

# Seismic Models For the Bay Area 3-D Velocity Models

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<sup>1</sup>U.S. Geological Survey and <sup>2</sup>Cal State East Bay

# Model Suggestions

- Existing 3-D models should incorporate more of the seismic models where possible.
- Where the seismic models and the existing 3-D models differ, seismic models should be more heavily weighted.
- Shallow Vp and Vs models, where available, should be incorporated into the 3-D model.
- Highly variable Vp/Vs ratios make it difficult to extrapolate 3-D Vs models from Vp models.

# Improving the Existing Bay Area 3-D Velocity Model

**Existing 3-D models should incorporate seismic models where possible.**

- There are nine deep tomography profiles along and across the bay, some with both Vp and Vs
- There are numerous shallow tomography profiles in the Bay Area, many with both Vp and Vs.
- Near-surface and shallow-depth (100 – 500 m) surface-wave (Vs) models can be developed from all profiles.
- There are several deep Vs models in the Bay Area, based on ambient noise measurements (Koichi Hayashi, Geometrics)

# Improving the Existing Bay Area 3-D Velocity Model

## Comparison: Existing 3-D and Seismic Models

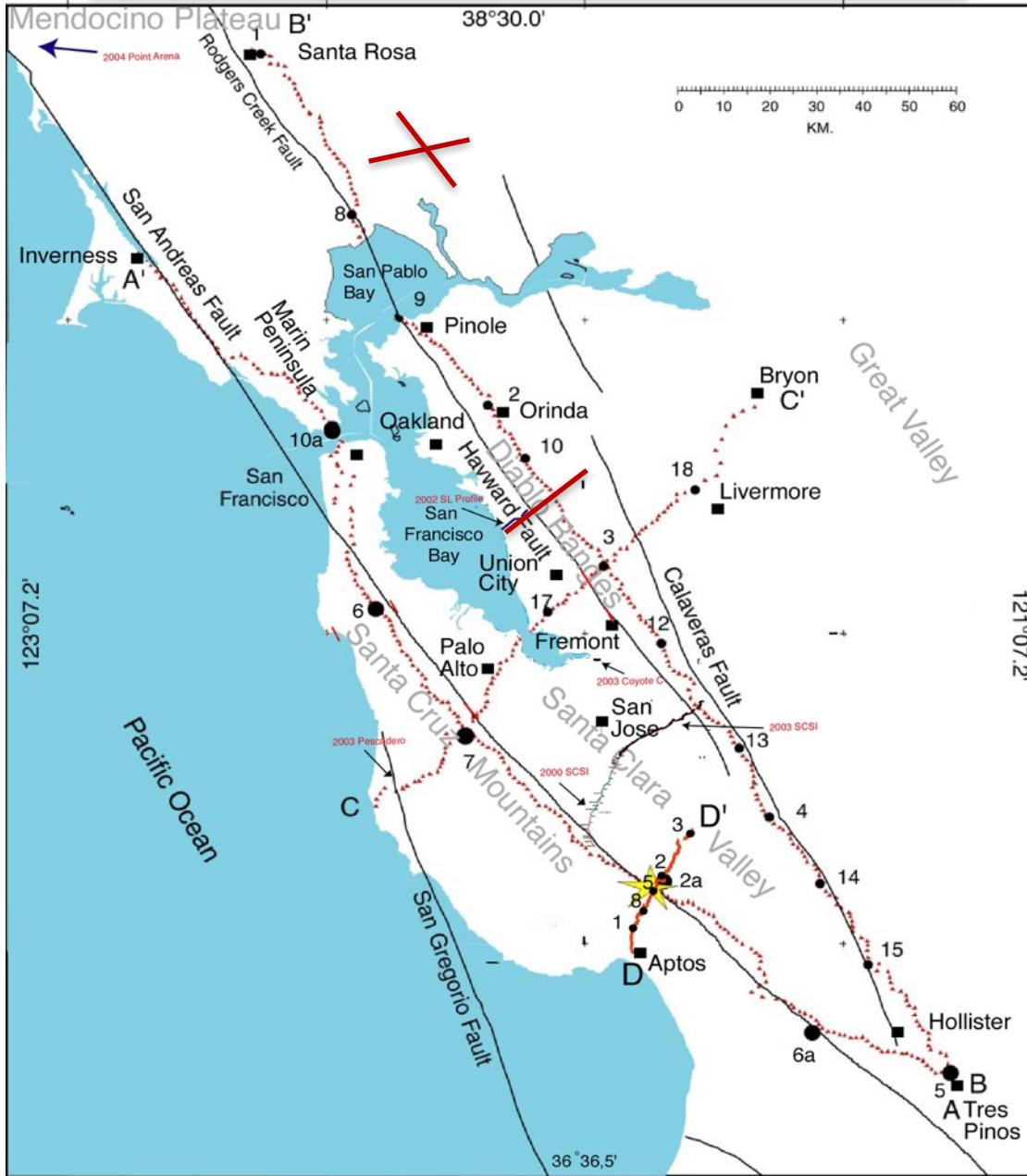
- The existing 3-D models do not compare well with the seismic-based models.
  - Areas of some models differ by 100% or more in velocity.

