#### Integrated Active-Passive Source Seismic Exploration

The best of both worlds...



8 June 2017 – Cargese Summer School

#### Dan Hollis

Sisprobe SAS

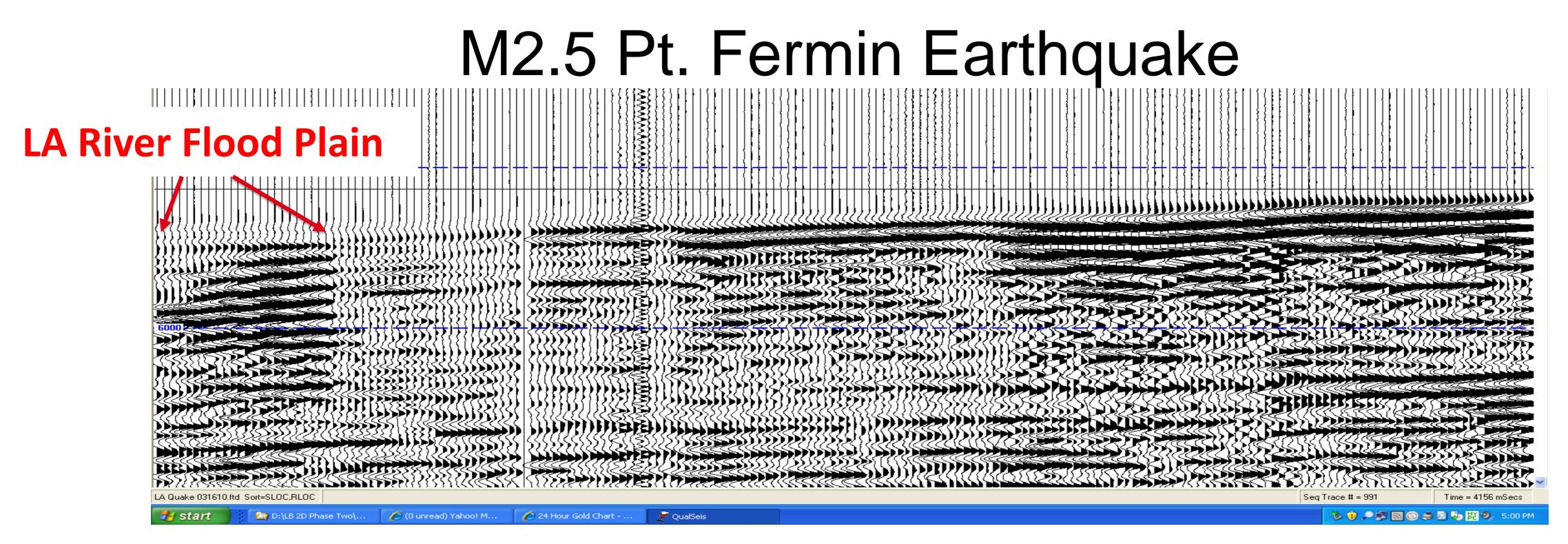
### Outline

- Industrial Seismic Reflection Instrumentation \_\_
- **Active Source Reflection Exploration** -
- Incorporating Passive Data into Active Source Reflection Exploration Passive Imaging and Other Data Products
- --
- Sweetwater Data Set —
- Where to from here —

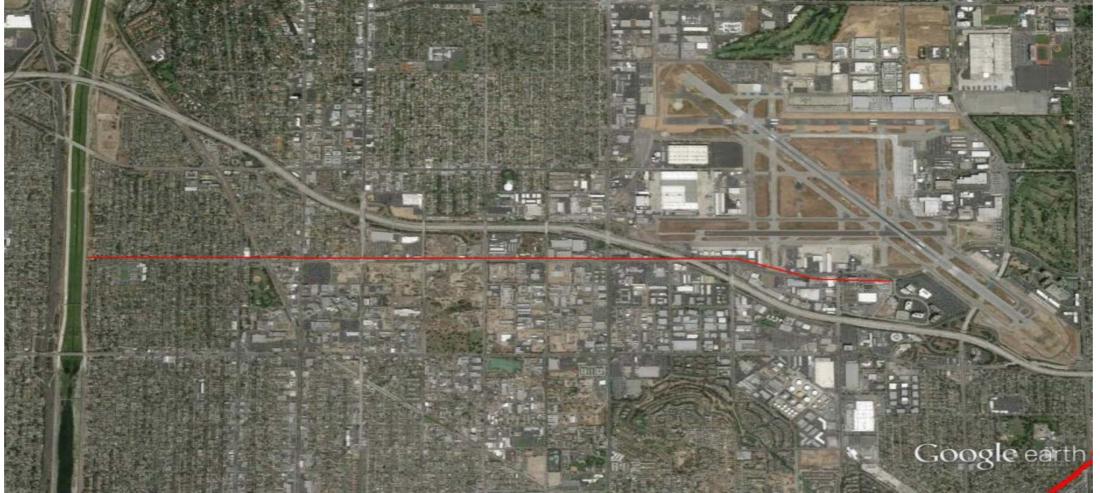
#### **Nodes - Evolution in Reflection Seismic Recording**



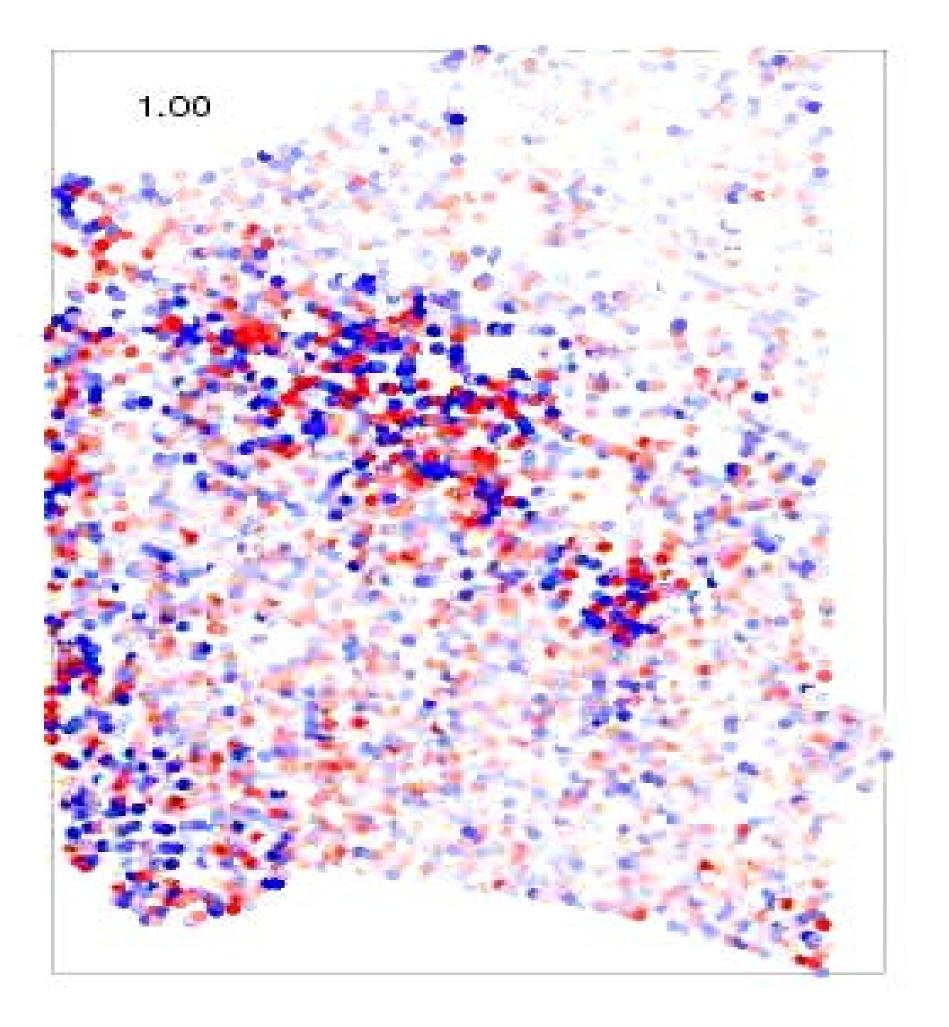
- Cabled to Cable-less
- Lower Cost/More Reliable
- Continuous vs. Segmented\*
- Better HSE footprint
- 30-40 day recording
- First nodes deployed in 2008 +/-
- Nodal instruments now >50% of channels used
- Continuous data not always saved, but industry now realizing it should be saved

