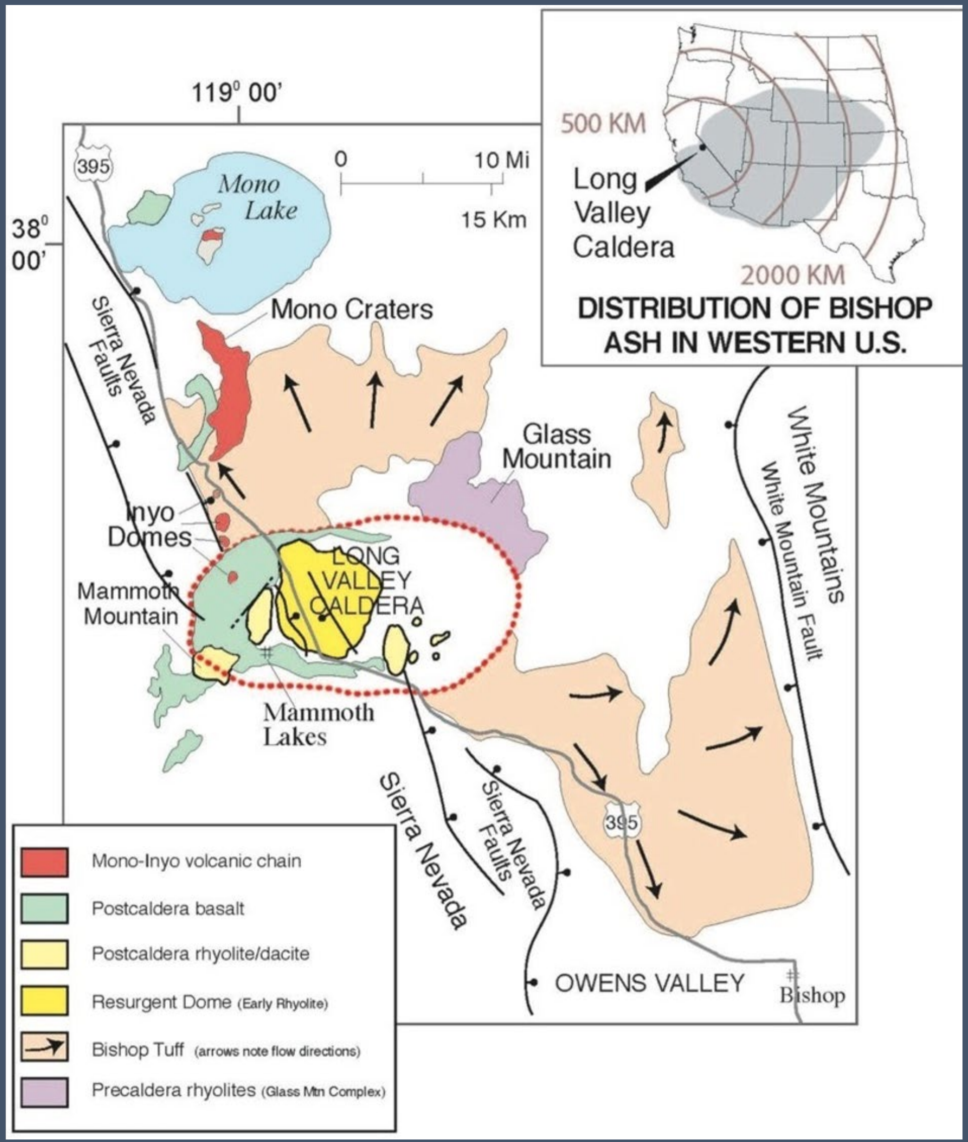
Bounded on the west by the Sierra Nevada fault

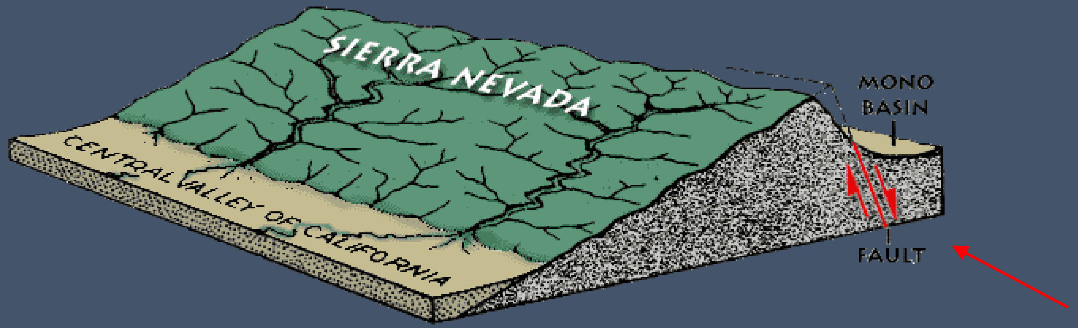
Uplift of the Sierra Nevada and White Mountain escarpments with down-dropped blocks, forming the basin

Inyo-Mono Crater chain consists of 30+ explosive eruptions beginning about 50,000 years ago

-Youngest rhyolitic volcanos in the western United States

-Highly ranked volcanic threat in the United States



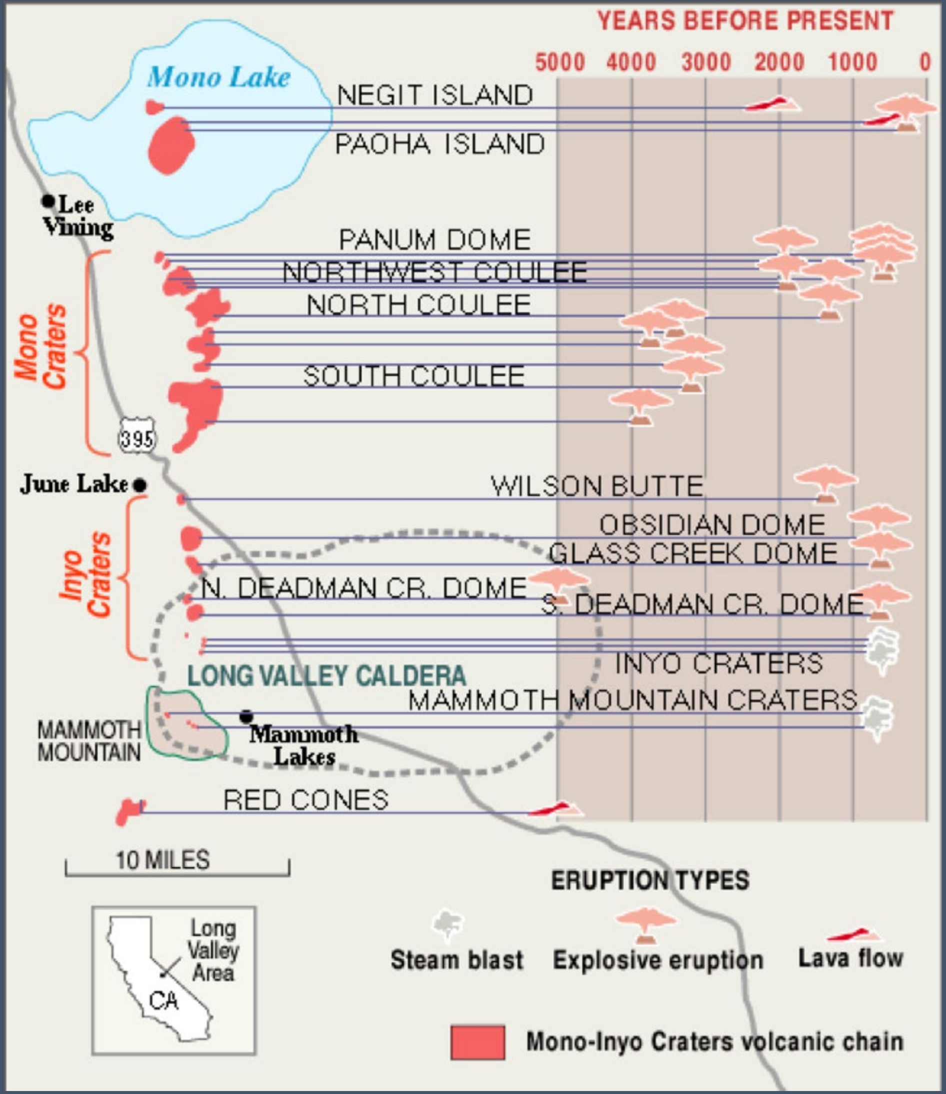


Bounded on the west by the Sierra Nevada fault

Inyo-Mono Crater Chain

Began south of Mammoth Mtn with phreatic (steam) explosions and rhyolitic lava flows (**Inyo)**

Then a northward progression of phreatic volcanoes plugged or overtopped by rhyolite domes and lava flows (**Mono)**



Mono Lake

180 km2 saline lake (81 g/l) with a max depth of 48 meters

Local volcanism poured basalt into nearby valleys creating natural dams – water filled into the area to create Mono Lake