# Deep Seismic Profiles

At least 9 deep profiles ranging in depth between 5 and 30+ km – Some part of existing model

Dozens of shallow-depth (10s to 100s of m) profiles

Several Ambient noise ( $V_s$ ) profiles



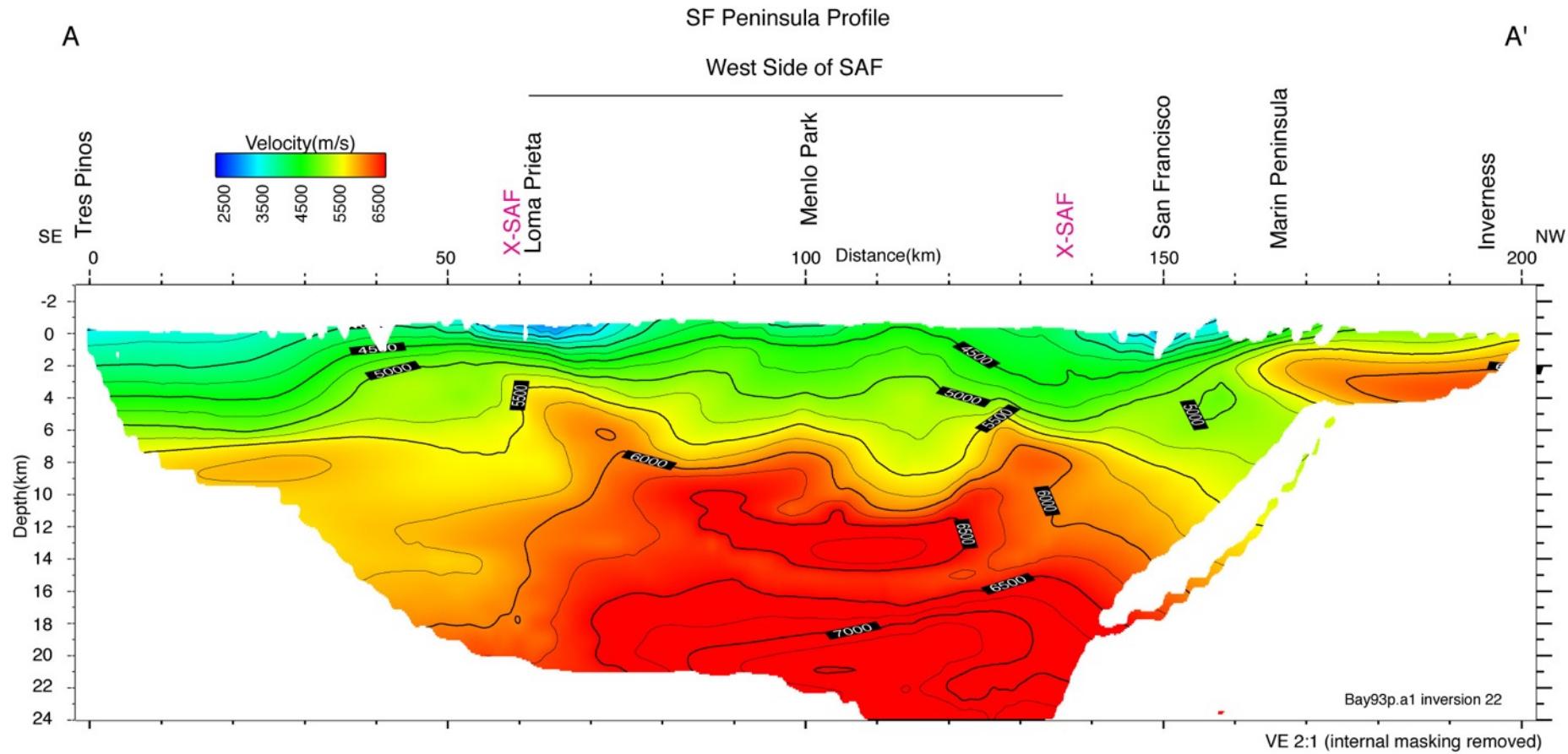
# Model Comparisons

## SF & Marin Peninsulas

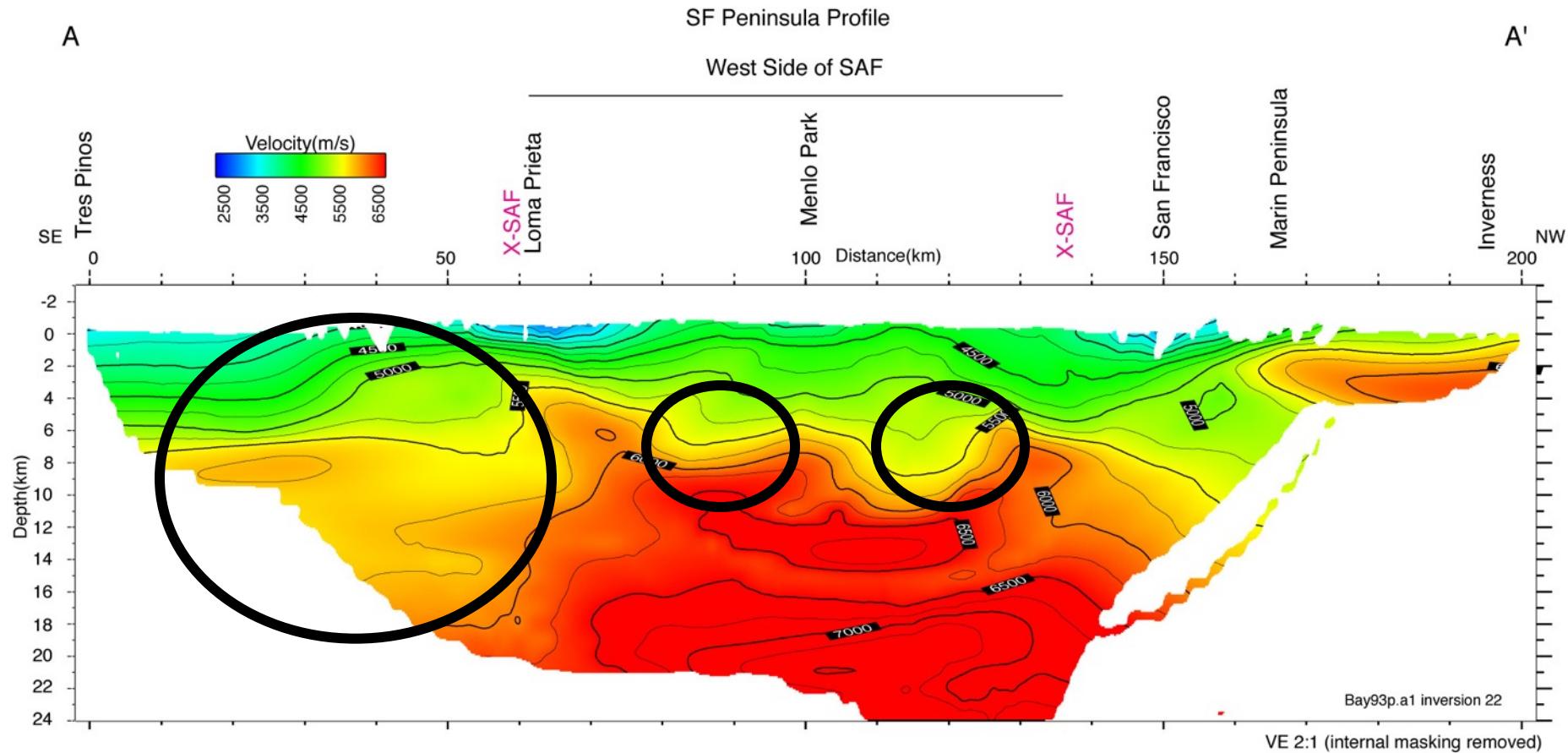
### Deep Seismic Profiles