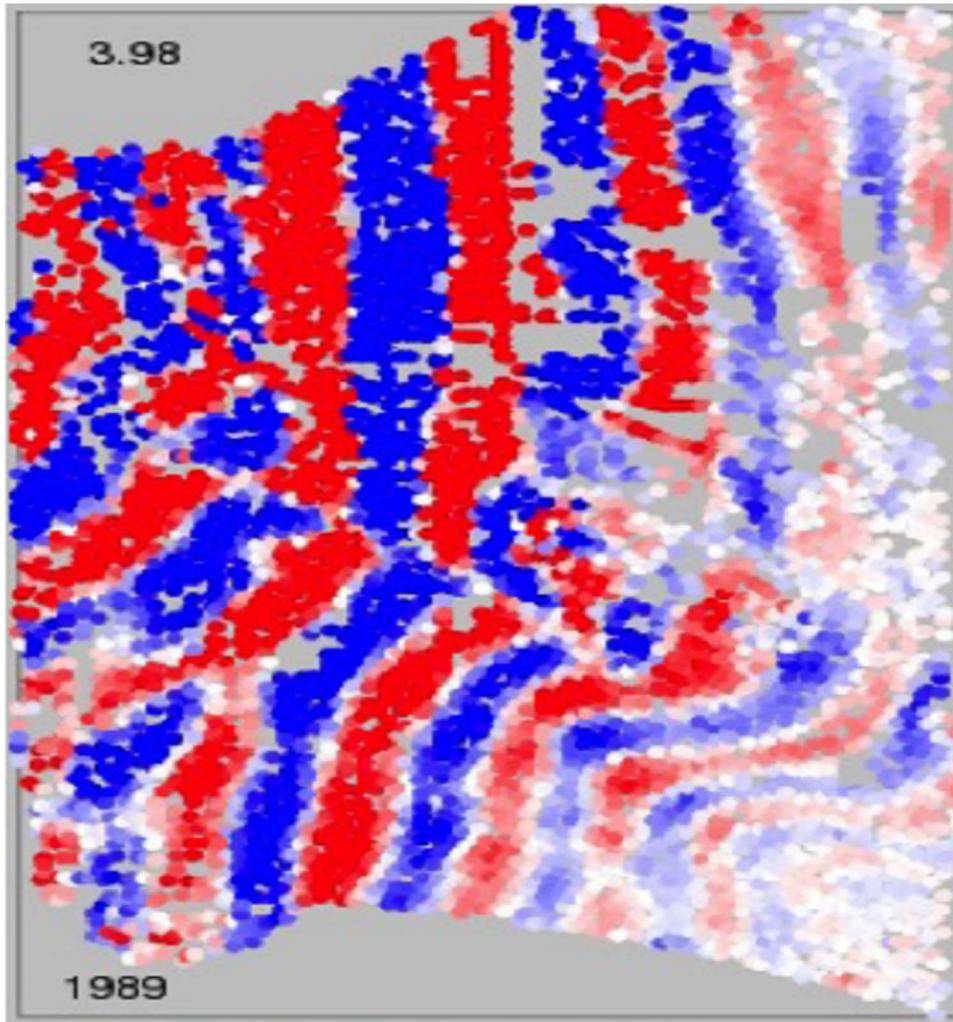


#### Local earthquake recorded on 180 nodes on a 2D array



#### Earthquake Recorded on Long Beach 3D Array (5400 stations)

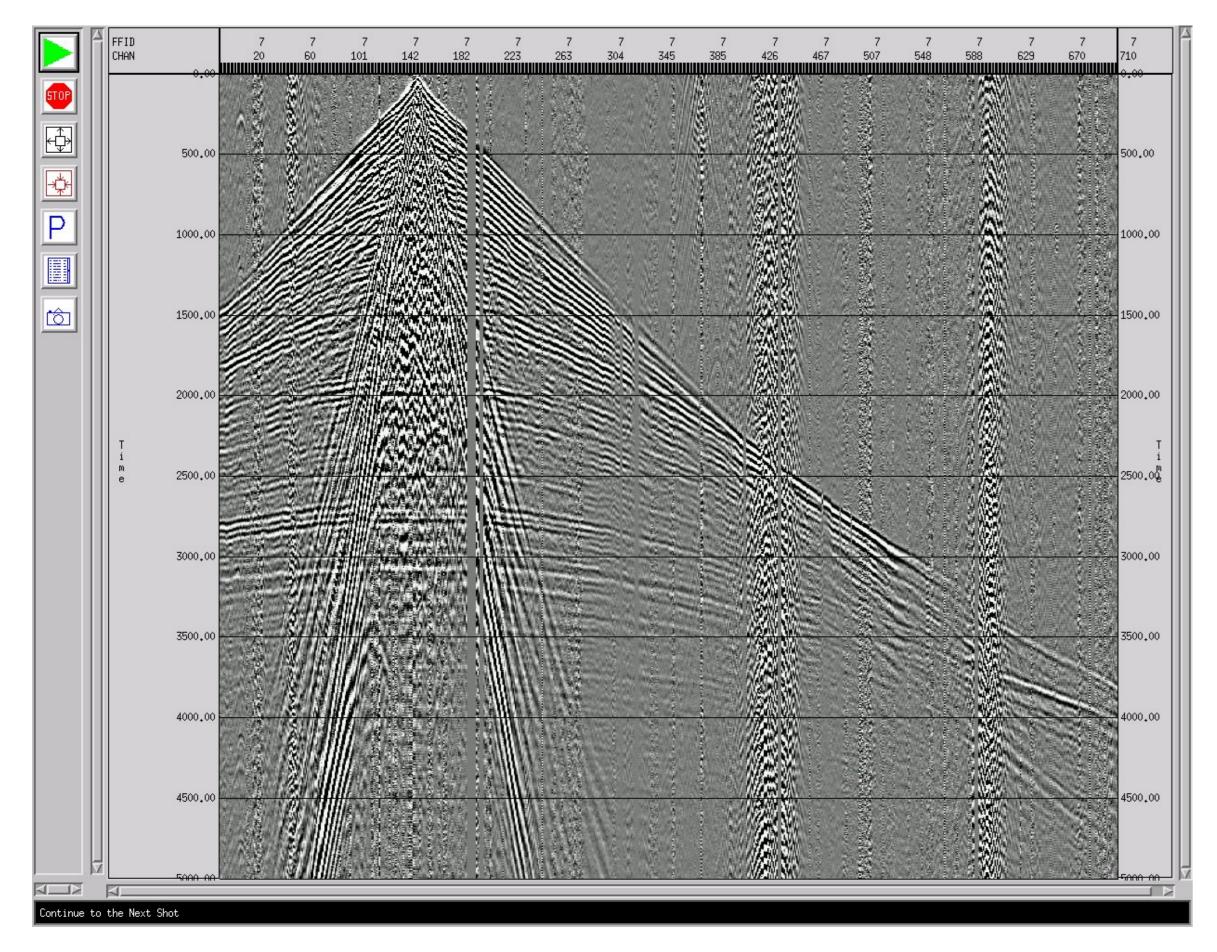






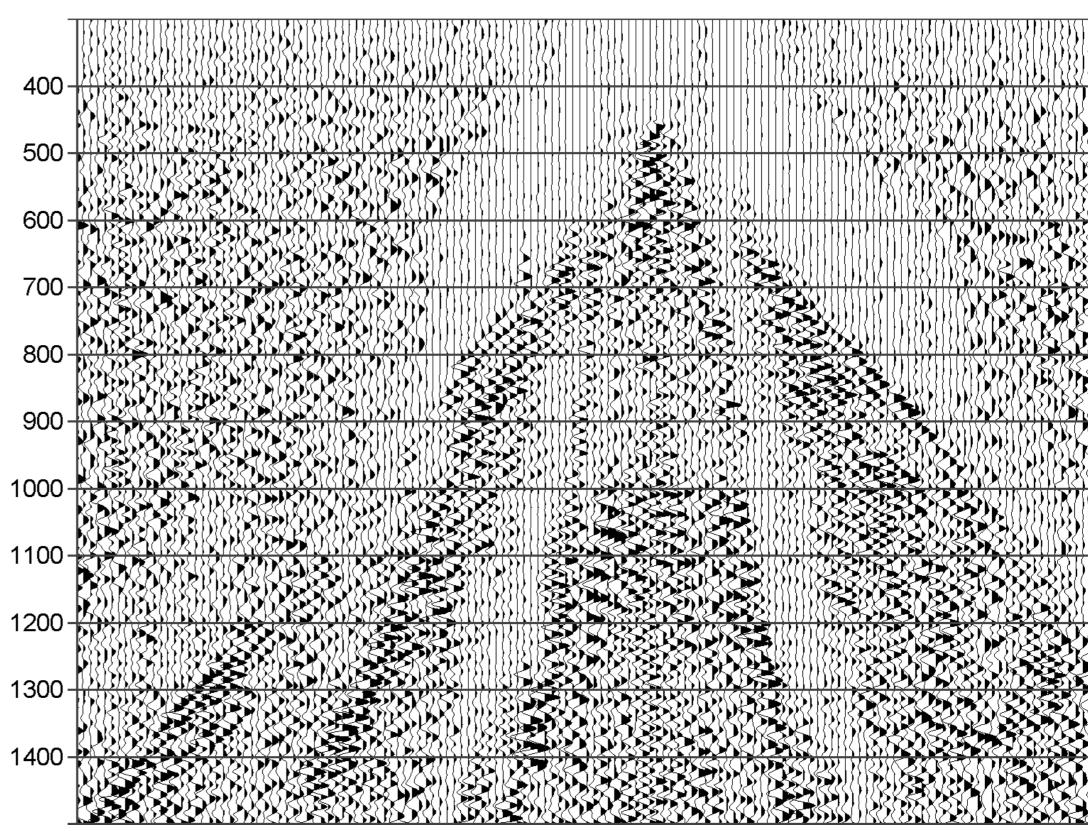
#### Active Source Seismology Shot Gathers

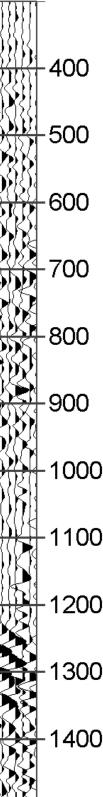
#### U.S. Gulf Coast



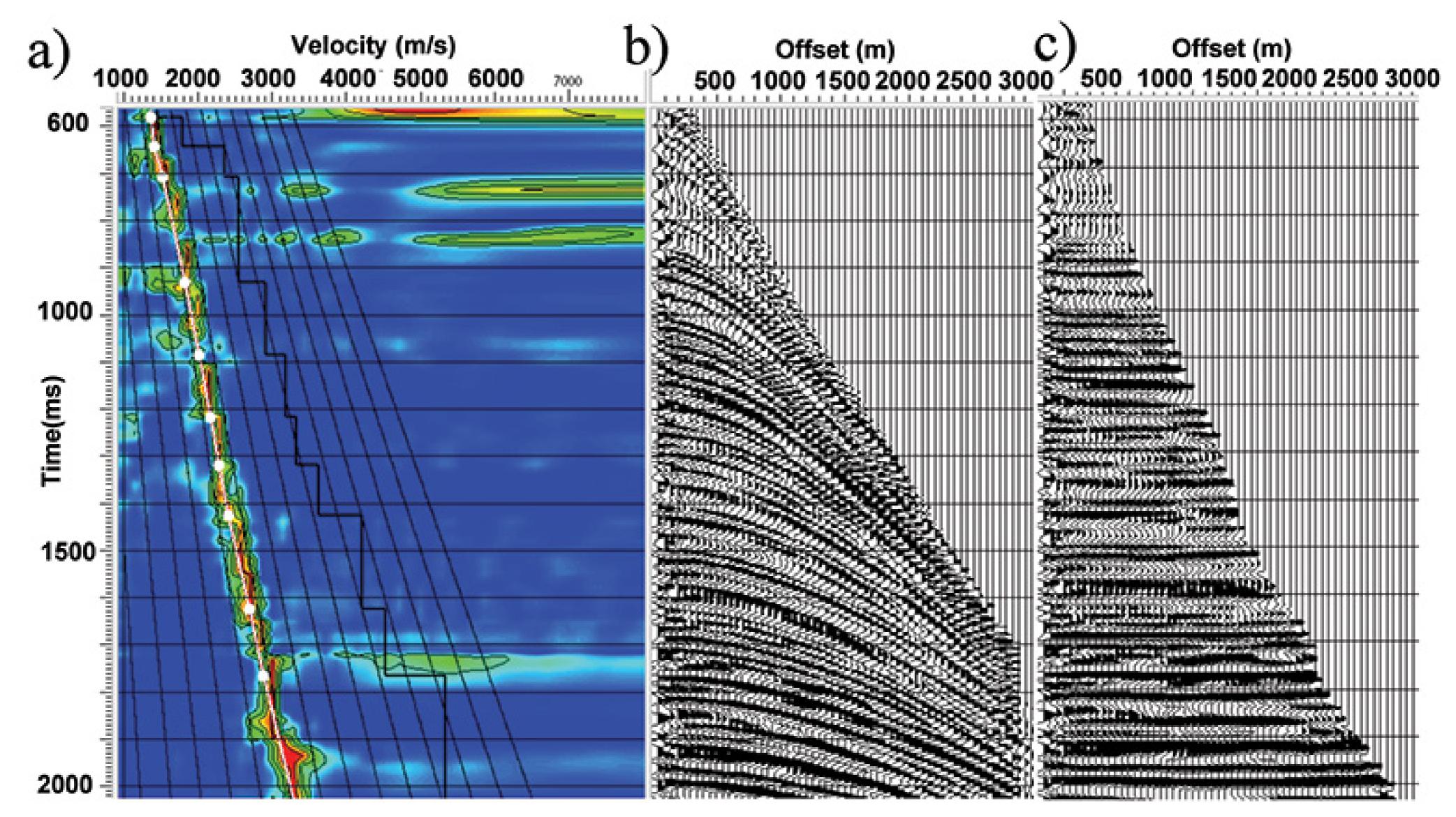
High resolution raw data, but need a simple velocity field to retain resolution in stack.