Tufa towers from freshwater springs mix with saline lake water

Calcium rich water + carbonate rich (saline) water = $CaCO_3$ *(limestone)*

Paoha Island

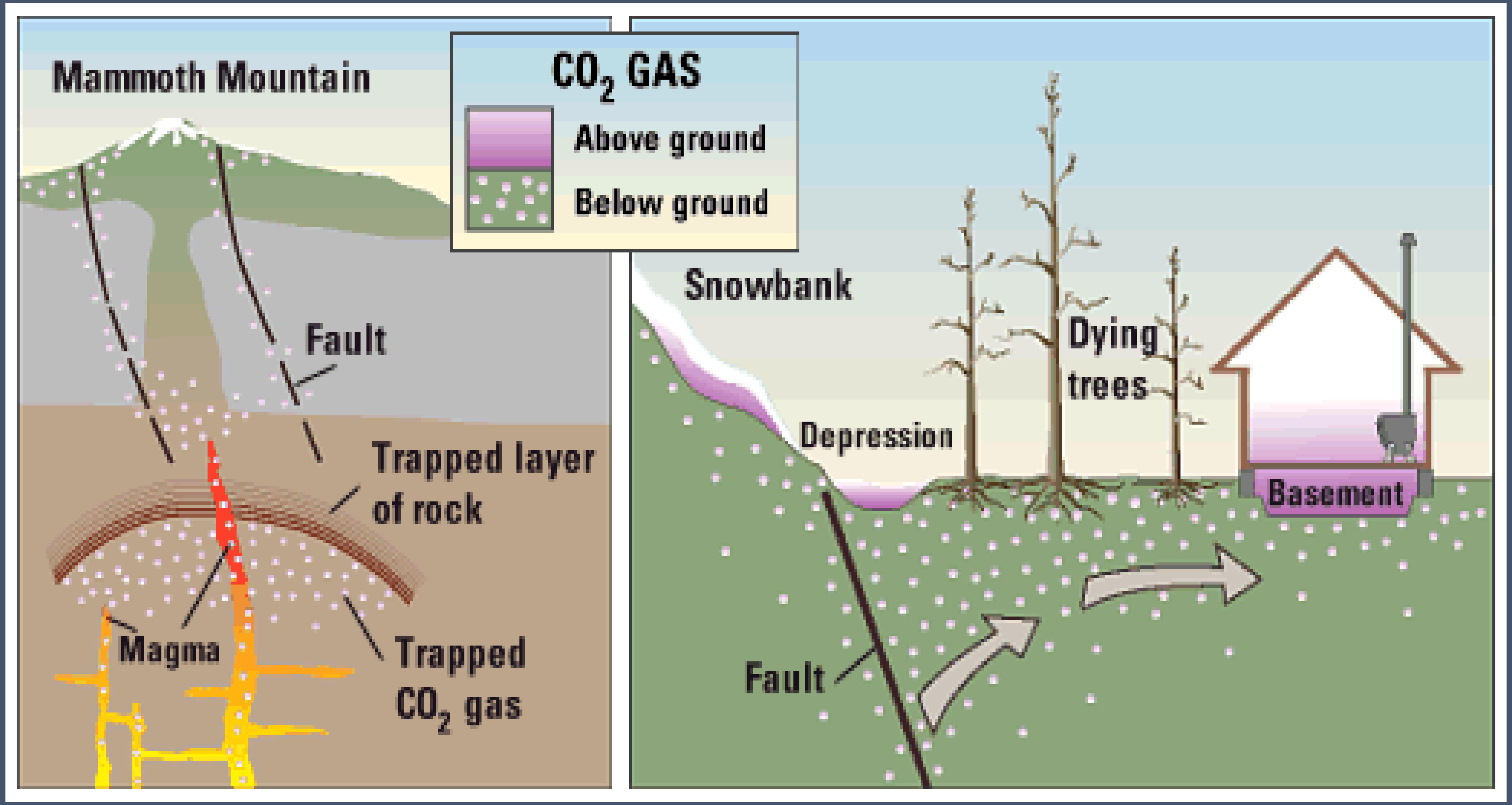
9.2 km^2 formed around 350 years ago

Composed of lake-bed sediments and volcanic material

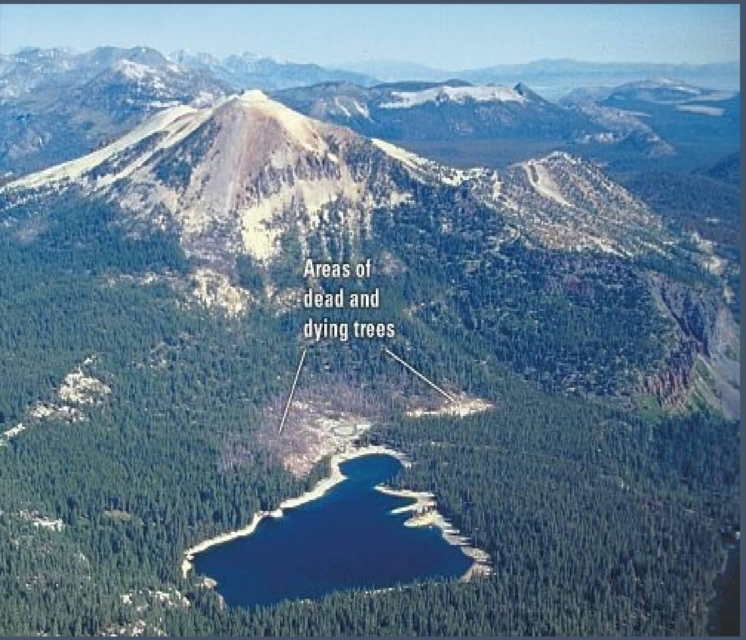
Motivation

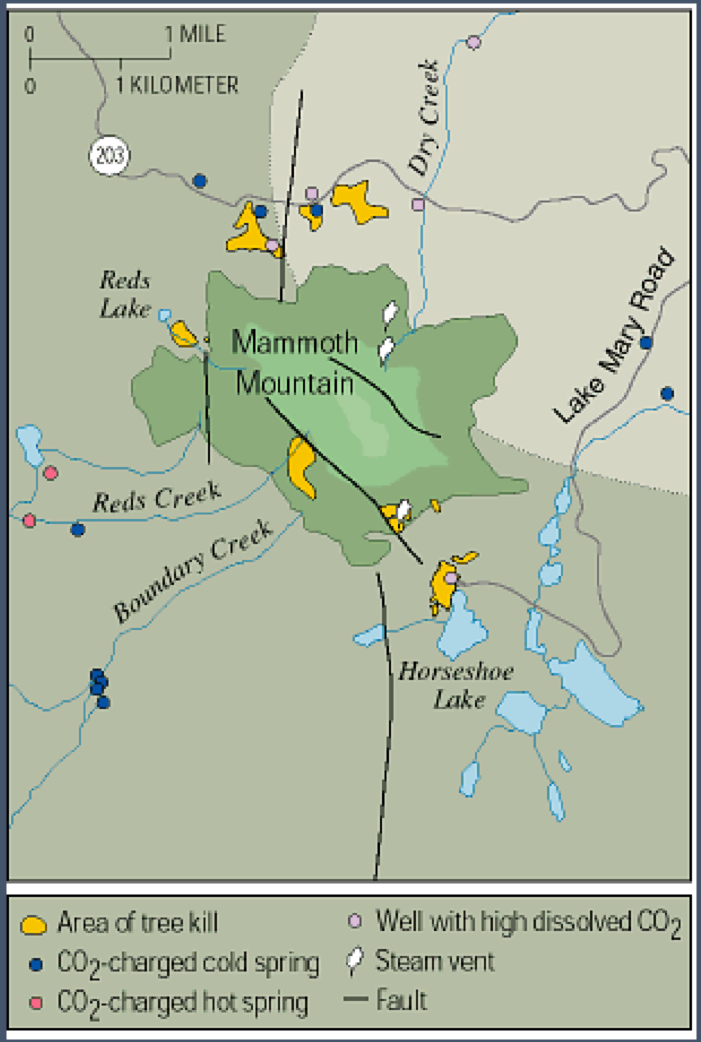

MONO BASIN
National Forest
Scenic Area
VISITOR
CENTER


CLOSED AREA
CO2 EMISSION AREA
SYMPTOMS:
SHORTNESS OF BREATH
AVOID:
TREE WELLS
FALLING IN FRESH SNOW
DO NOT DIG SNOW CAVES


Mammoth Mountain
CO_2 GAS
Above ground
Below ground
Fault
Trapped layer of rock
Magma
Trapped CO_2 gas
Snowbank
Dying trees
Depression
Basement
Fault

Motivation


Areas of
dead and
dying trees


0 1 MILE
0 1 KILOMETER
203
Dry Creek
Reds
Lake
Mammoth
Mountain
Lake Mary Road
Reds Creek
Boundary Creek
Horseshoe
Lake
Area of tree kill
CO_2-charged cold spring
CO_2-charged hot spring
Well with high dissolved CO_2
Steam vent
Fault

Objectives for this study

1) Processing land and lake-bed MT data using multi-station processing schemes

2) Combination of data types for 2D inversion

3) To interpret 2D conductivity models to further study the volcanic systems in the Mono Basin area

4) To develop a process for upward continuation of lake-bed MT data in order to use in ModEM 3D code

Why MT?

Contrast between resistive host rock and electrically conductive targets (fluids, melt, etc.) in deeper structures

Method is sensitive to where fluids currently are and where they have been

Natural currents span a broad range of frequencies, thus wide range of penetration depths

A good method for seeing deeper structures at multiple kilometers

Imaging the magmatic system of Mono Basin, California, with magnetotellurics in three dimensions

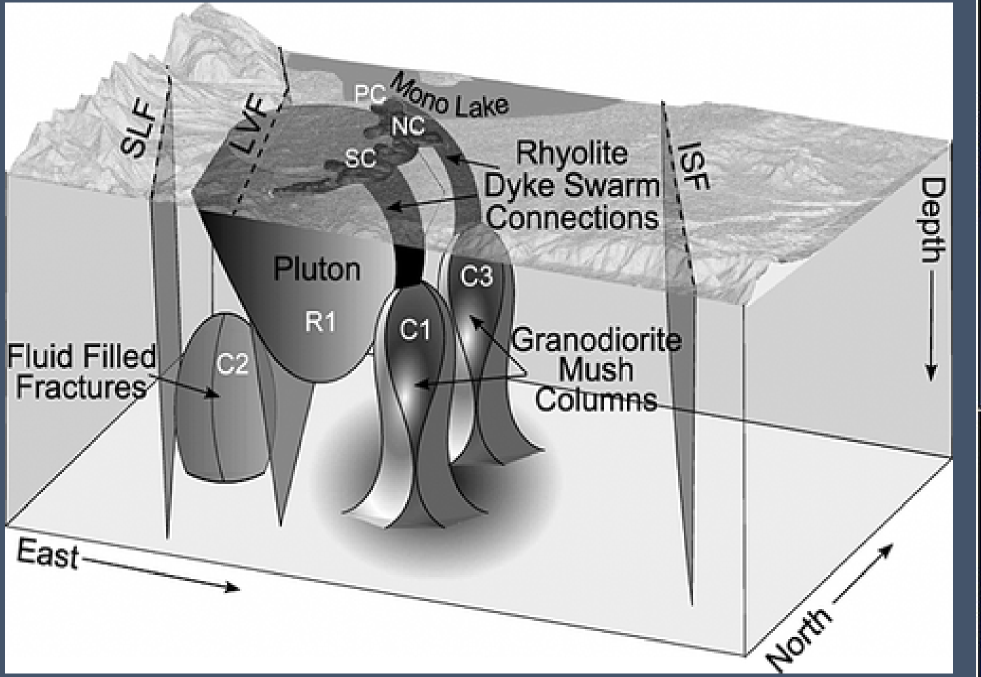
J. R. Peacock[1], M. T. Mangan[1], D. McPhee[1], and D. A. Ponce[1]

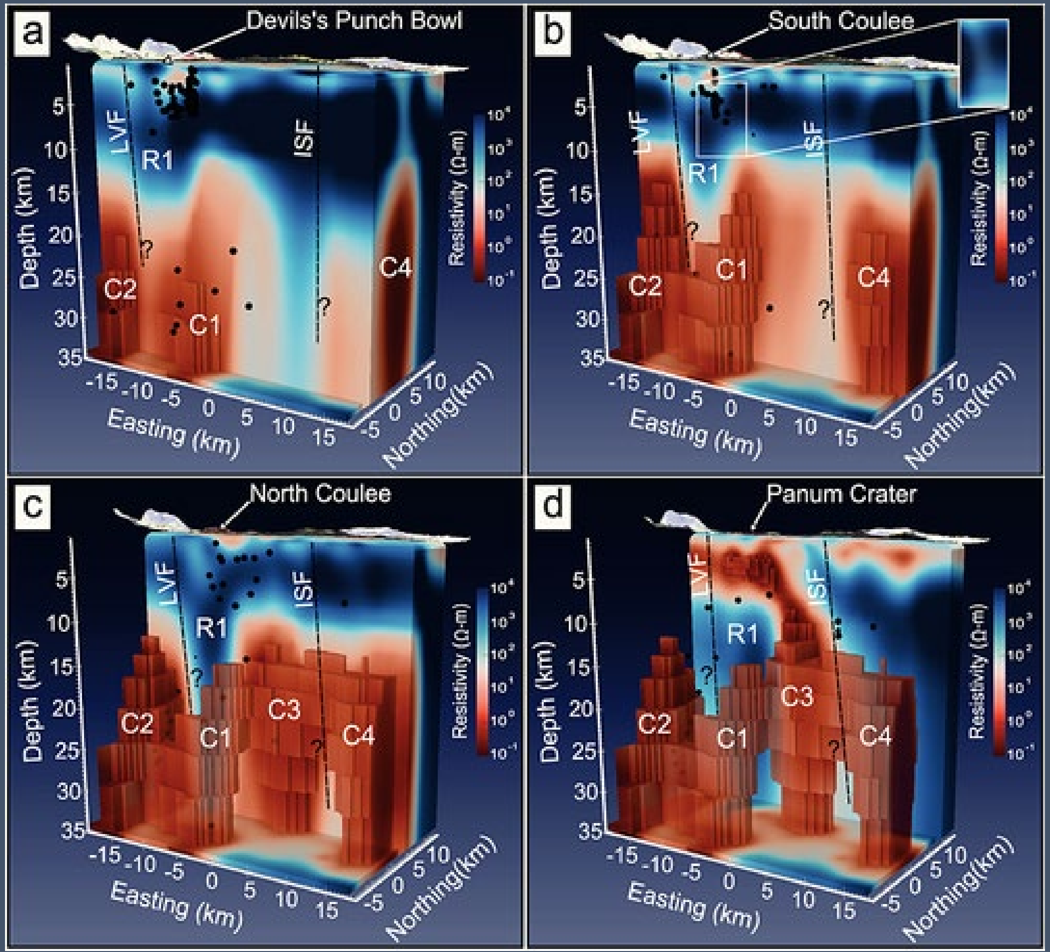
[1] U.S. Geological Survey, Menlo Park, California, USA

3D resistivity models show complex structure under Mono Craters

Large near-vertical conductors at 10+ km

Connection of deeper conductors to shallower portions of the crust





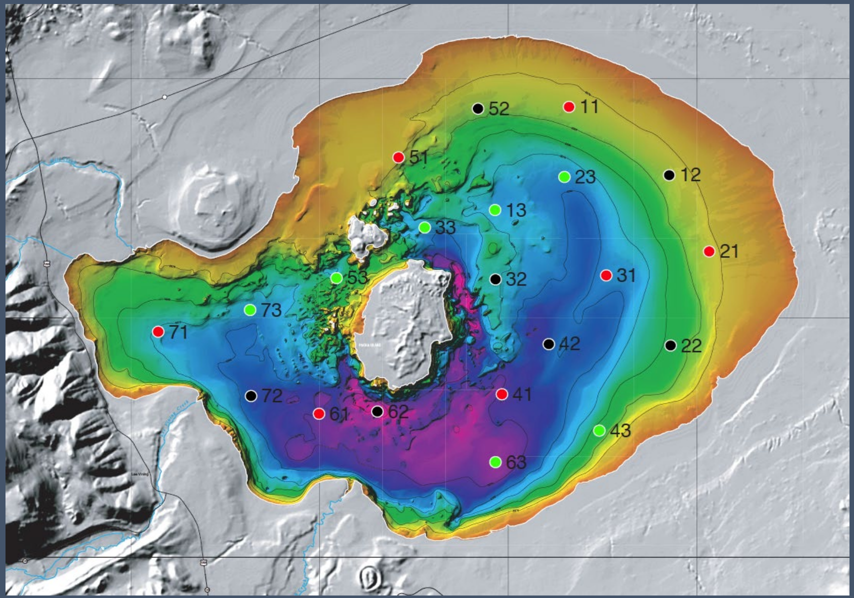
R1 is a cold pluton (resistor) that is outcropped at the base of the Aeolian Buttes

C1, C3 are crystal-melt columns that fed the Mono Crater eruptions through east-dipping dikes

Mono Lake Collection (2017)

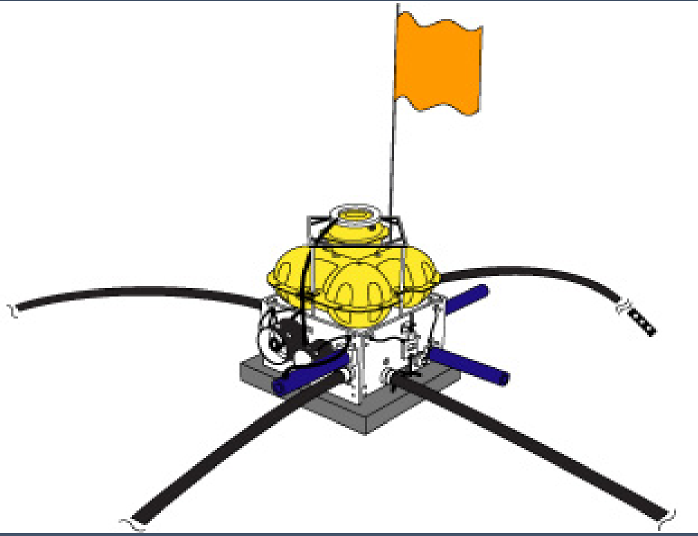
21 stations in the lake, logged 2 days each