# Peninsula Refraction Tomography Model



# Peninsula Refraction Tomography Model



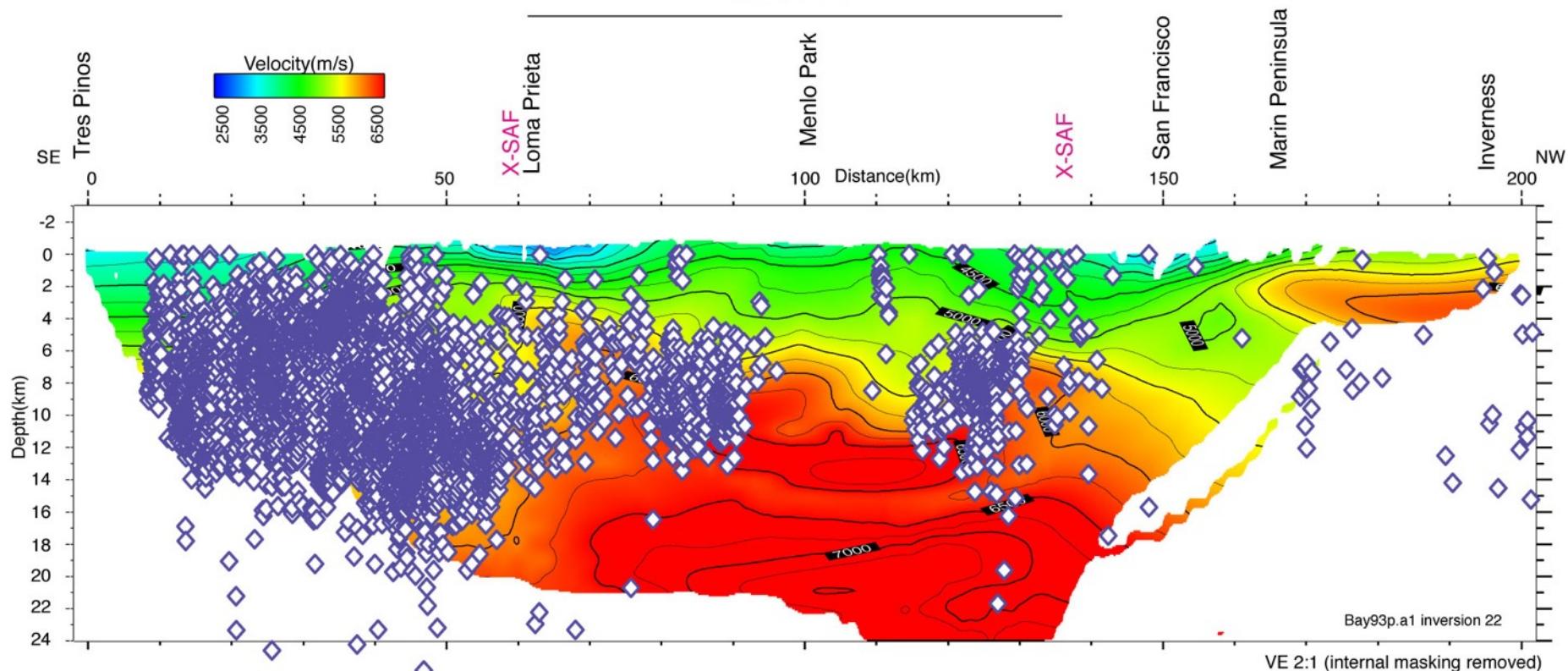
# Peninsula Refraction Tomography Model with Seismicity

A

A'