Long Beach

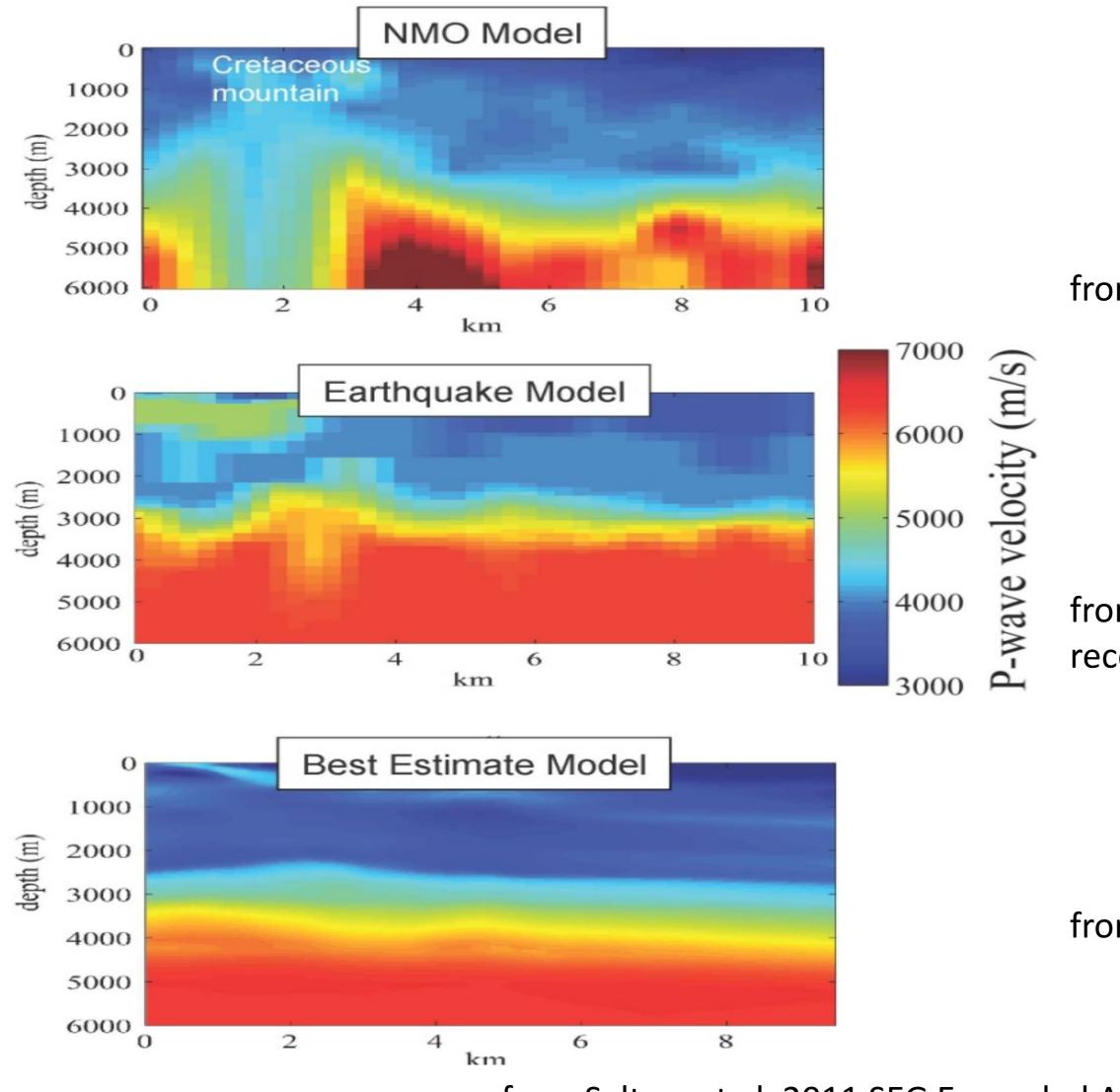




#### Active Source Seismology Normal Move-Out (NMO) Velocity Analysis



### Velocity, Velocity, Velocity



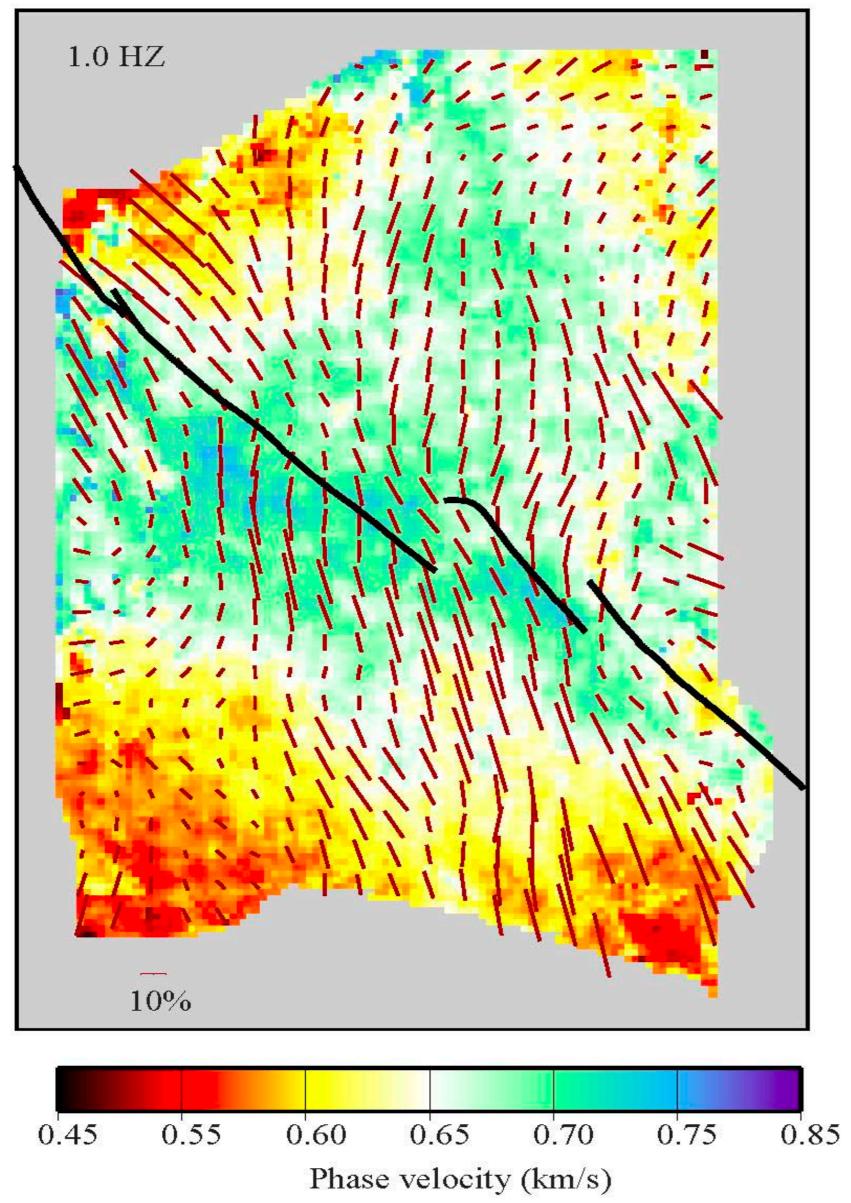
from Saltzer et al, 2011 SEG Expanded Abstract