Remote magnetics recorded several km south of the lake



SIO seafloor EM receiver

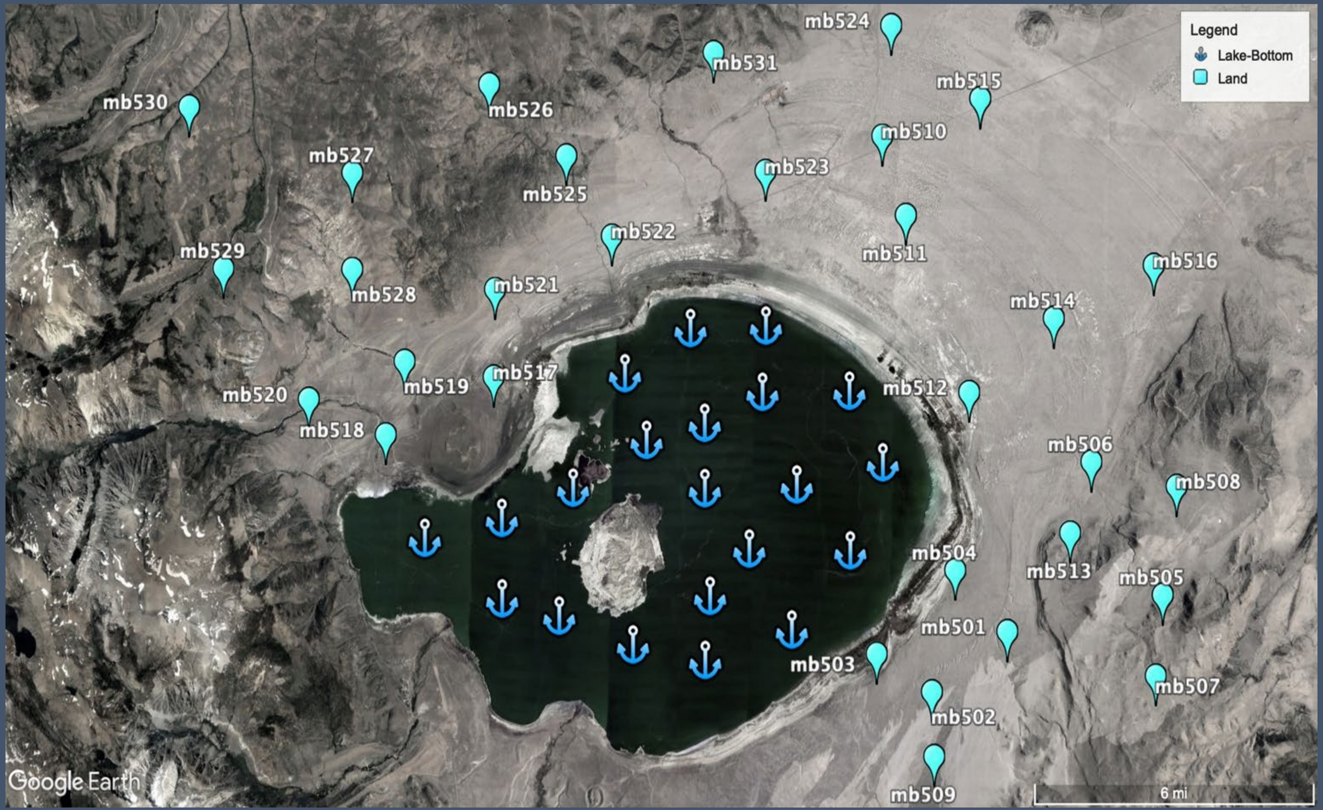
A completely autonomous seafloor data logging system



Land data (2018)

24 stations, recorded overnight using Zonge ZEN receivers

6-channel wideband system



Modifications to land data

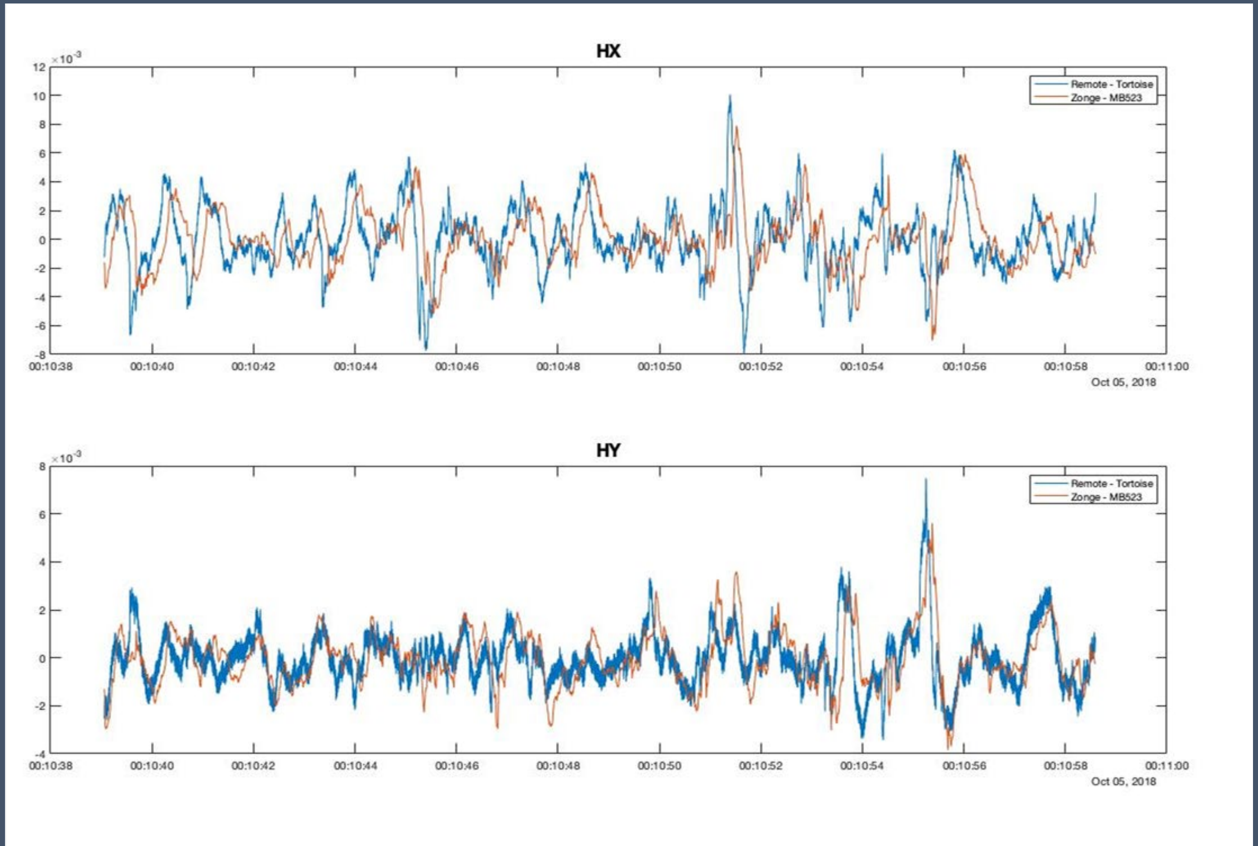
Files from Zonge instruments rewritten into a format compatible with multi-station processing code

Remote magnetic data (Scripps format) were down-sampled to match the land data sampling frequency (1000 Hz to 256)

Some resolution lost from going from 32-bit to 24 but not detrimental

Magnetic channels and remote data in good agreement

Small shift due to difference in instruments



Robust multiple-station magnetotelluric data processing

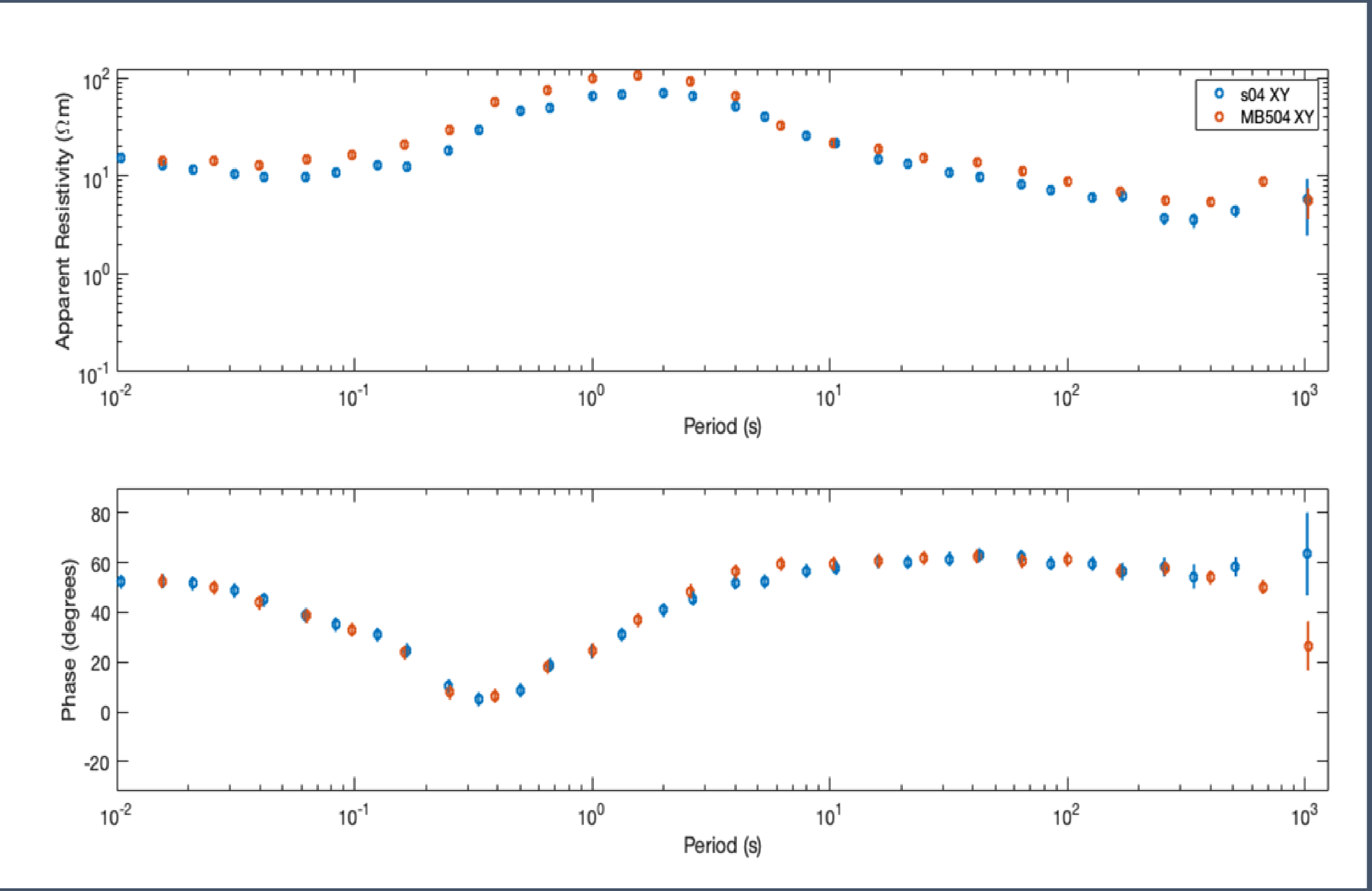
Gary D. Egbert
College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503, USA. E-mail: egbert@oce.orst.edu

Commonly used processing methods are based on univariate statistical procedures; conversely use multivariate statistical processing

Use data from all channels to improve signal-to-noise ratios and diagnose possible biases due to coherent noise

Data were sectioned into different groupings of stations to determine the best for processing output
- -Typically used one noisy station with better stations to improve noisier station
- -Clean stations were processed with clean stations

Comparison of processing methods



North side land data processed using both single-station and multi-station techniques
Remote reference not used in orange points

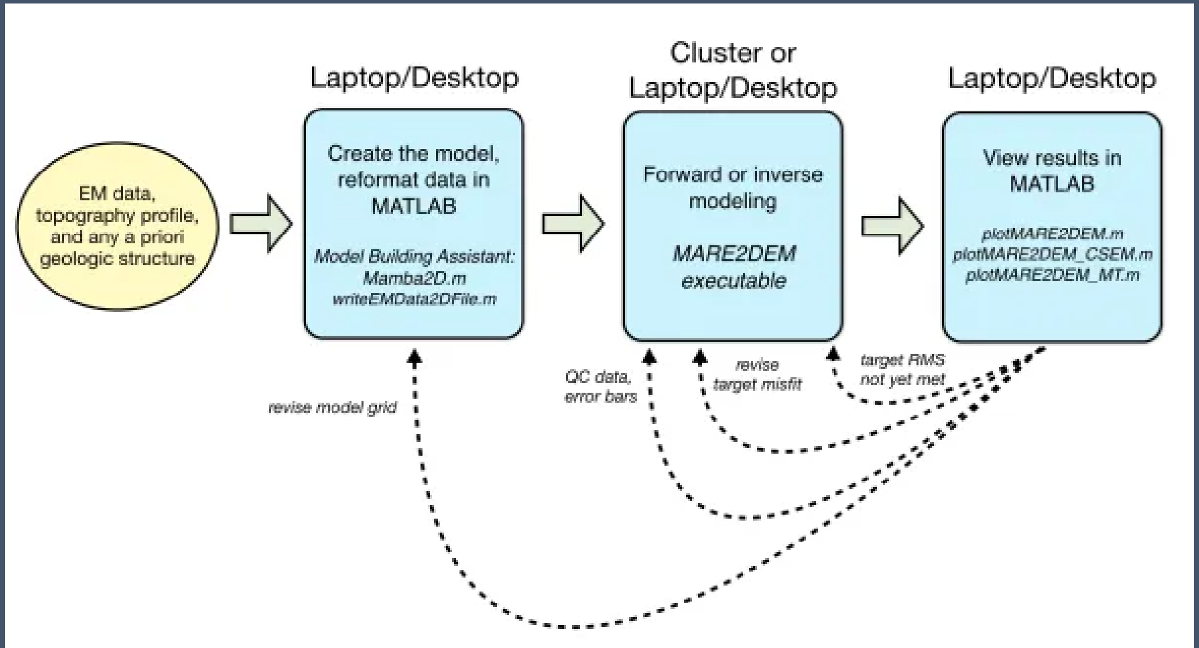
Most differences appear in longer periods

Data was particularly clean, however in a noisier environments we've seen it clean up the data very well

MARE2DEM

MARE2DEM (Modeling with Adaptively Refined Elements for 2D Electromagnetics) **Key (2016)**

Finite element code for 2D forward and inverse modeling



MARE2DEM uses Occam inversion method (Constable et al., 1987)

“A practical algorithm for generating smooth models from electromagnetic sounding data”