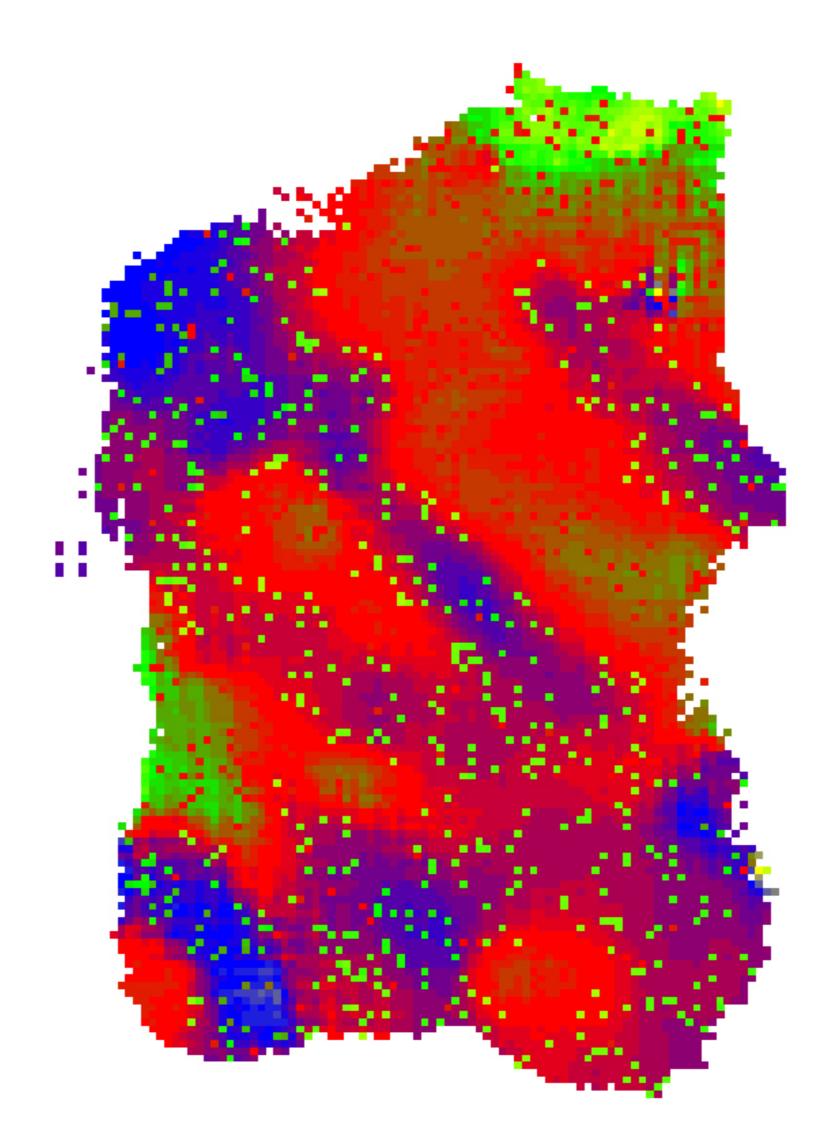
from NMO analysis

from travel-time tomography & receiver function

from well control

### Anisotropic Velocity Variations

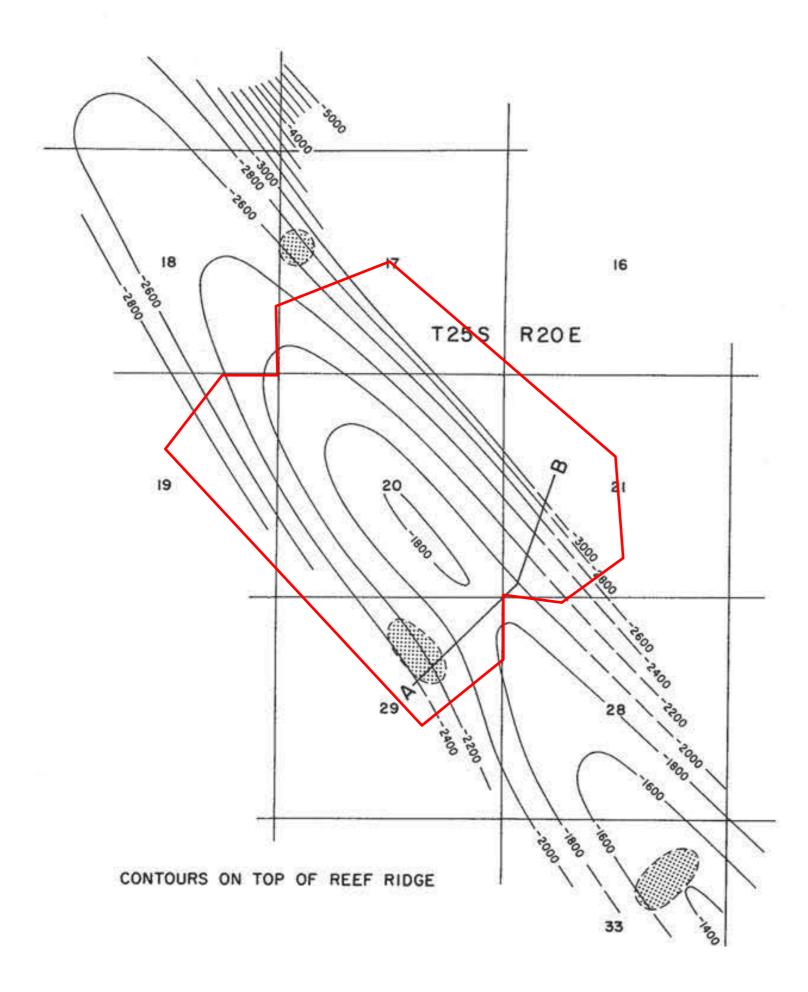


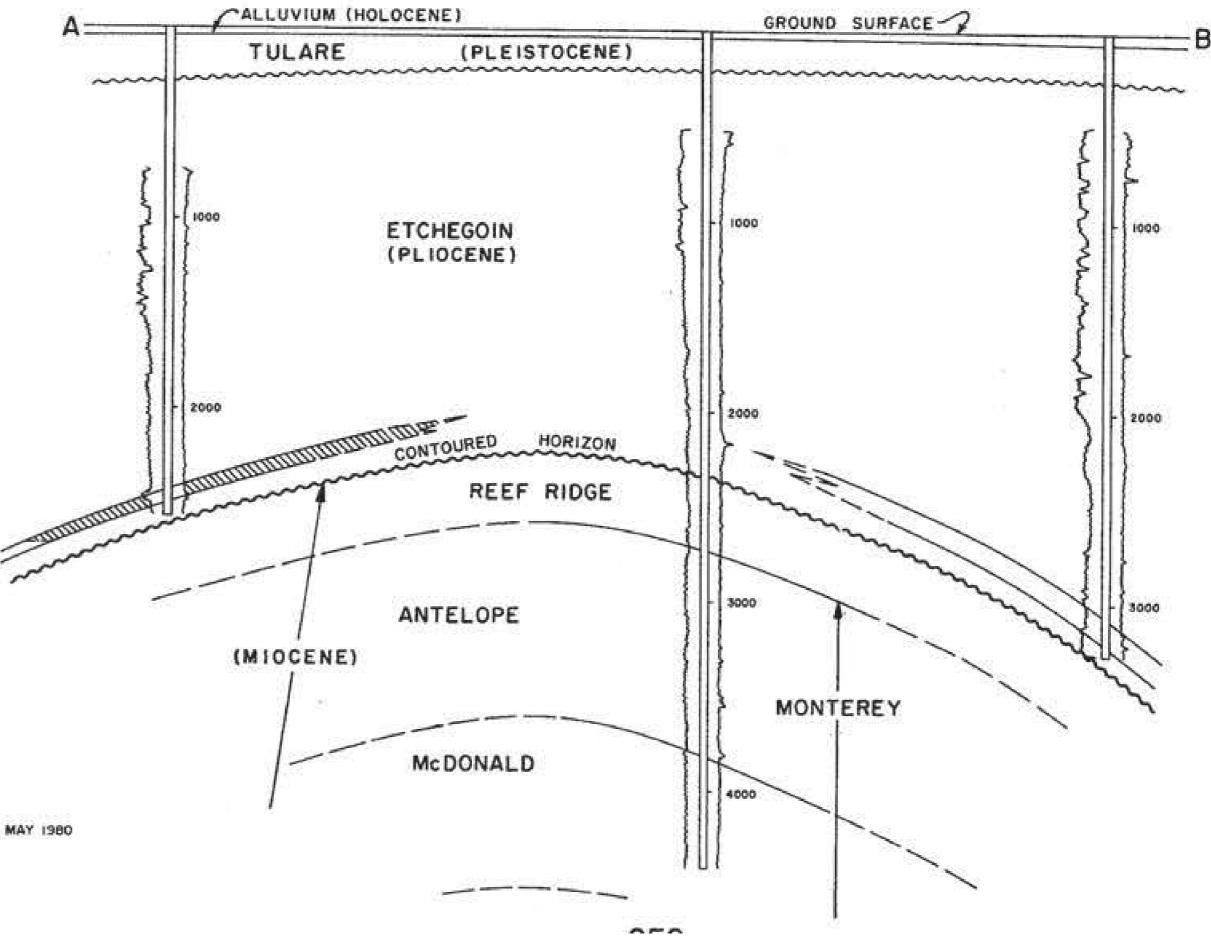


Azimuth coded by color

### Weathering Statics - Almond Crest 3D

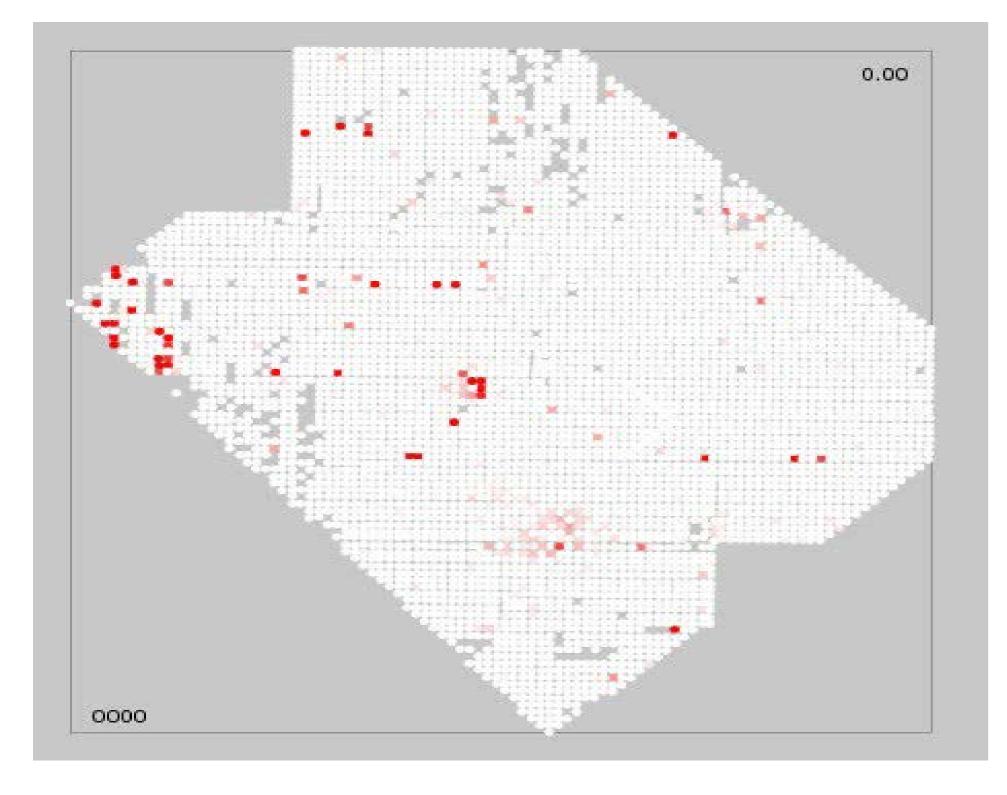
NORTHWEST LOST HILLS OIL FIELD



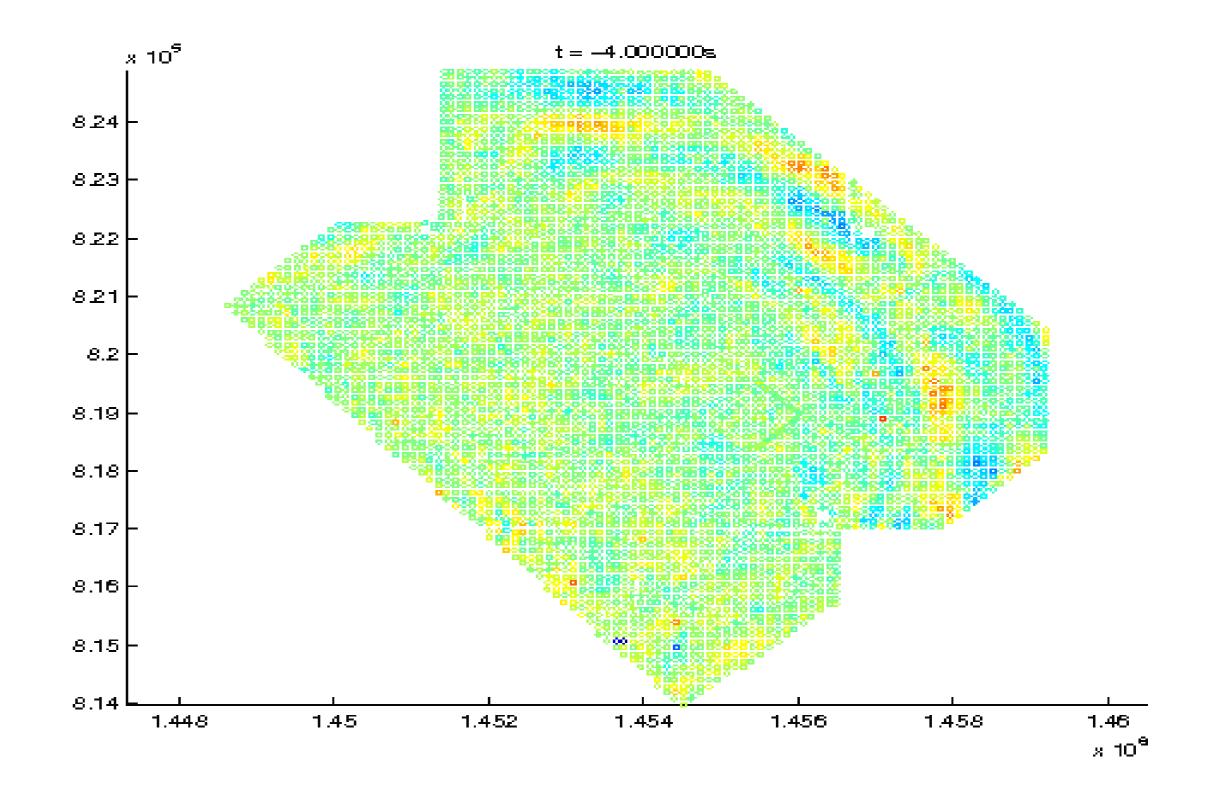


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## Almond Crest 3D

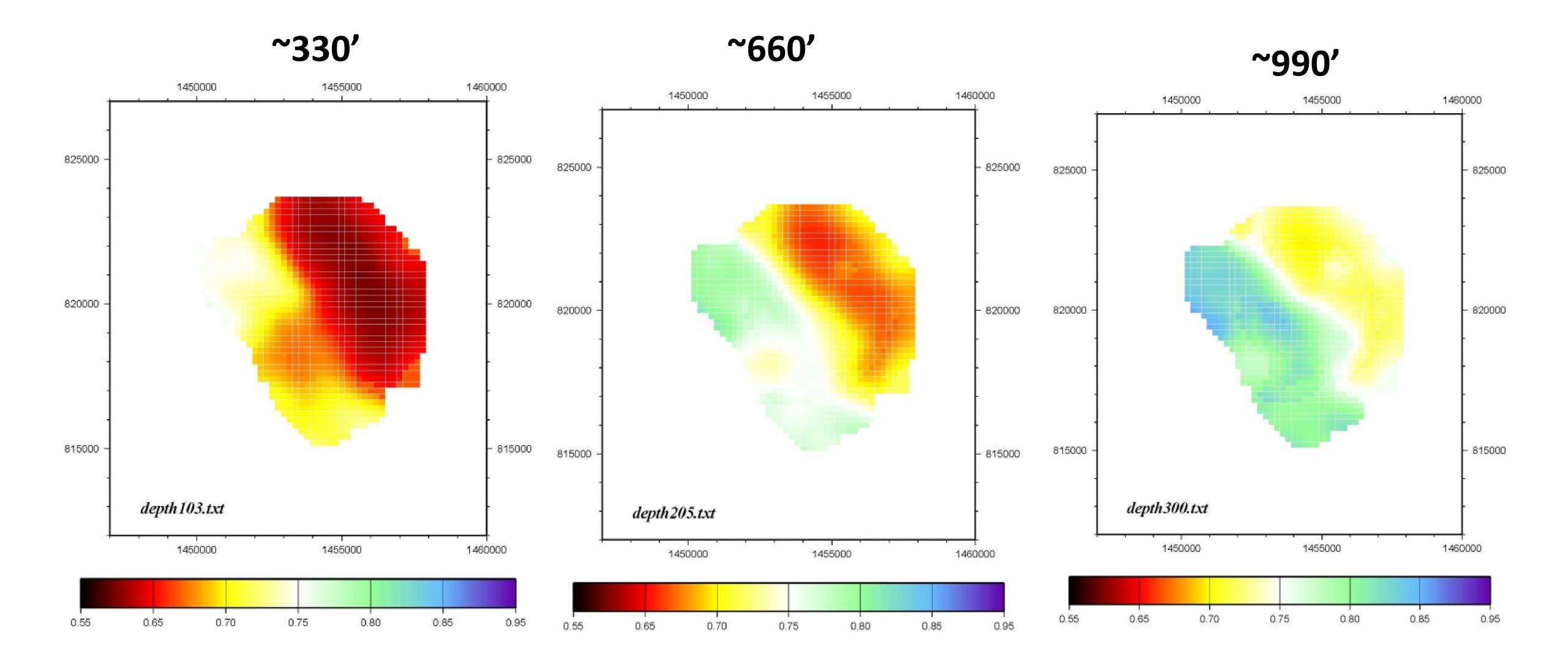


Shot hole dynamite: 2.2# at 20'

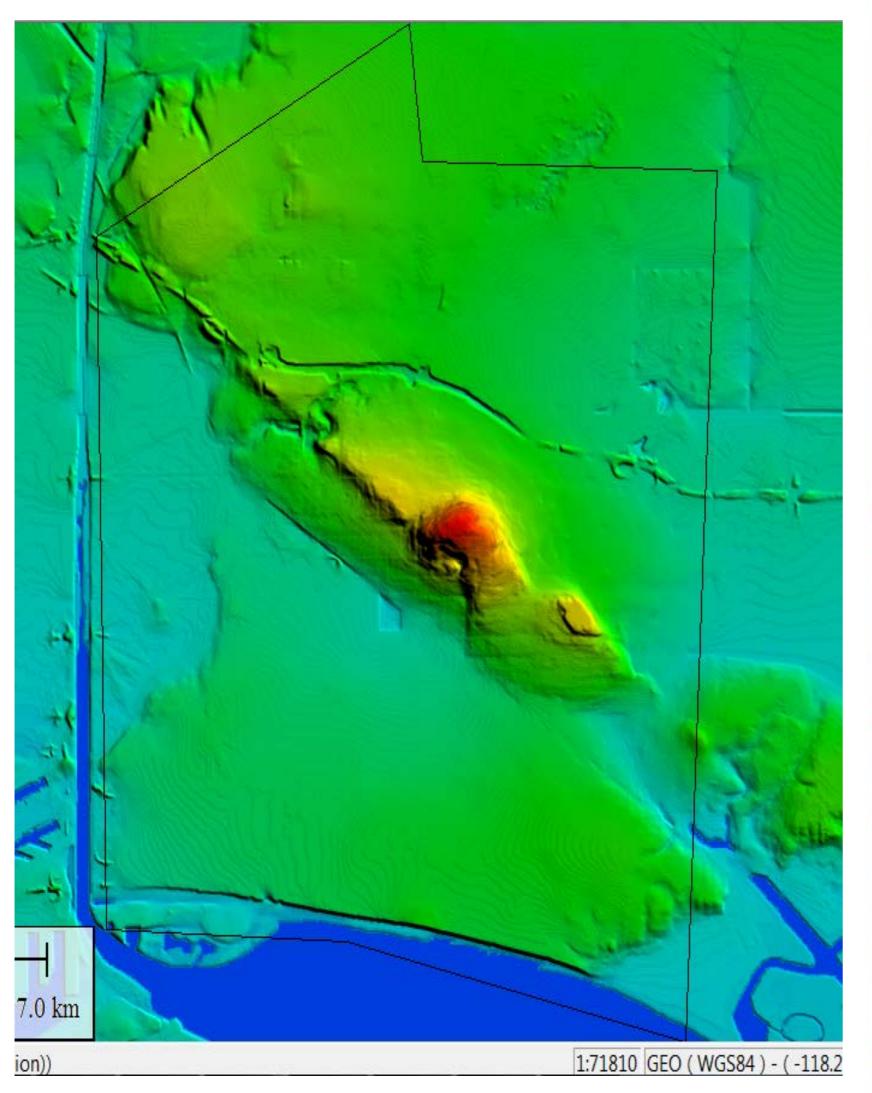


Virtual source from ambient noise cross-correlation

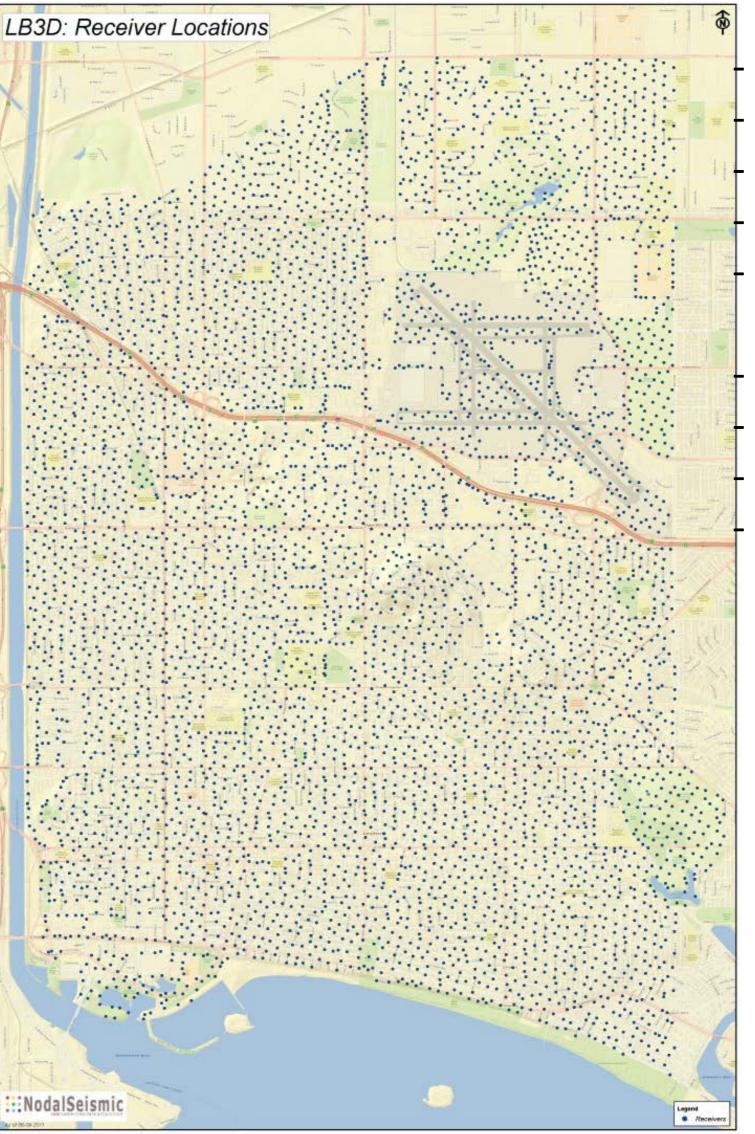
#### Almond Crest 3D ANSWT Velocity Model



#### Long Beach 3D Example **Survey Statistics**

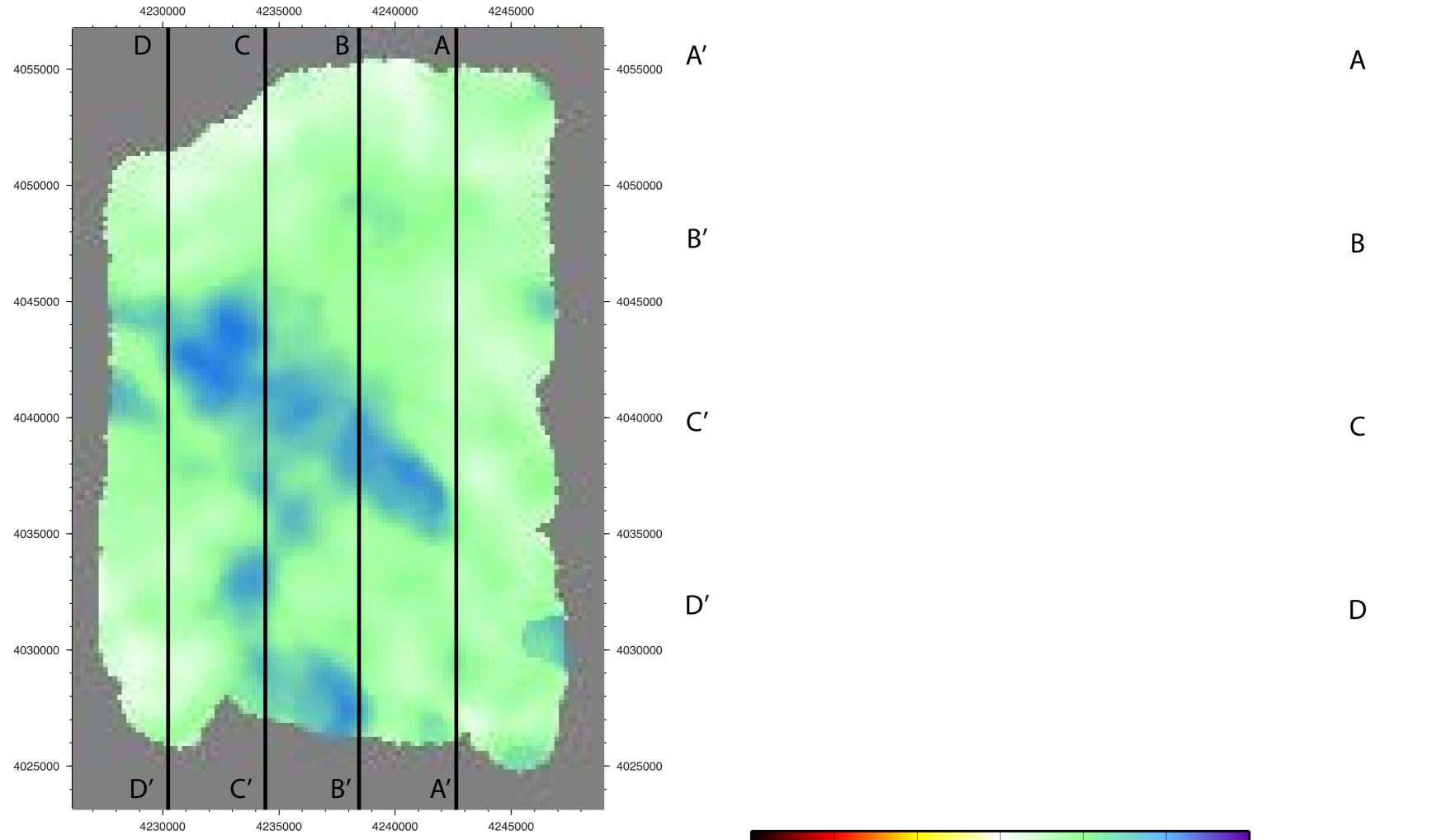


NodalSeismic

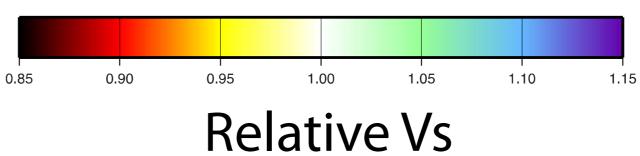


~60 sq. km Active Source (Vibroseis) Urban survey 5400 receivers/nodes (static) Receiver spacing 100m inline & 100m X-line (<u>uniform</u> array) 10 Hz CT-30 geophone (vertical) 3 Hz low cut filter 6 months of continuous data ~150 Tbytes of data

#### Long Beach 3D Example ANSWT Velocity Model (V<sub>s</sub>)



Vs (km/sec)

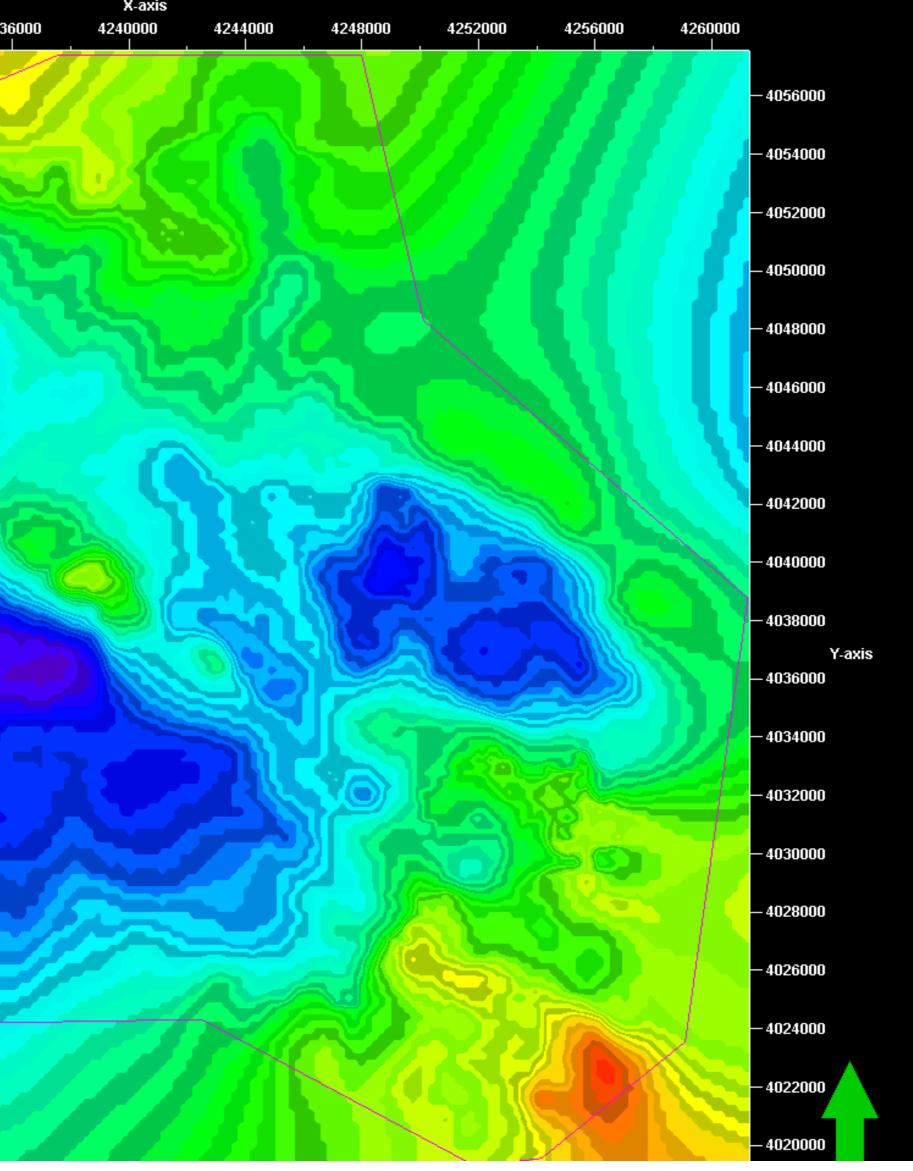




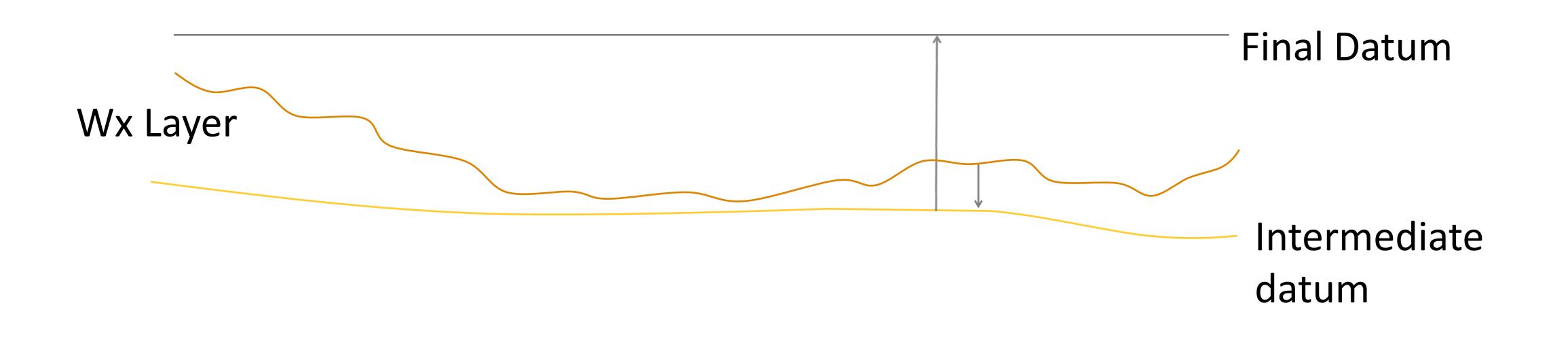
### Long Beach 3D Example Depth Slice of 3D Velocity Model (V<sub>P</sub>)