2D inversion

Sites were chosen along a 135° line (line of strike) in two parallel profiles

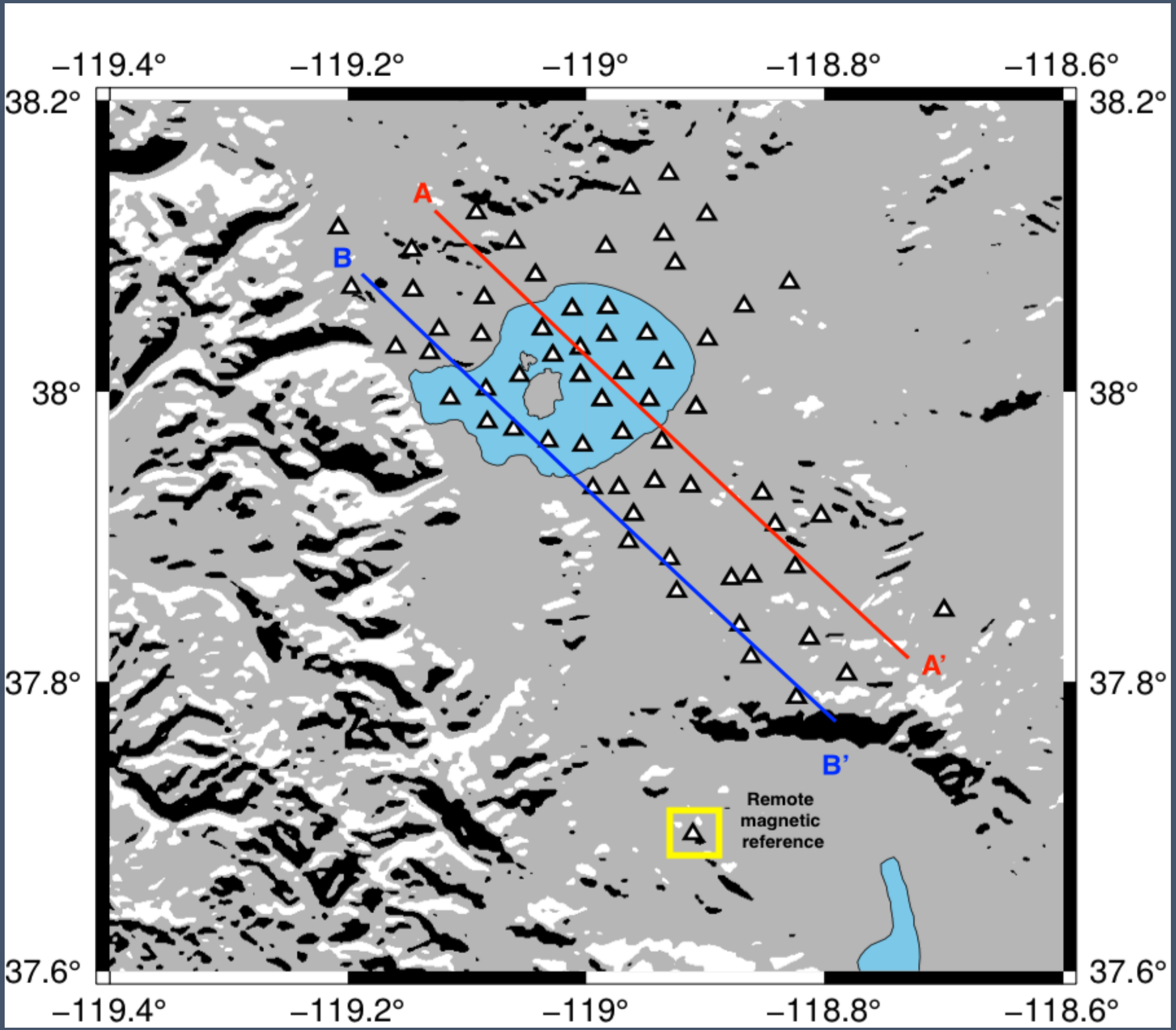
A: 13 land sites and 9 lake bottom sites

B: 13 land sites and 6 lake bottom sites

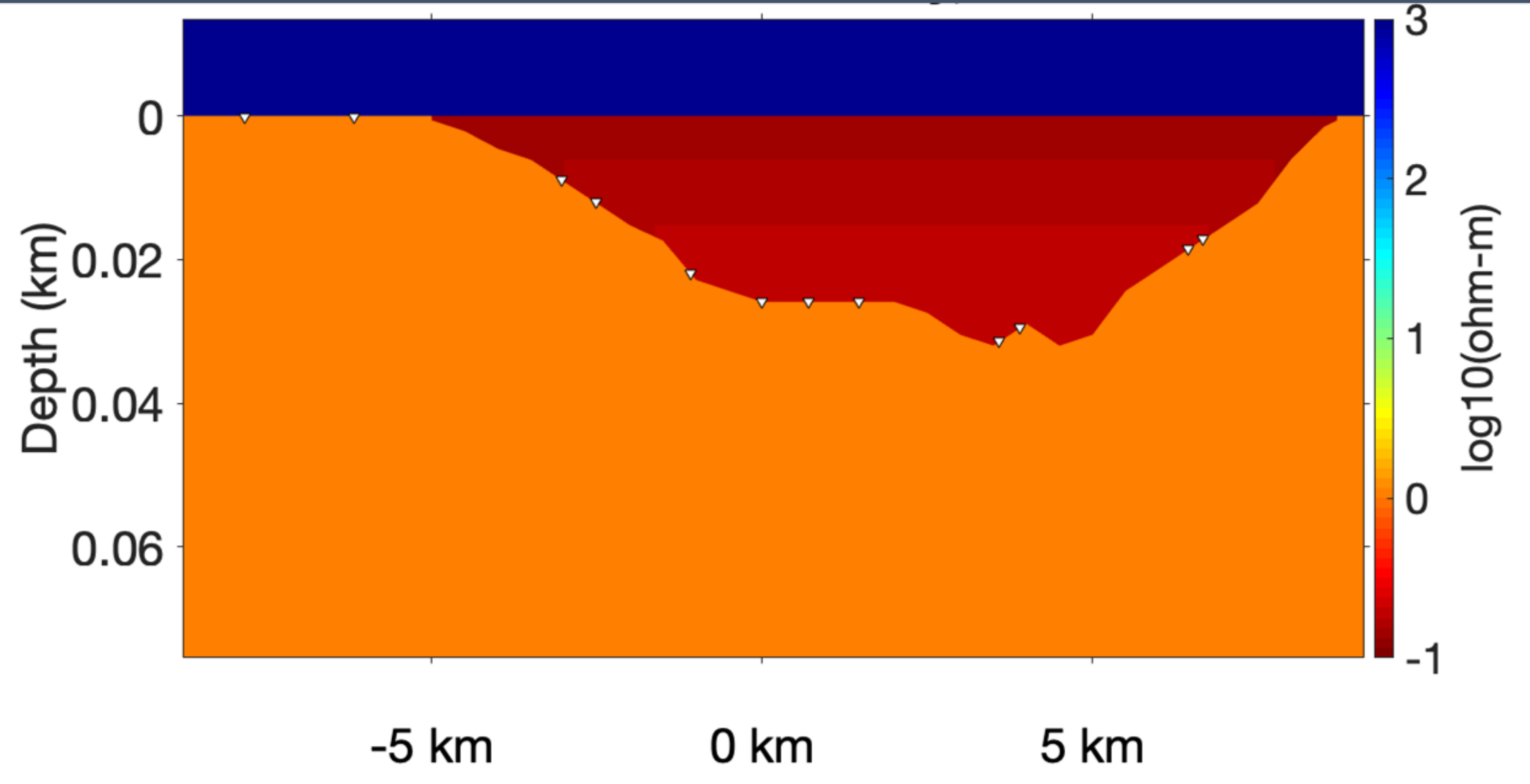
Data was cleaned up using Matlab codes

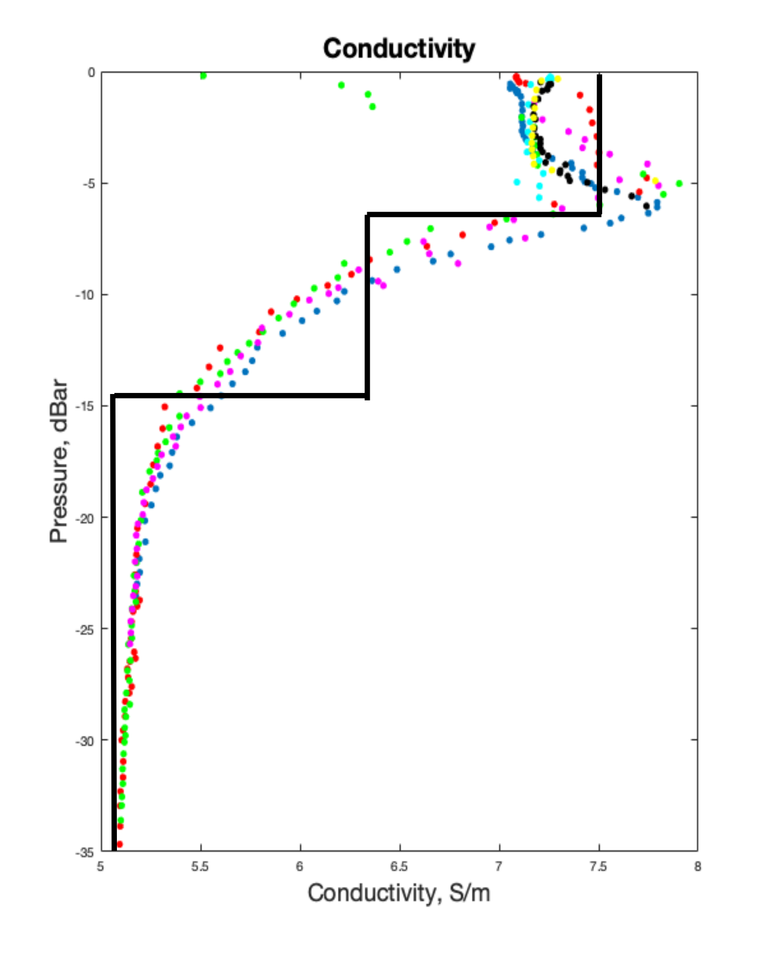
Very noisy data were removed (mostly at the longer periods)