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velocity

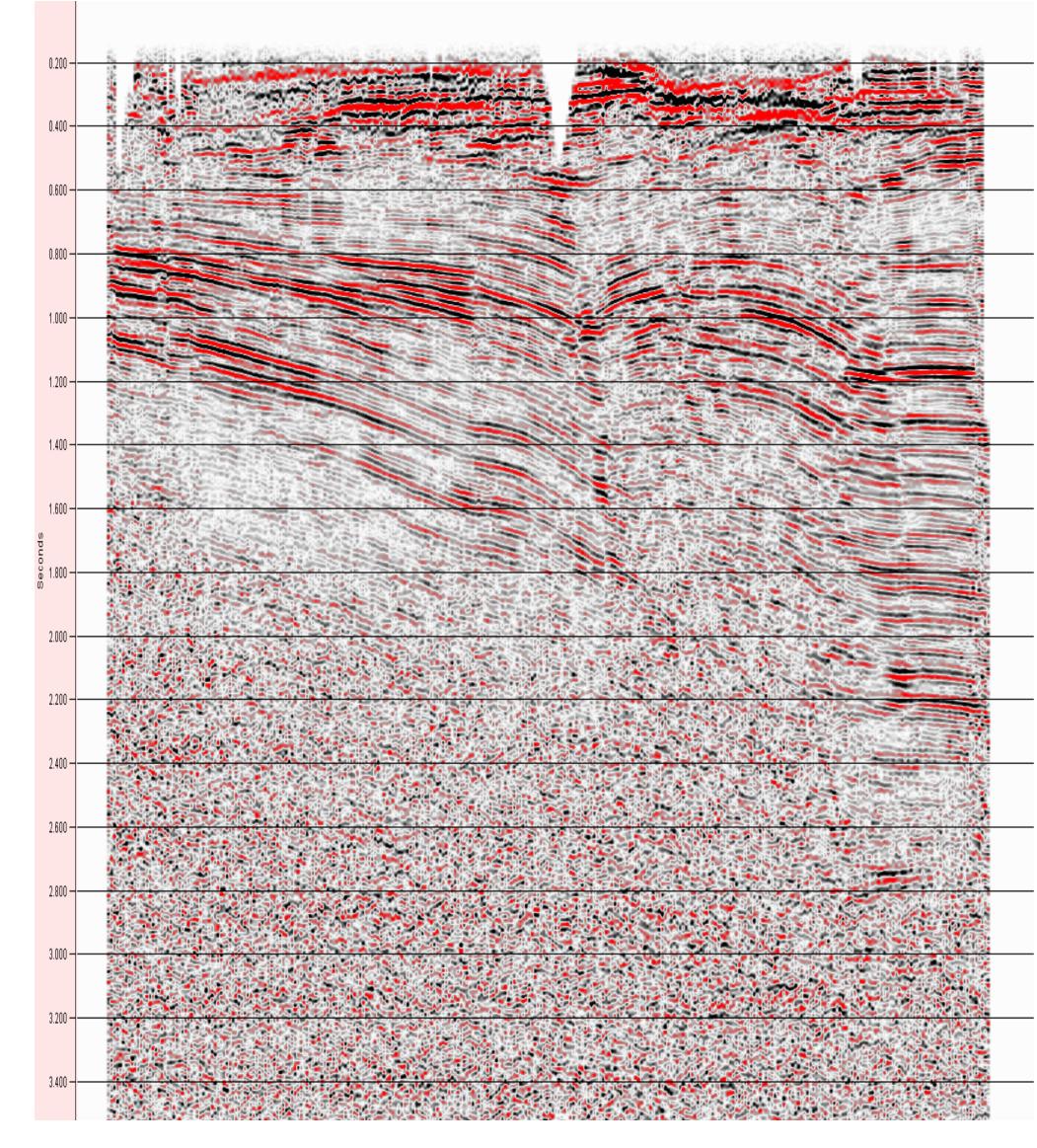


Weathering Statics Derivation

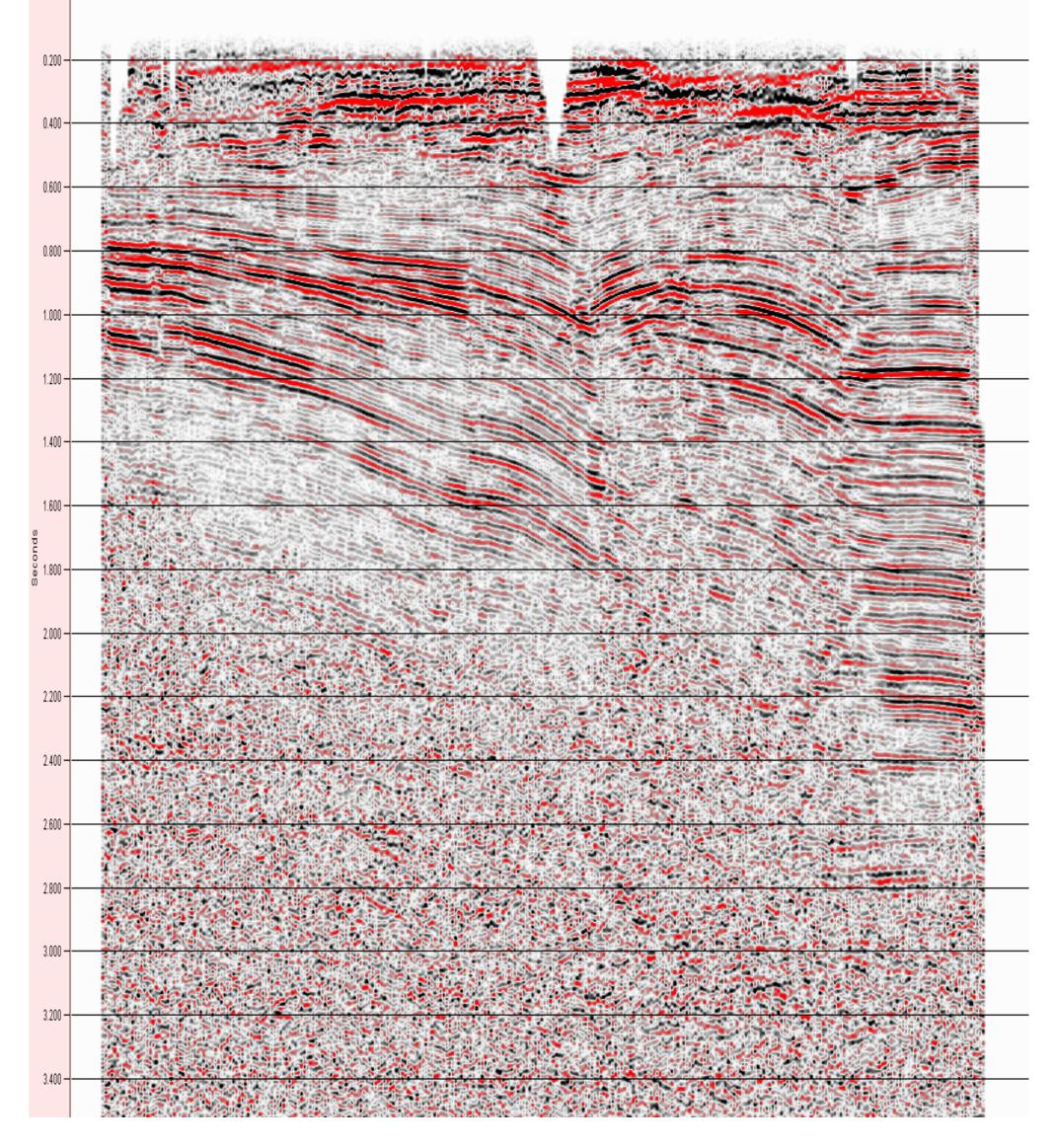
#### • Calculate time shifts from topography down to intermediate datum through P-velocity model and then to final datum using replacement

## Long Beach 3D Example

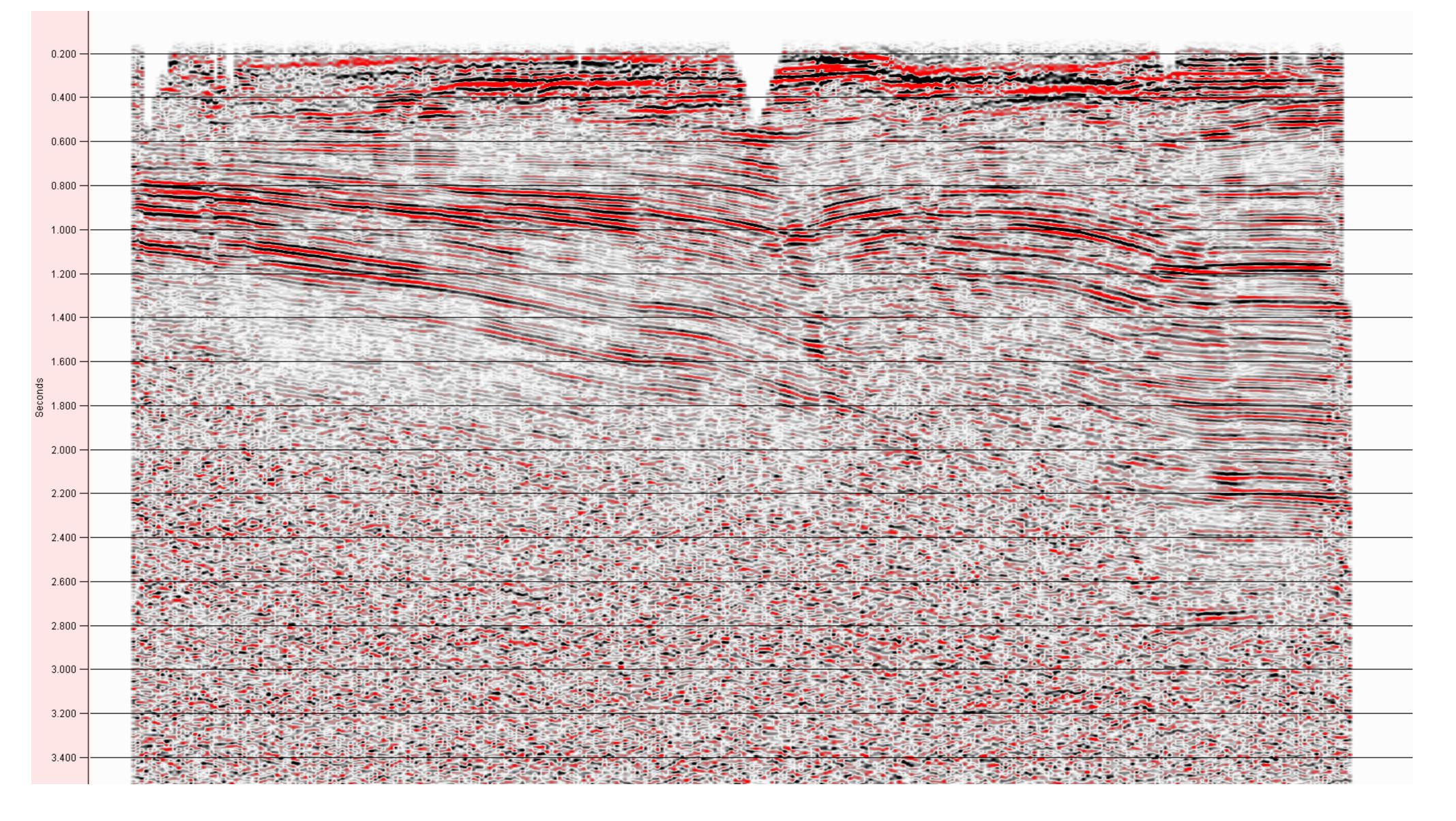
#### **Without Statics**



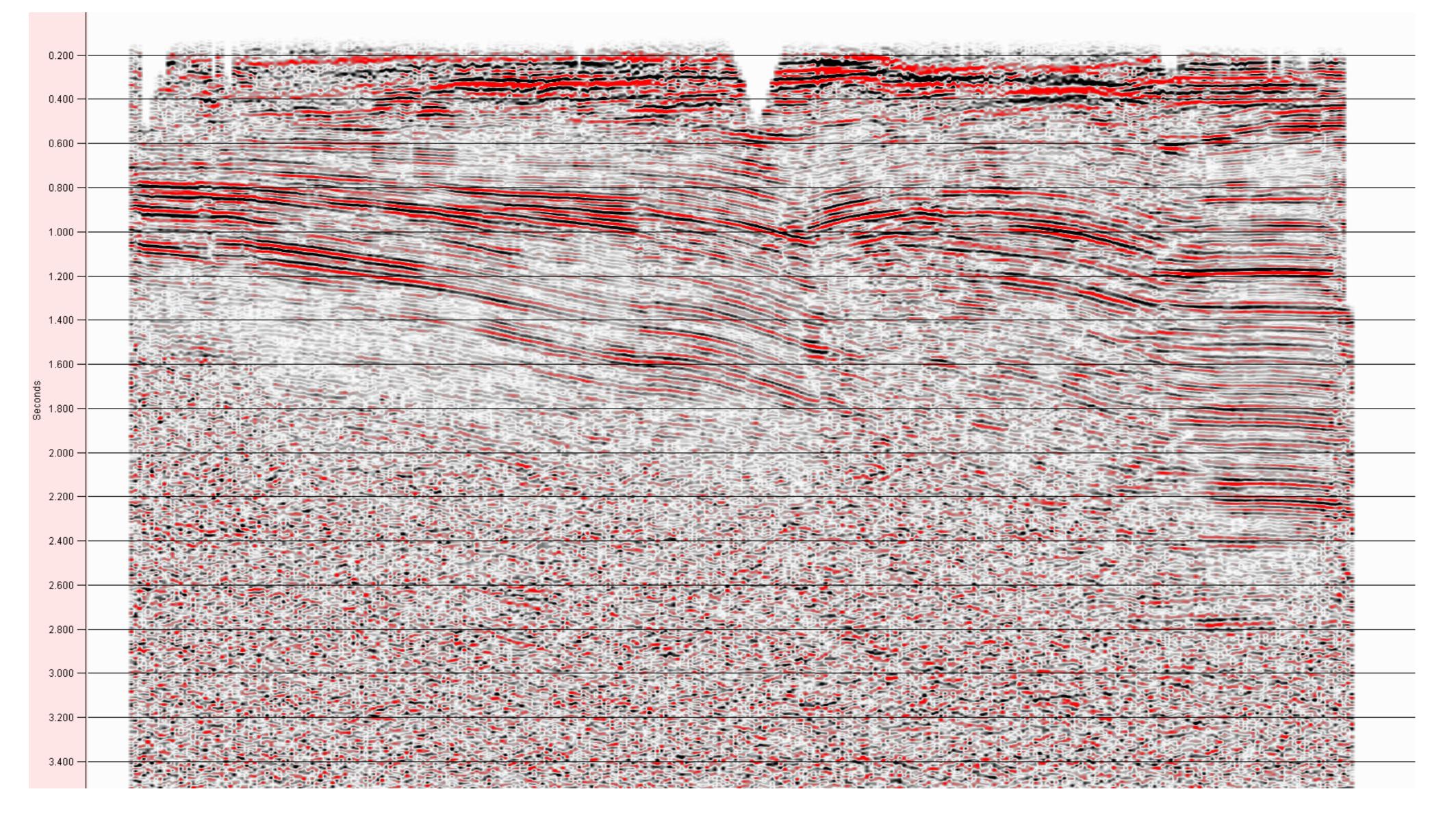




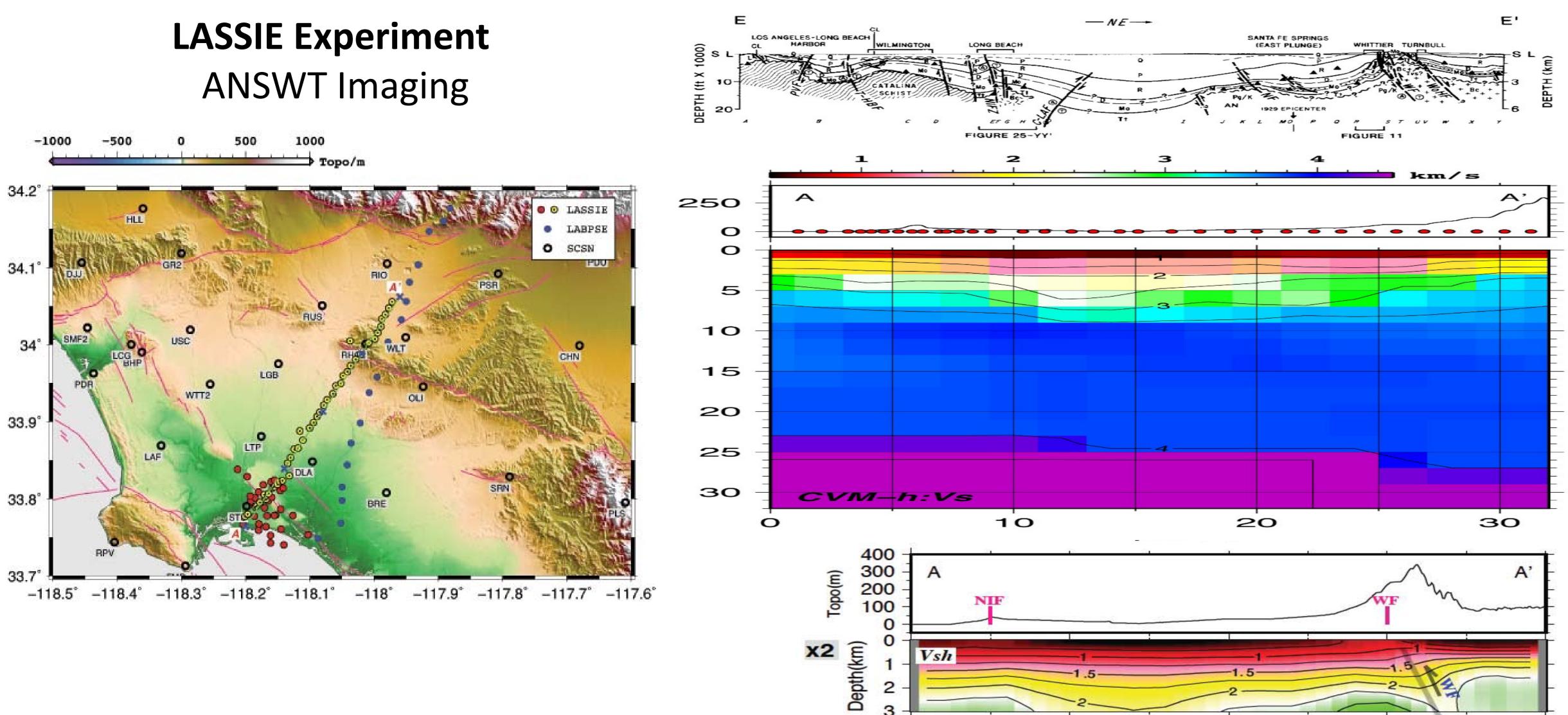
#### Long Beach 3D Example Elevation Statics Only



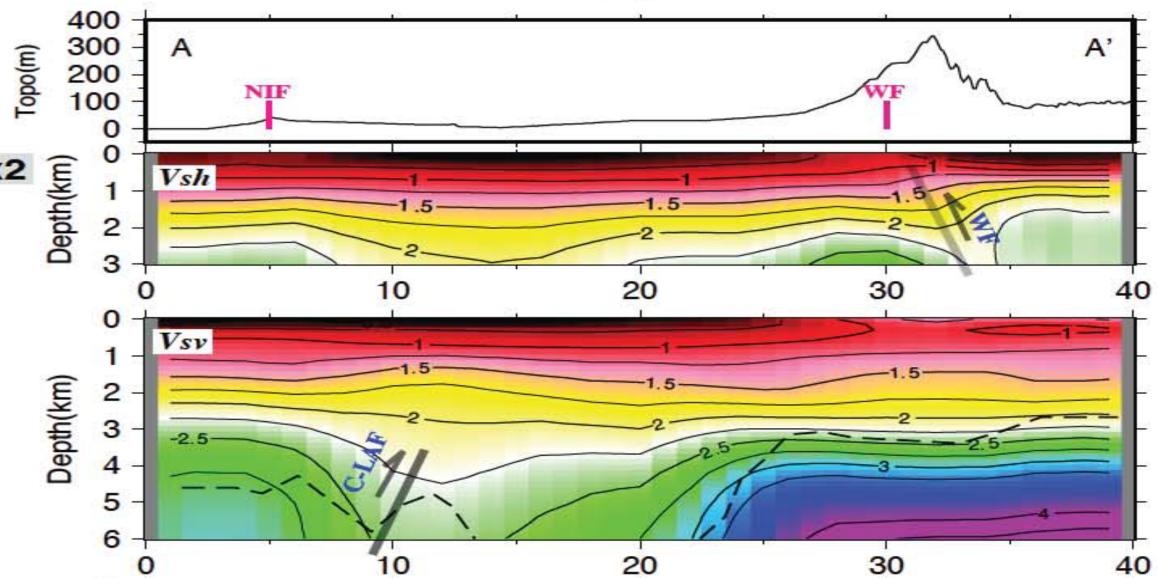
#### Long Beach 3D Example Elevation plus ANSWT-derived Statics