Data interpolated to the same frequencies post-processing for consistency



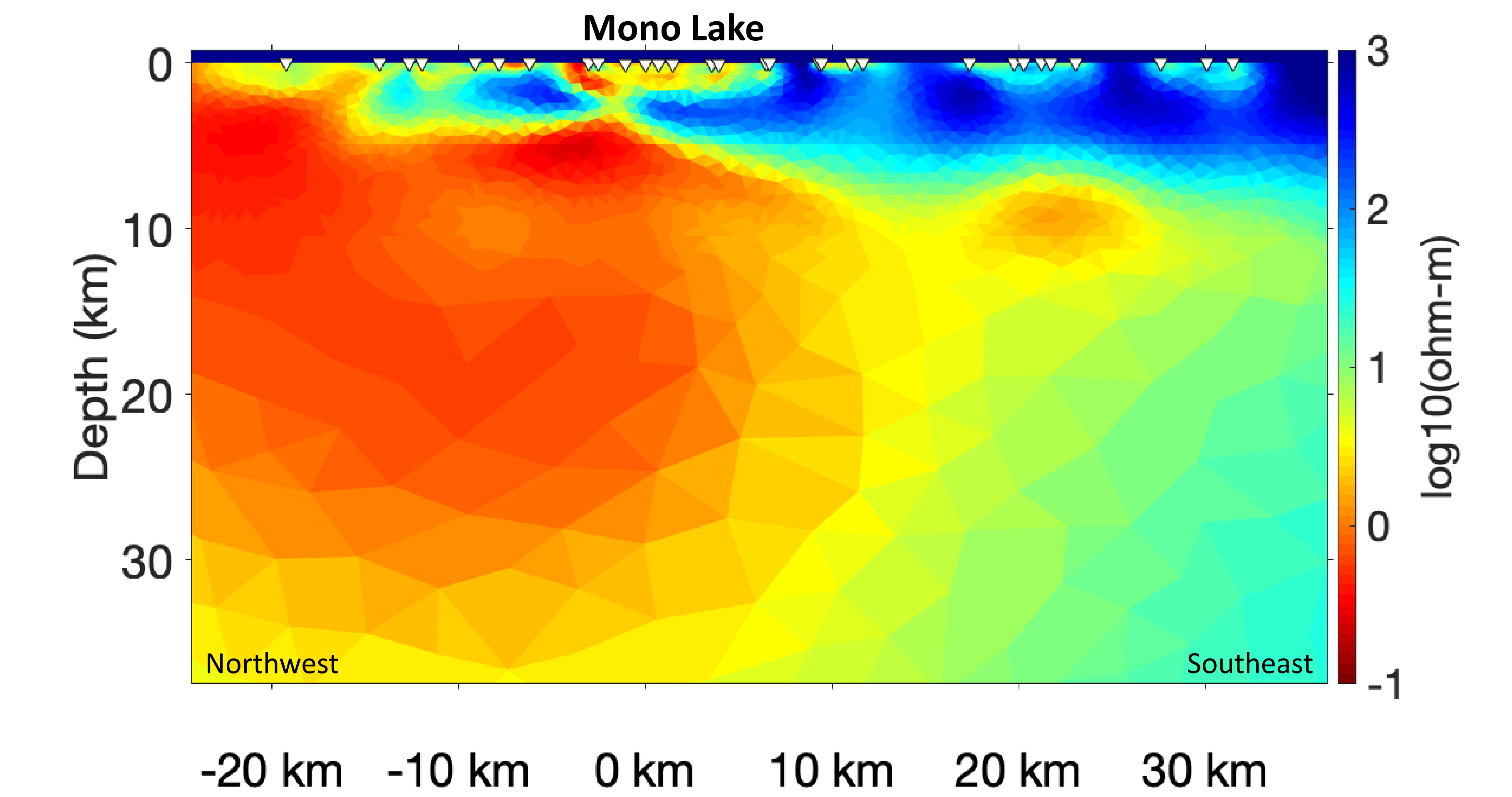
Modeling in Mamba2D

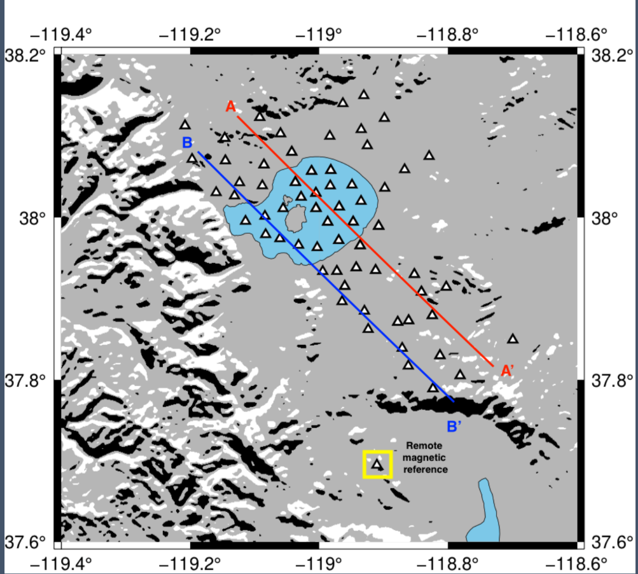




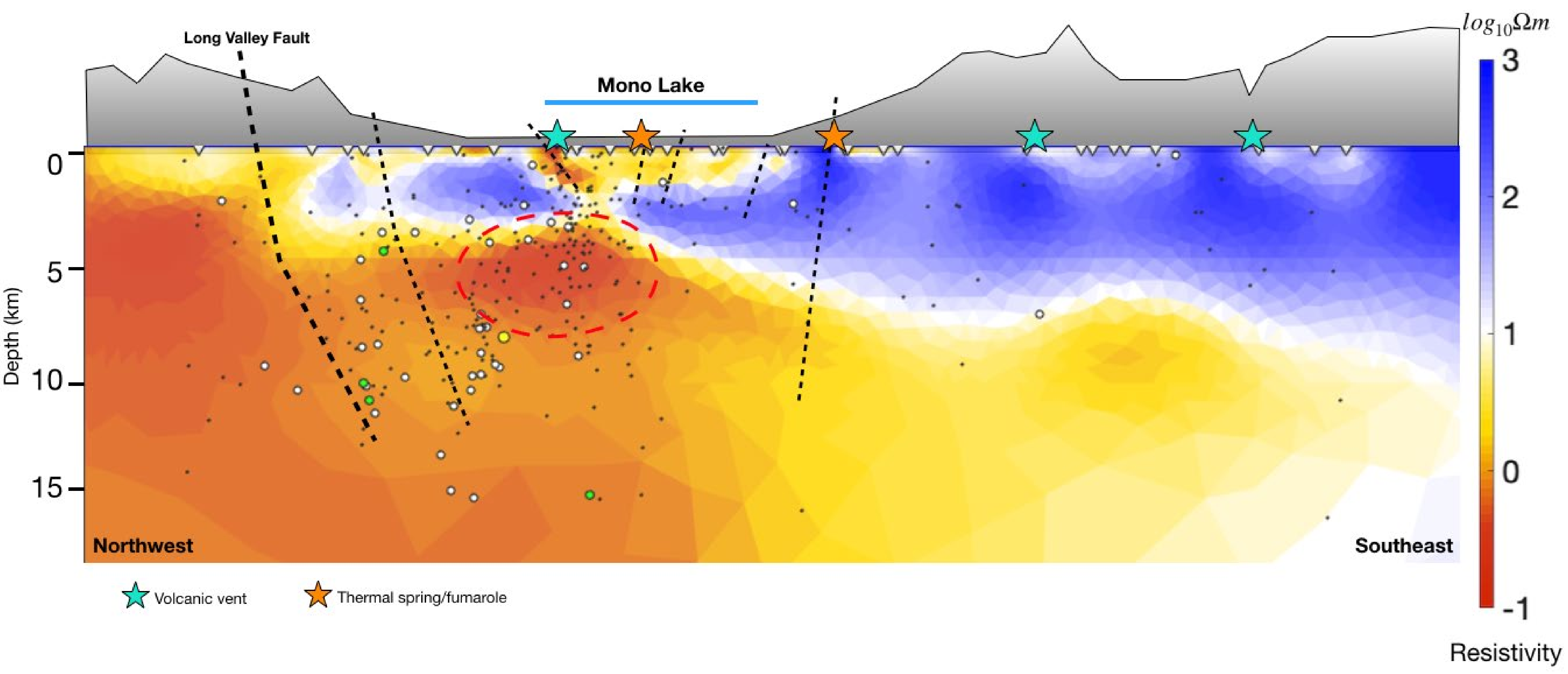
Layers derived from Conductivity-Temperature-Depth (CTD) soundings

Starting model is a 3-layer lake (fixed parameter) in a uniform 1 Ohm-m half space (free parameter)

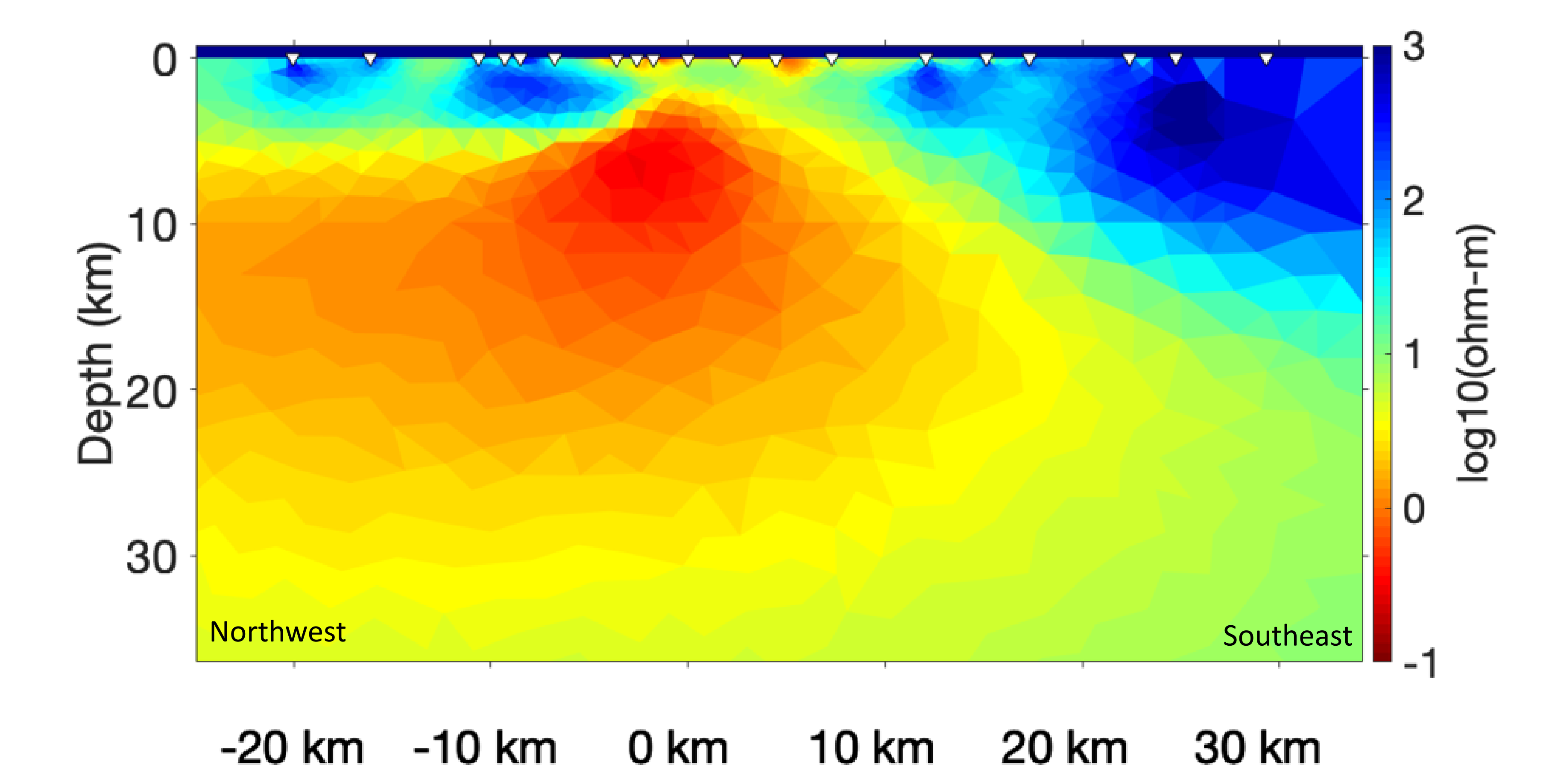


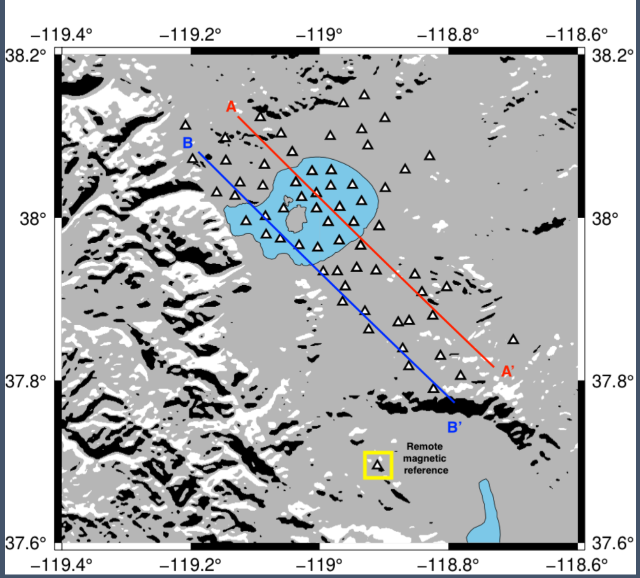


Profile A:
RMS = 1.24

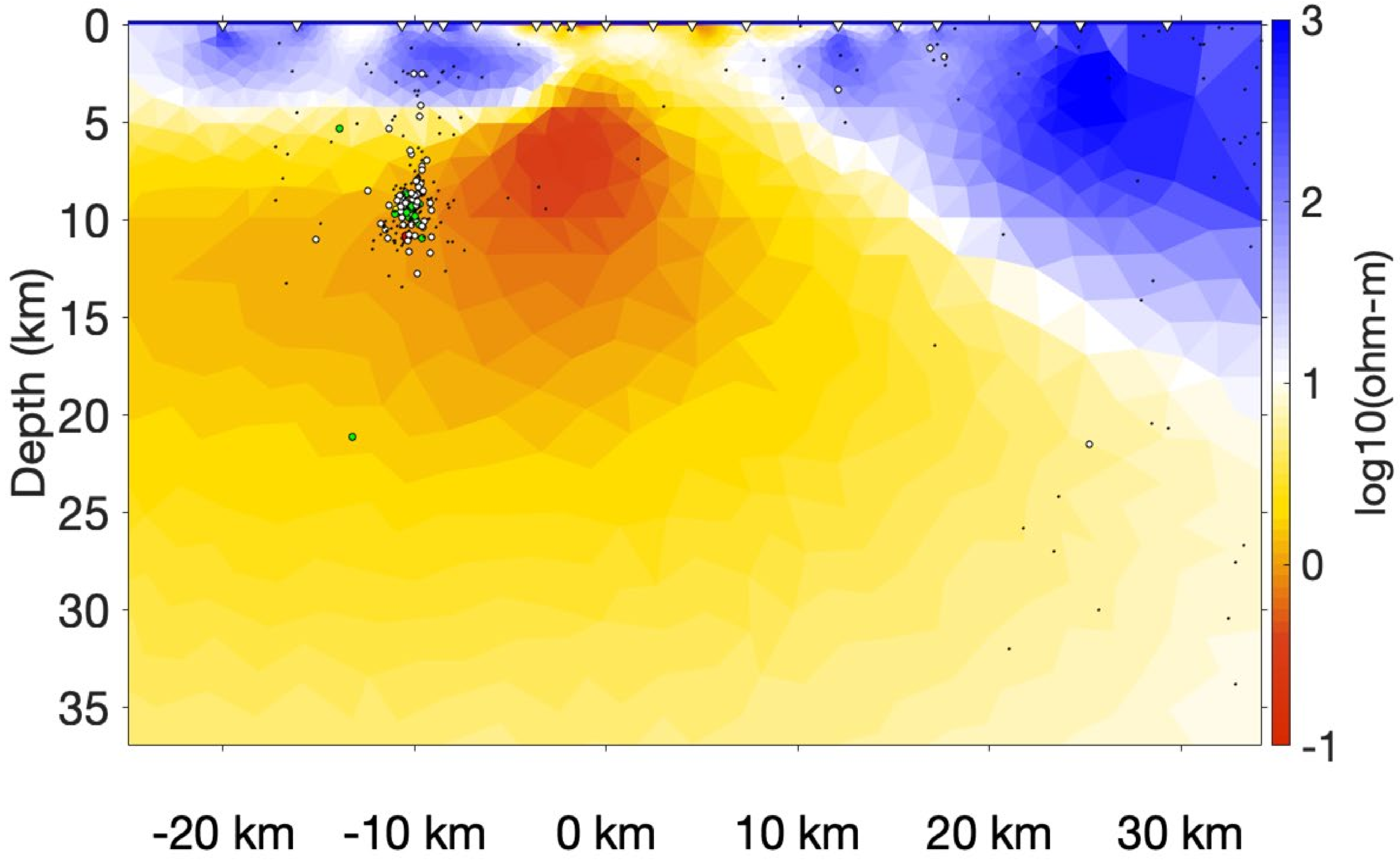


Long Valley Fault
Mono Lake
0
5
10
15
Depth (km)
Northwest
Southeast
Volcanic vent
Thermal spring/fumarole
$log_{10}\Omega m$
3
2
1
0
-1
Resistivity

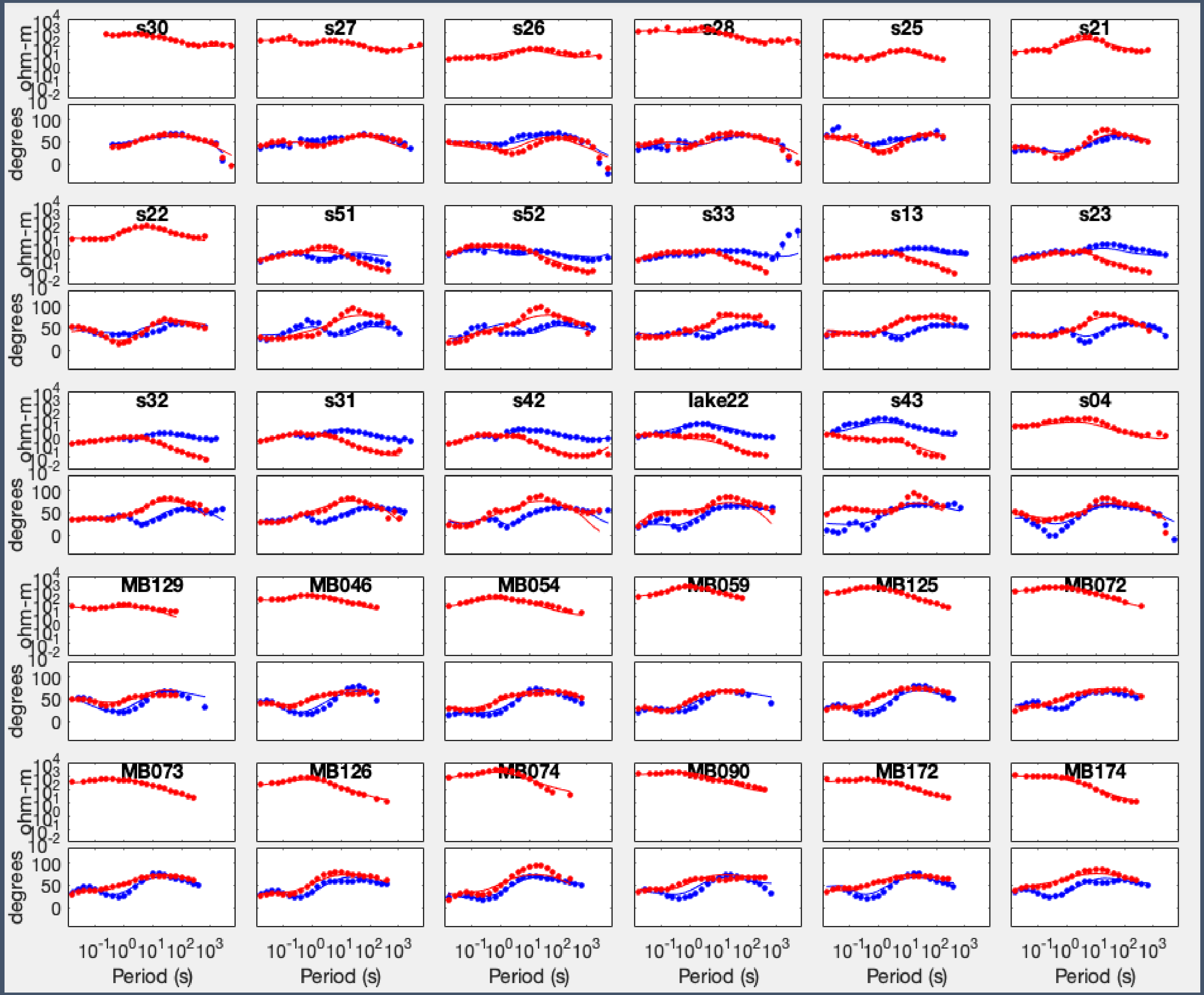




Profile B:
RMS = 2.29



0
5
10
15
20
25
30
35
Depth (km)
-20 km
-10 km
0 km
10 km
20 km
30 km
3
2
1
0
-1
log10(ohm-m)



2D data fits

Data is fitting well, with some exception in the longer periods that such as in site 33 (points were later removed)

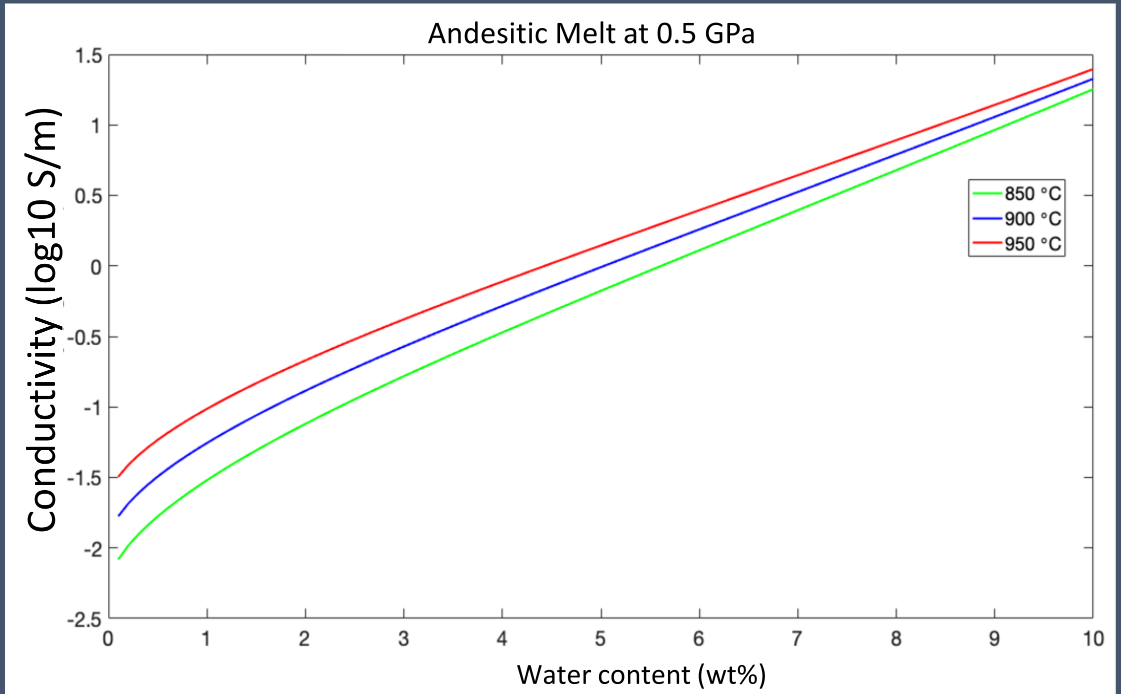
TE resistivities were removed for the land data due to their sensitivity to 3D geologic structure, which is present in this area

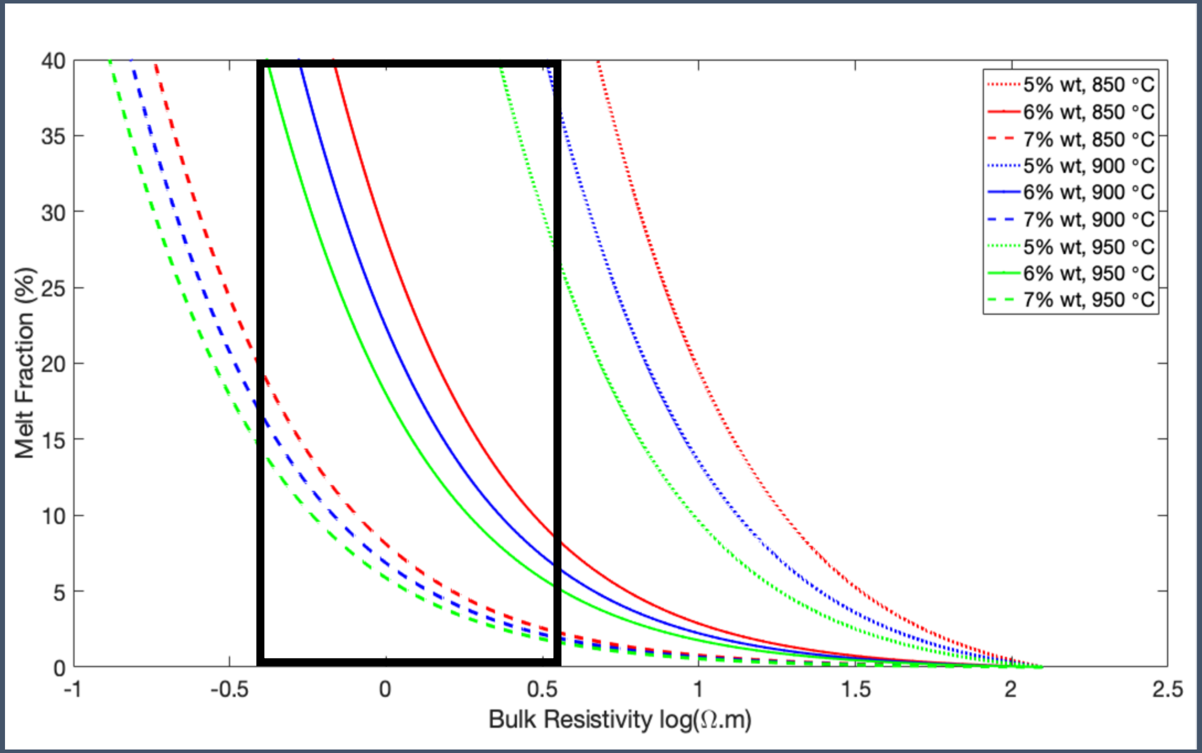
Partial Melt

Hydrous andesitic melt conductivity model (Guo et al., 2017)

$$log\sigma = 5.23 - 0.56w^{0.6} - \frac{8130.4 - 1462.7w^{0.6} + (581.3 - 12.7w^2)P}{T}$$

Estimates the conductivity of melt as a function of water content, temperature and pressure





Hashin and Shtrikman (HS+) upper bound model

Simulates interconnected melt

$$\sigma = \sigma_2\left[1 - \frac{3F_1(\sigma_2 - \sigma_1)}{3\sigma_2 - (1 - F_1)(\sigma_2 - \sigma_1)}\right]$$

Approximately 5-40% melt

Depends on true water content

3D inversion

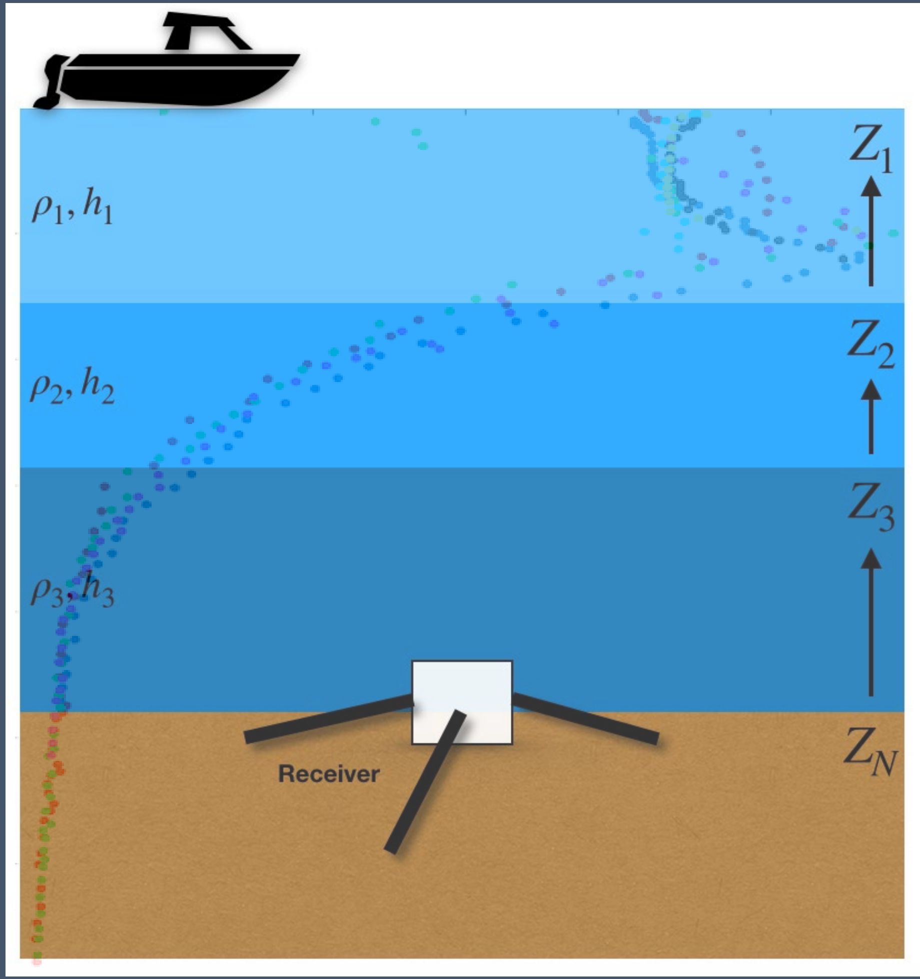
3D inversion code (ModEM) can't compute the fields properly if the receivers are in the water

"Data propagation" to model the response on the surface of the lake

For 1D case, impedance of the top of each layer is a function of the top of the layer *beneath* it

$$\hat{Z}_n = Z_n \frac{\hat{Z}_{n+1} + Z_n tanh(ik_n h_n)}{Z_n + \hat{Z}_{n+1} tanh(ik_n h_n)}$$

k term is complex wavenumber, depending upon the frequency and layer conductivity