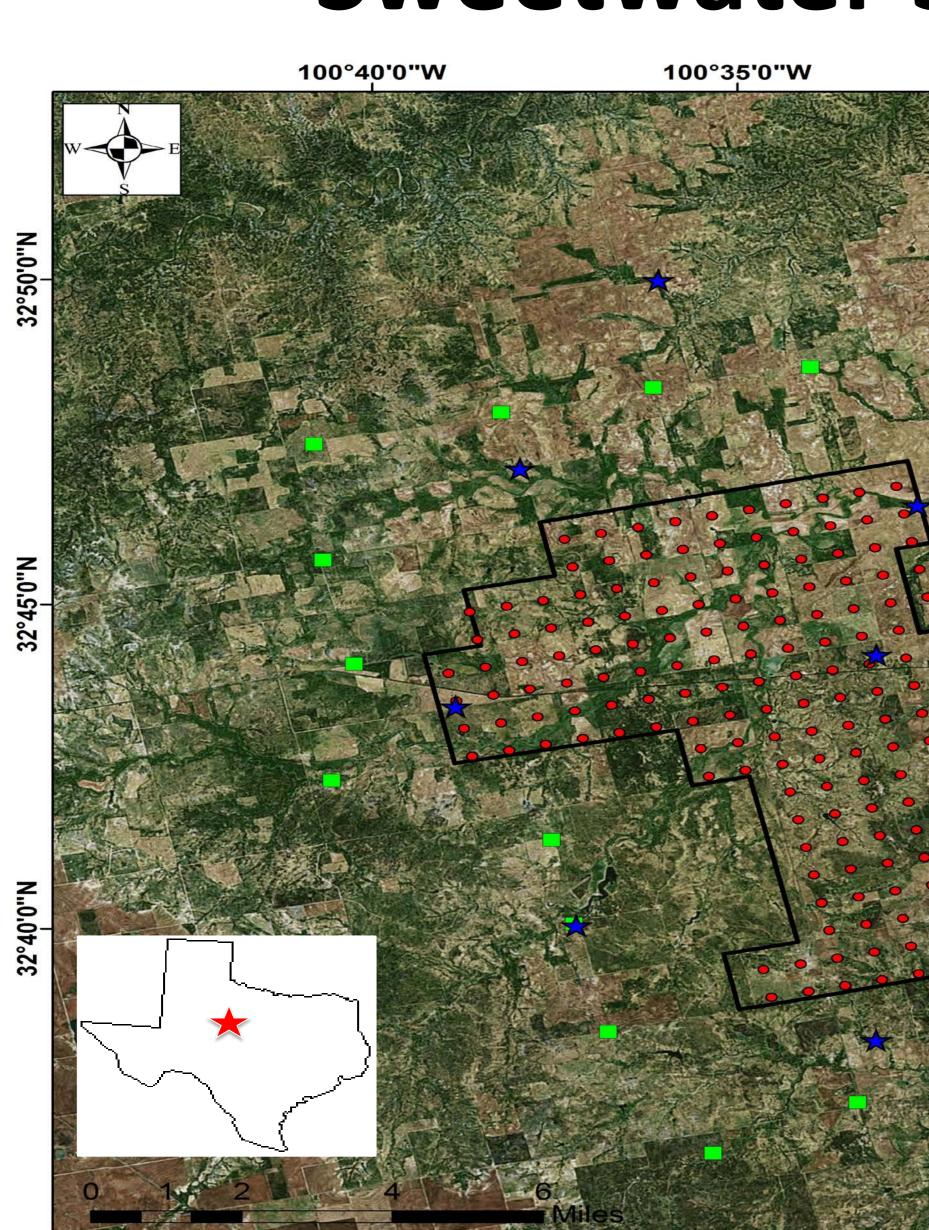


# **ANSWT** Imaging



Ma and Clayton, 2016





# Sweetwater 3D Seismic Array

100°30'0"W

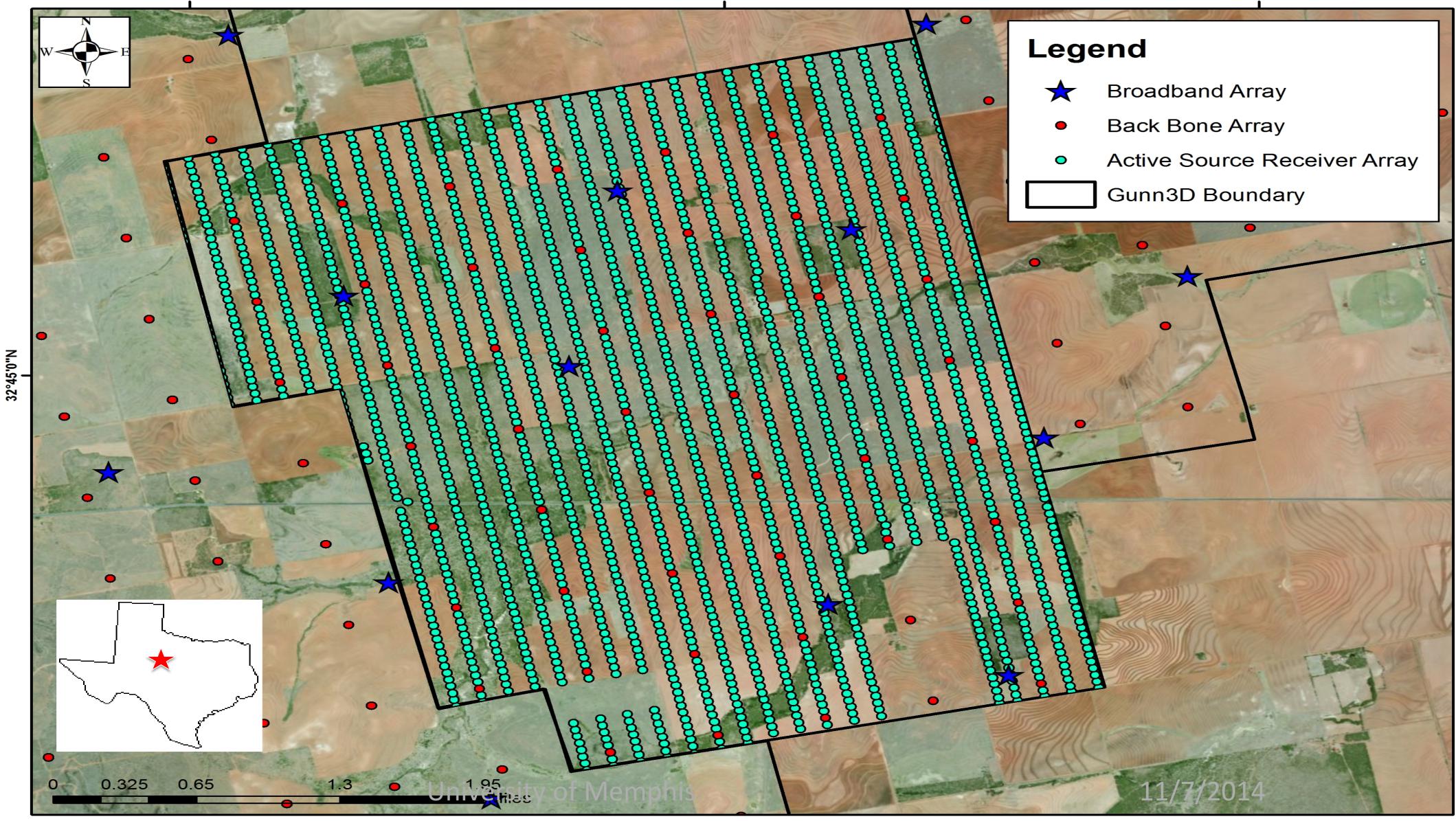
100°25'0"W

100°20'0"W

# Legend **Broadband Array** X **Outlier Array** Back Bone Array • Gunn3D Boundary

# Sweetwater 3D Seismic Array

100°32'30''W



100°30'0''W

100°27'30''W

25 broadband stations

5 Polar Trillium 120PHQs (From NSF equipment at PIC) 21 Trillium Compact Postholes from Nanometrics Centaur digitizers from Nanometrics 25 Polar quick deploy enclosures

2639 ZLand nodes

6" height - 5" diameter - 4.8lbs Single component vertical geophone 10 Hz natural frequency 2 week battery life GPS for timing

24 bit analog to digital converter







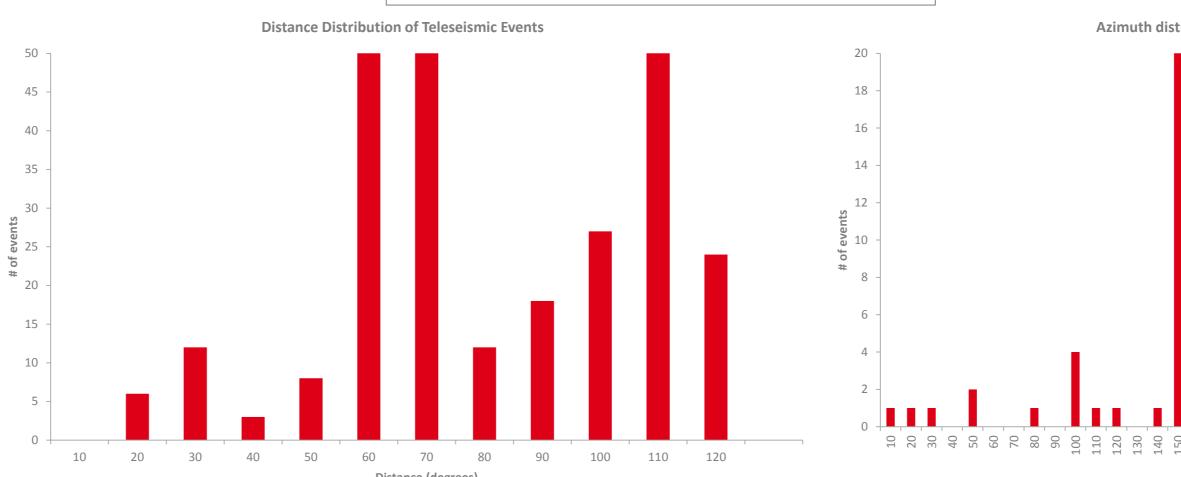




# Sweetwater 3D Sources



**Teleseismic Earthquakes Regional Earthquakes** Microseismic Earthquakes? Injection wells Oil Pump Jacks Large wind farms Fracking wells Roads Farm machinery



Telese	Teleseismic EQs				
M>8	1				
M>7	6				
M>6	27				
M>5	267				

**Azimuth distribution of Teleseismic Events** 

Distance (degrees)

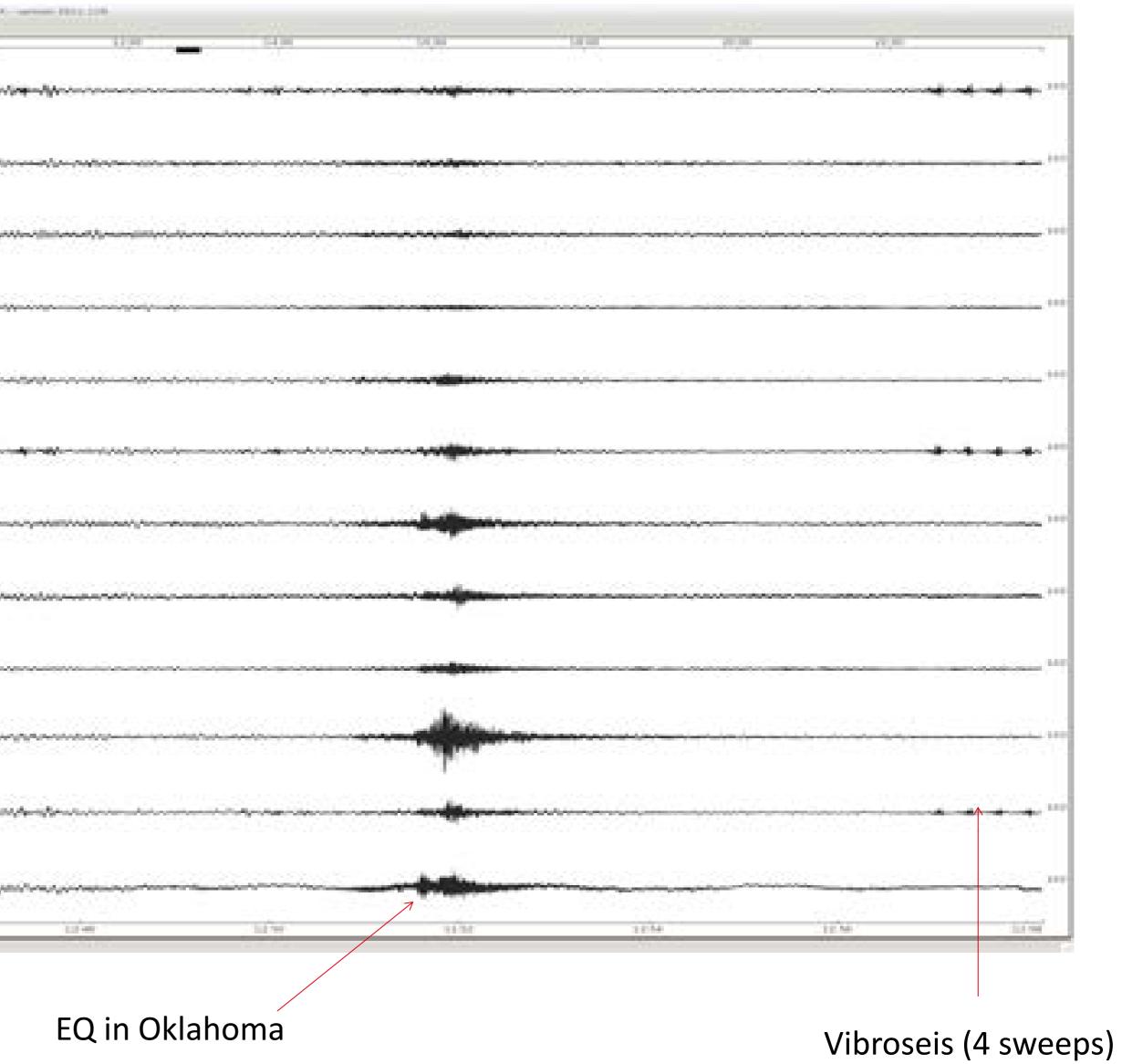
Azimuth (degrees)



#### 3 Events on Sweetwater Broadband Array

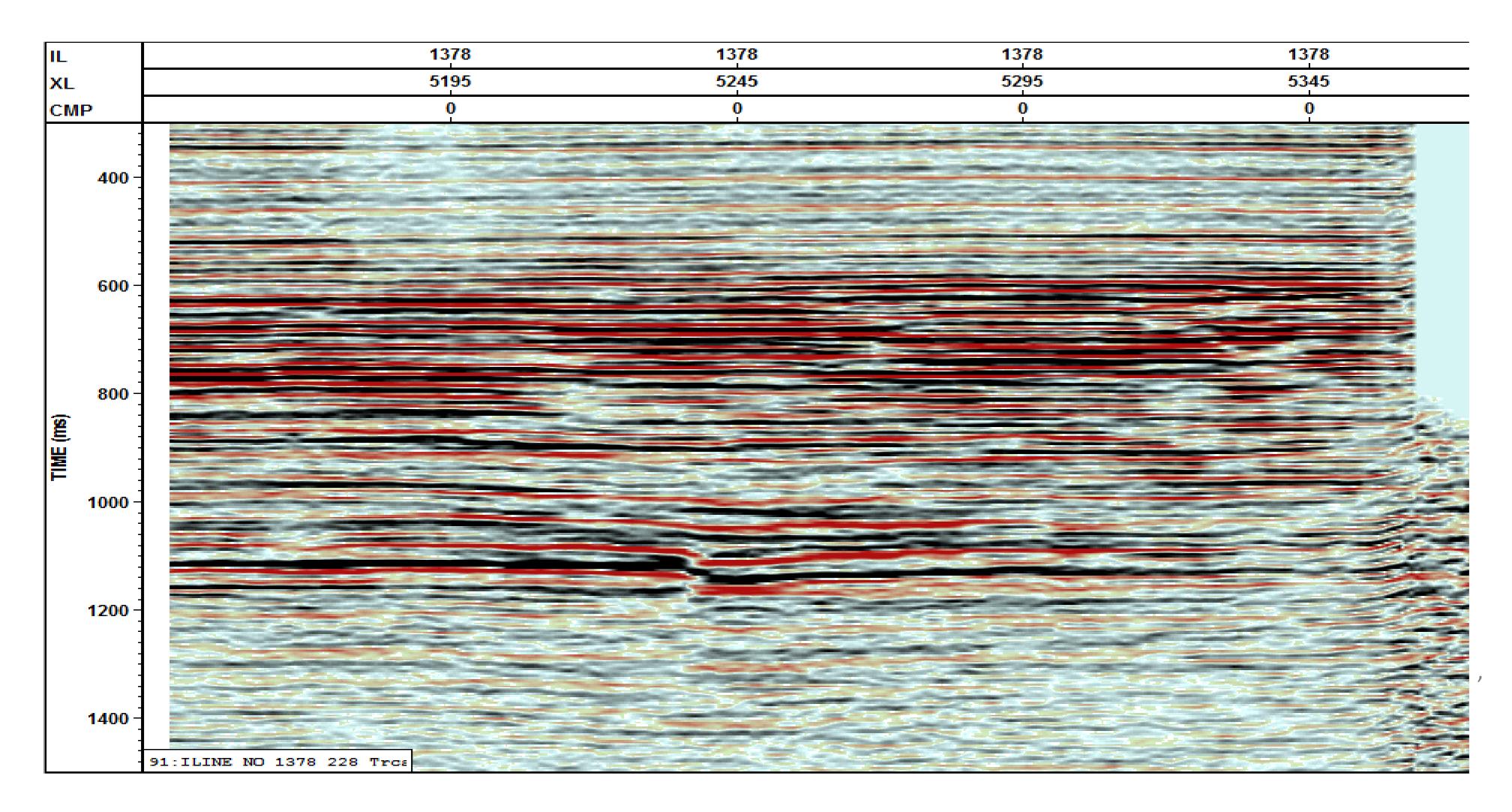
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M4.8 in Yellowstone





# SWEETWATER 3D PSTM



### Summary

- Improve active source imaging (velocity model)
- More information about the subsurface
- Growing untapped data
- If not La Jolla, consider Grenoble...

- Evolution to nodal active source instruments enables new opportunities

- Need for infrastructure (people, methods, software, etc.) to exploit data