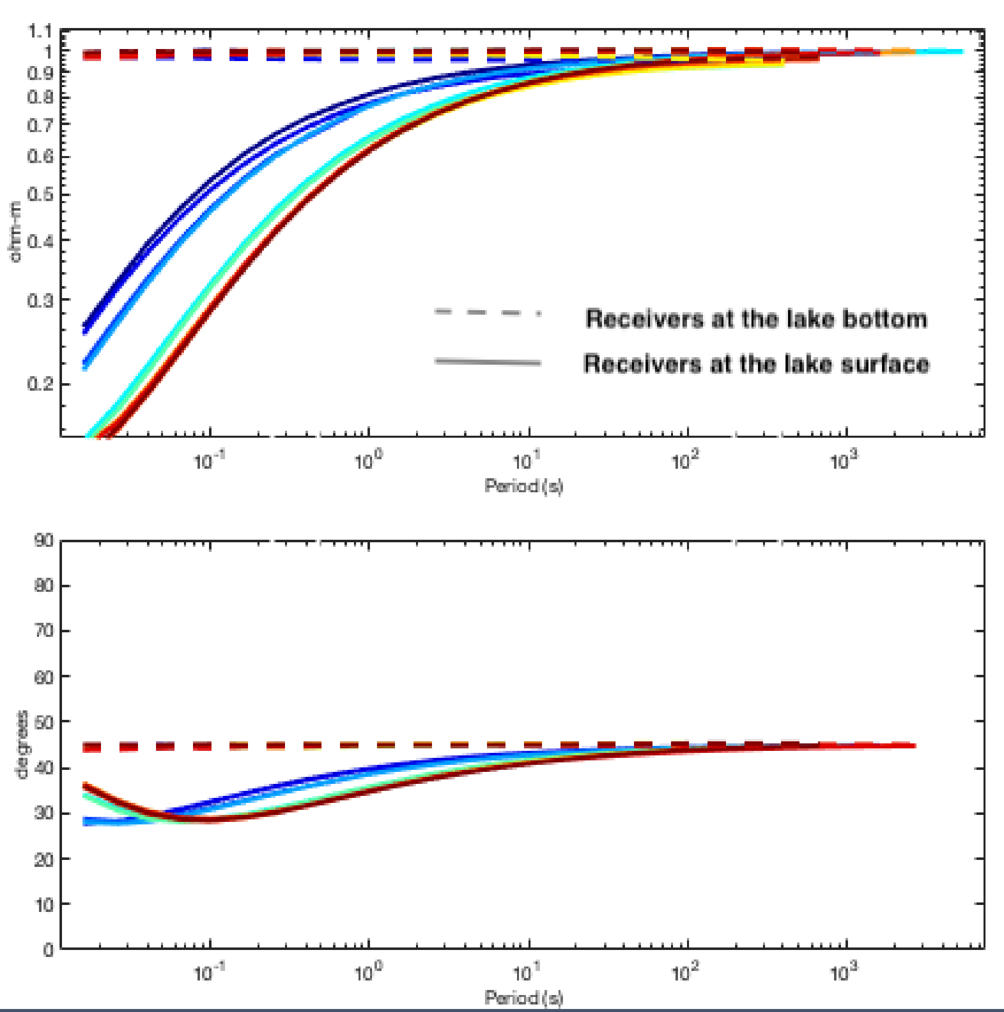


Forward modeling

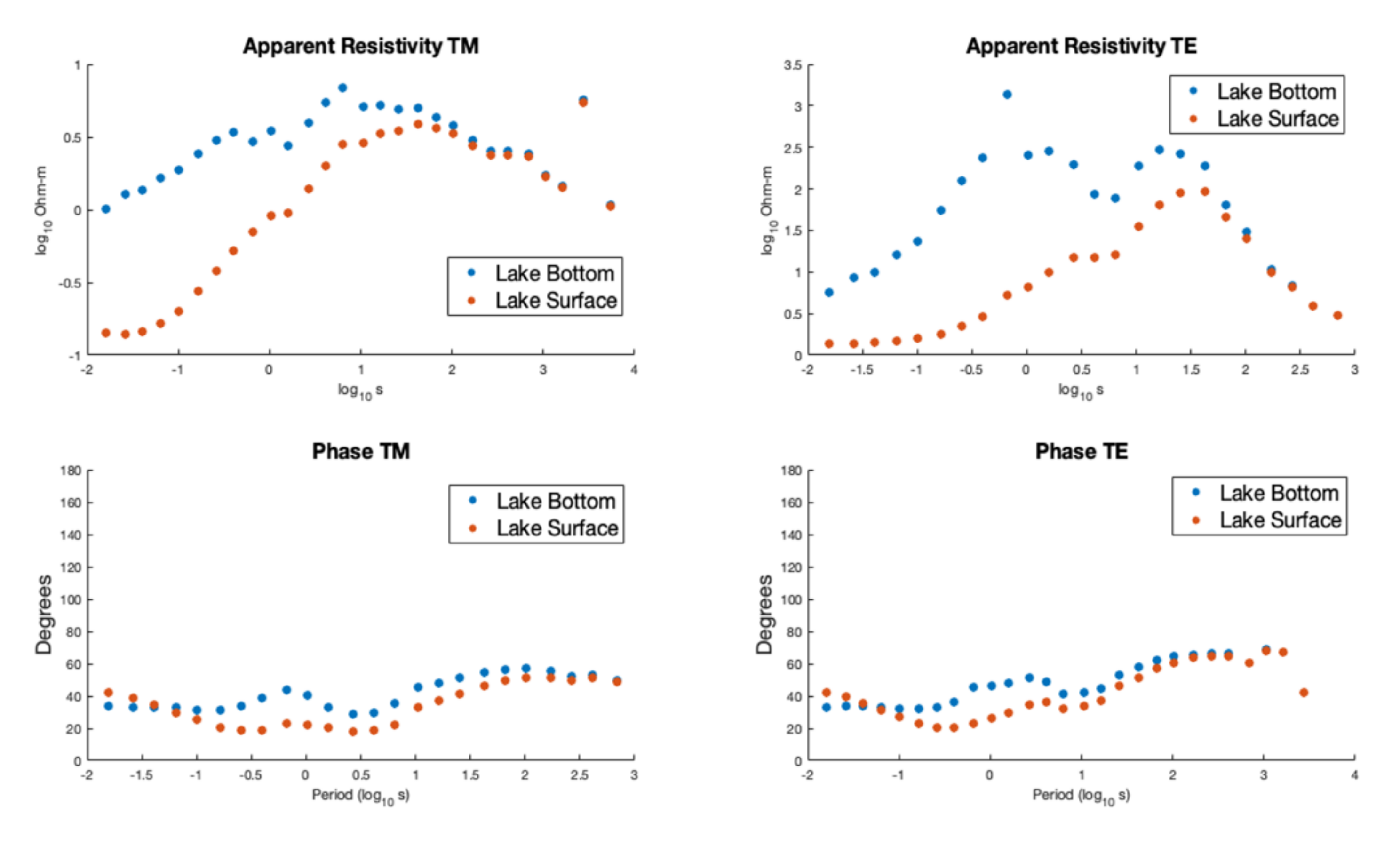
2D forward modeling done in MARE2DEM
Model: 3-layered lake overlaying a uniform halfspace

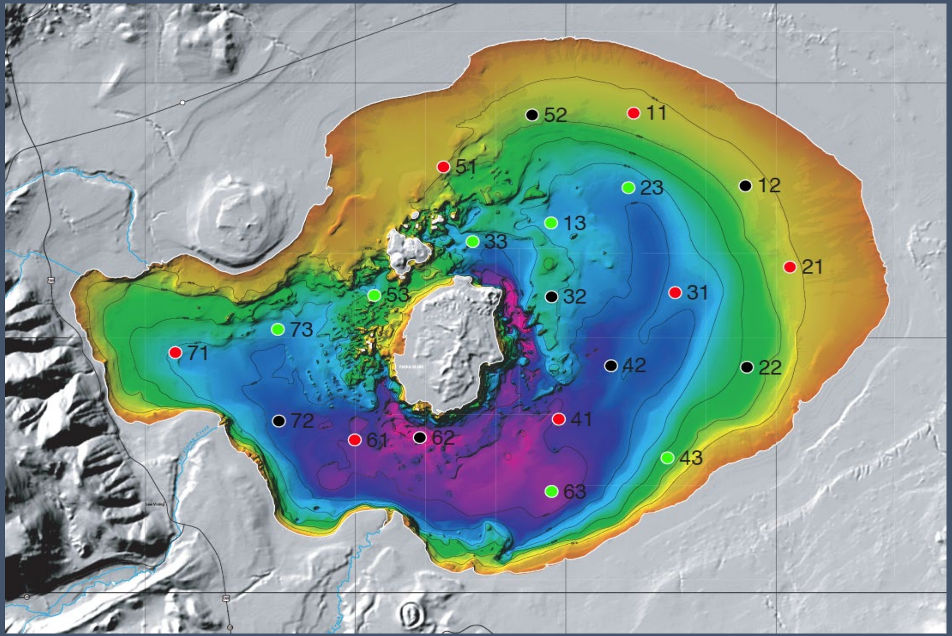
Effect is larger at higher frequencies due to depth of penetration

Difference in results confirm the need for modification of the data for inversion

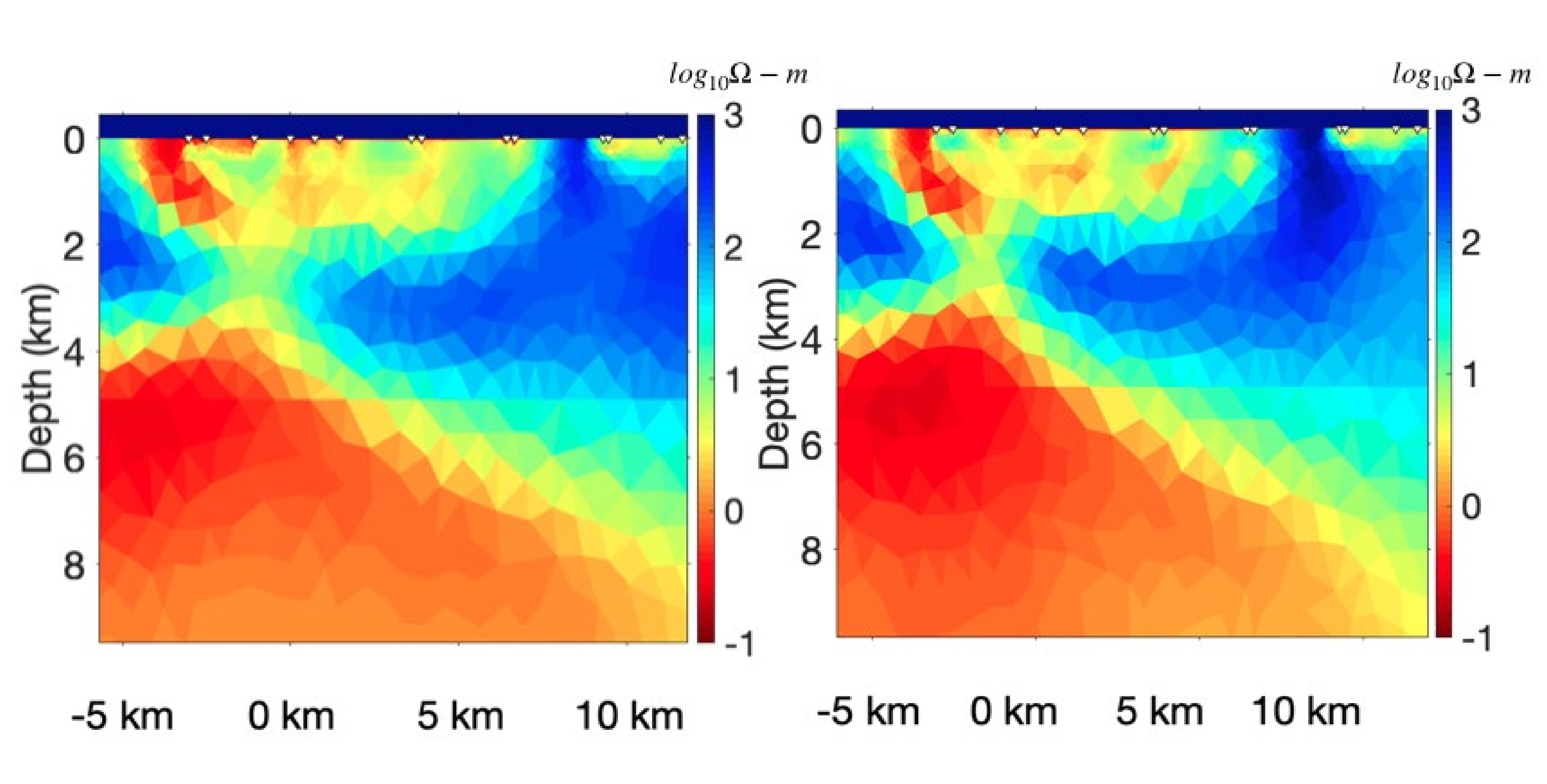


1D approximation





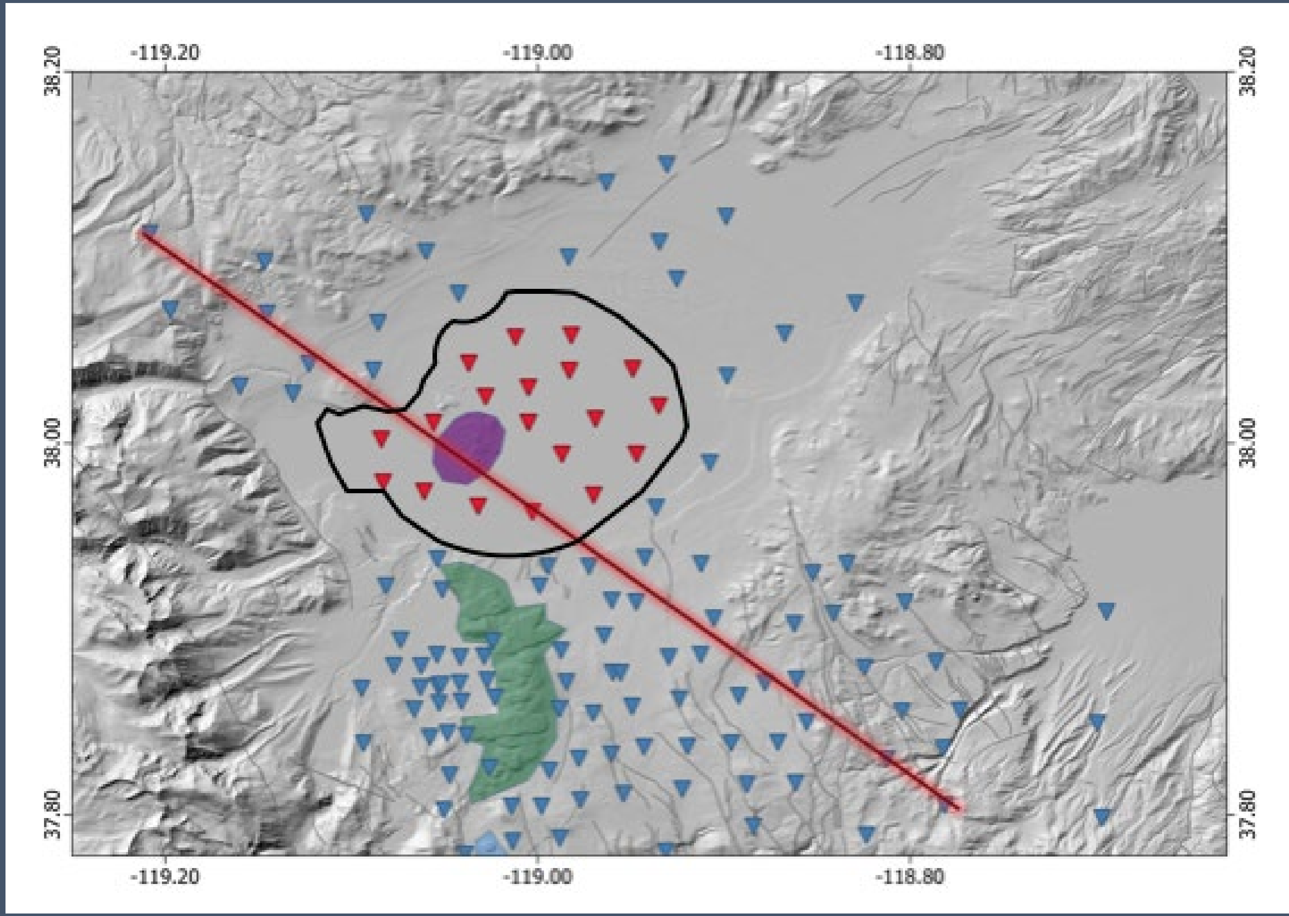
Validation using 2D inversion



Original 2D Inversion

Upward continued data
Lake receivers on surface

3D inversion using ModEM

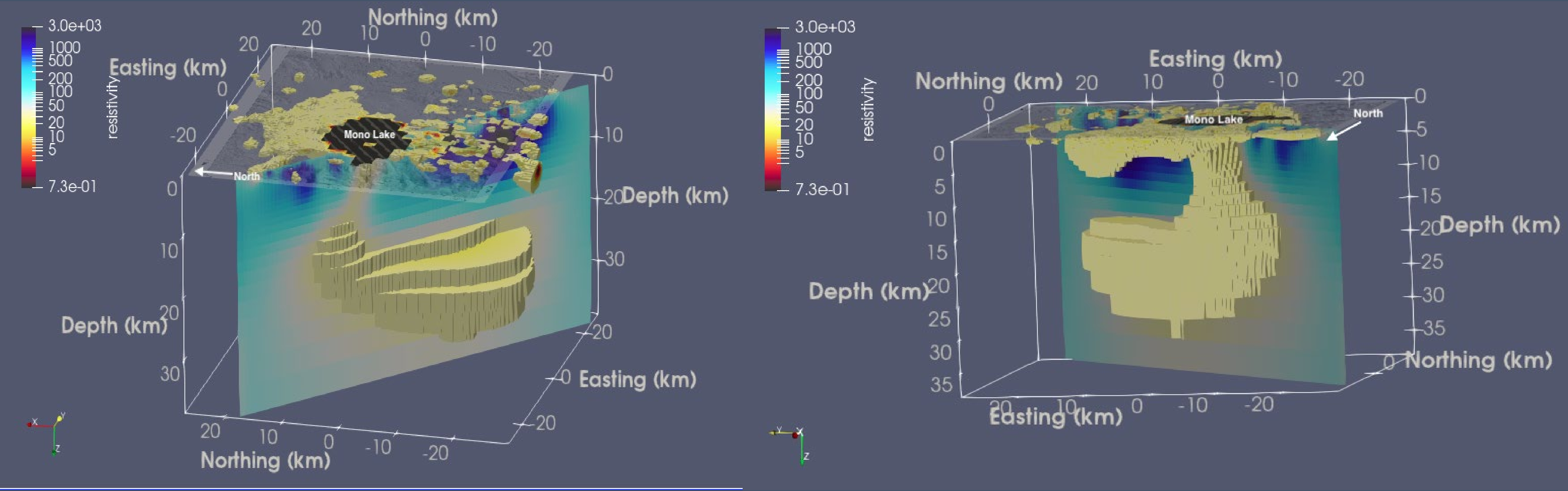


Ran on the USGS Yeti Supercomputer by Jared Peacock

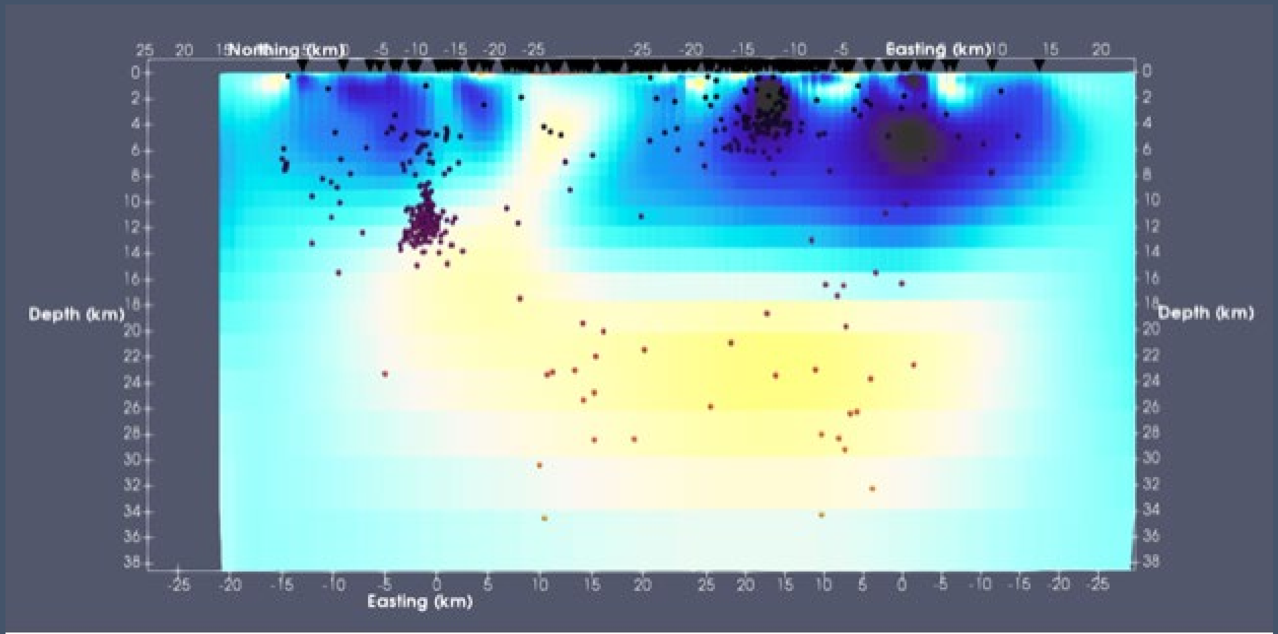
Started with 100 Ohm-m halfspace with the lake as a fixed conductive feature

Lake stations were processed with multi-station processing and upward continued to the surface

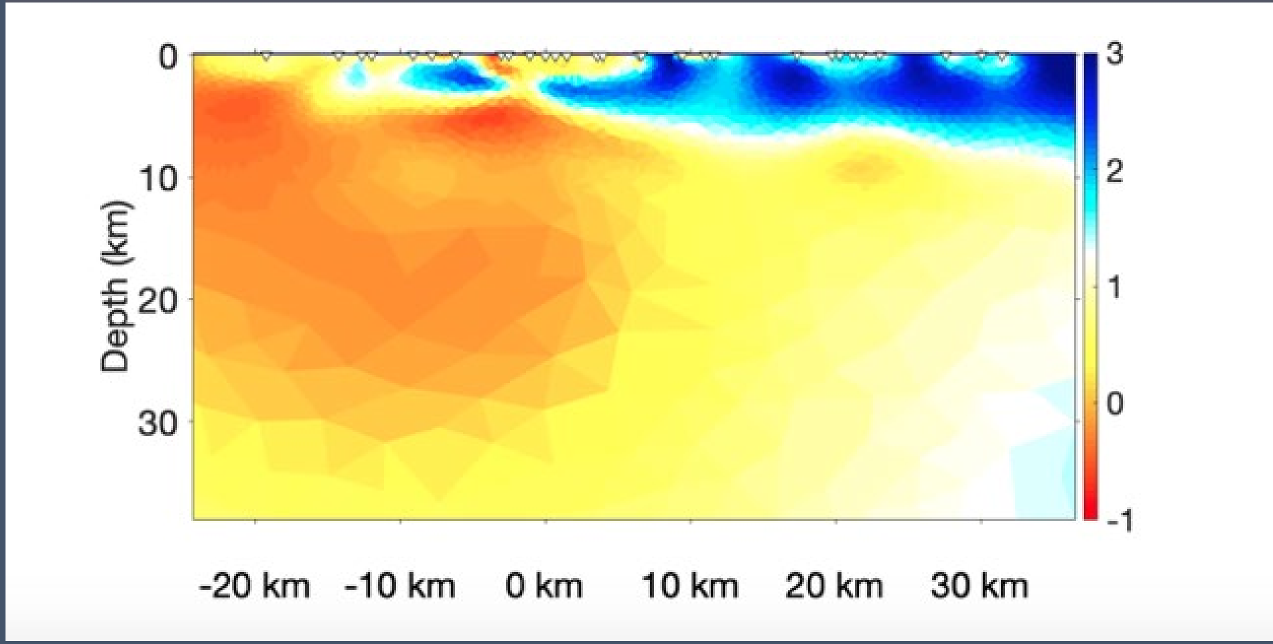
Station rotations done before upward continuation (validated with 1D modeling)



3.0e+03
1000
500
200
100
50
20
10
5
7.3e-01
resistivity
Northing (km)
Easting (km)
Depth (km)
Mono Lake
North
3.0e+03
1000
500
200
100
50
20
10
5
7.3e-01
resistivity
Easting (km)
Northing (km)
Depth (km)
Mono Lake
North
Northing (km)
Easting (km)
Depth (km)



3D inversion
ModEM

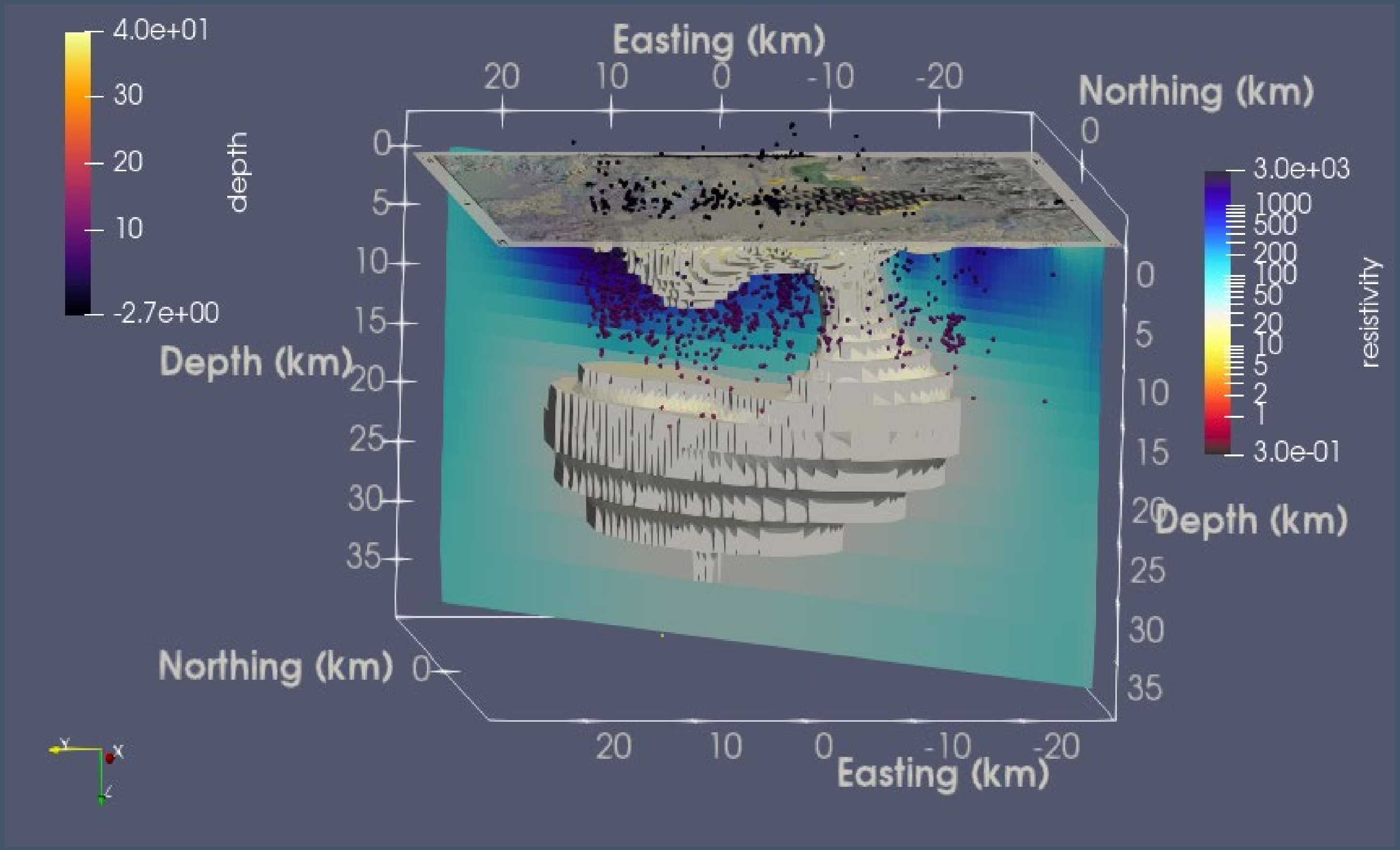


2D inversion
MARE2DEM

Shallow conductor aligns with earthquake clusters on the north side

Could be hydrothermal fluids, partial melt, or both?

Suggests volcanism is still moving northwards, next eruption likely north of Mono Lake



Conclusions

We’ve identified a shallow conductive feature under Mono Lake connected to a deeper conductor that feeds into a shallower portion of the subsurface possibly through a fracture – hydrothermal fluids?

A shallow conductor sits directly north of Mono Lake, suggesting northward progression of volcanism

Results agree with previous studies of Long Valley and Mono Basin

Conclusions

There is need for a process to modify lake bottom data for use in 3D inversion to mitigate lake effect on response

Upward continuing using the 1D MT recursion relation proves to be successful in accounting for this

This technique is useful for future shallow water MT work

What’s next?

More MT data north of the last data set would show the extent of the conductive features towards the Bodie Mountains

Near surface work focusing on the upper 5 km of the area to better map the hydrothermal systems

Time-dependent data could show at what rate these features are growing/moving and would help forecast the next big eruption

Acknowledgements

Alan Jones

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Gabi Laske

Geoff Cook

Pieter Share

Jared Peacock

Kerry Key

Thank you!