SF Peninsula Profile

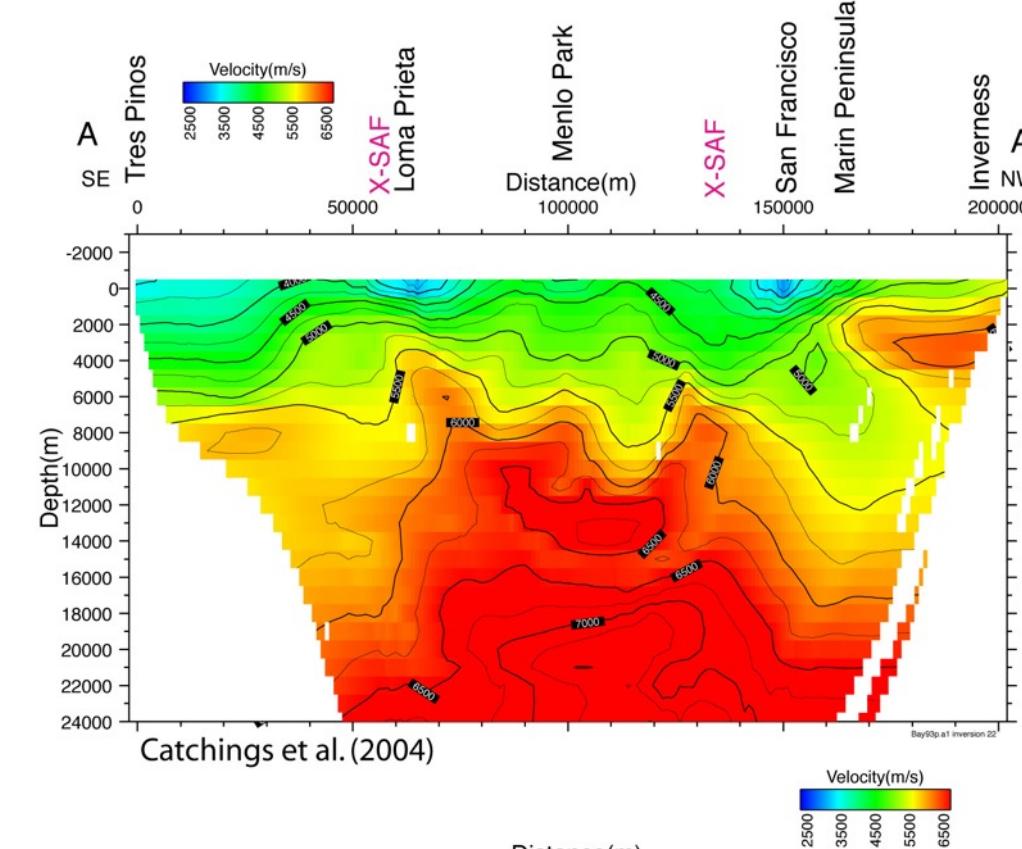
West Side of SAF



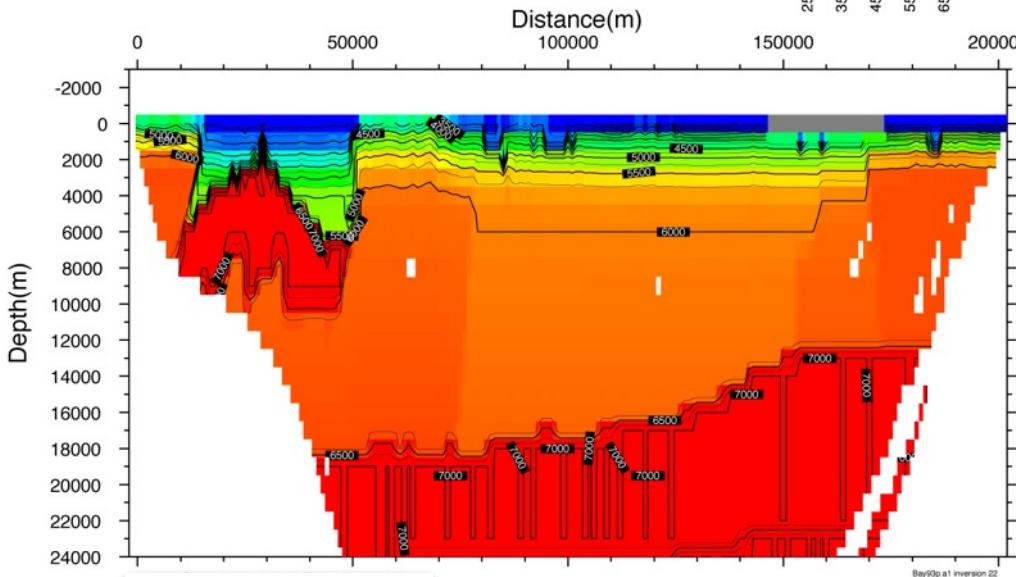
- Seismicity Tracks Low Velocity Zones
- Little Seismicity in Higher Velocity Areas

# Comparison of Peninsula Velocity Models

## Refraction Tomography Model



## Existing 3-D Velocity Model



Velocity Differences Up to 2750 m/s

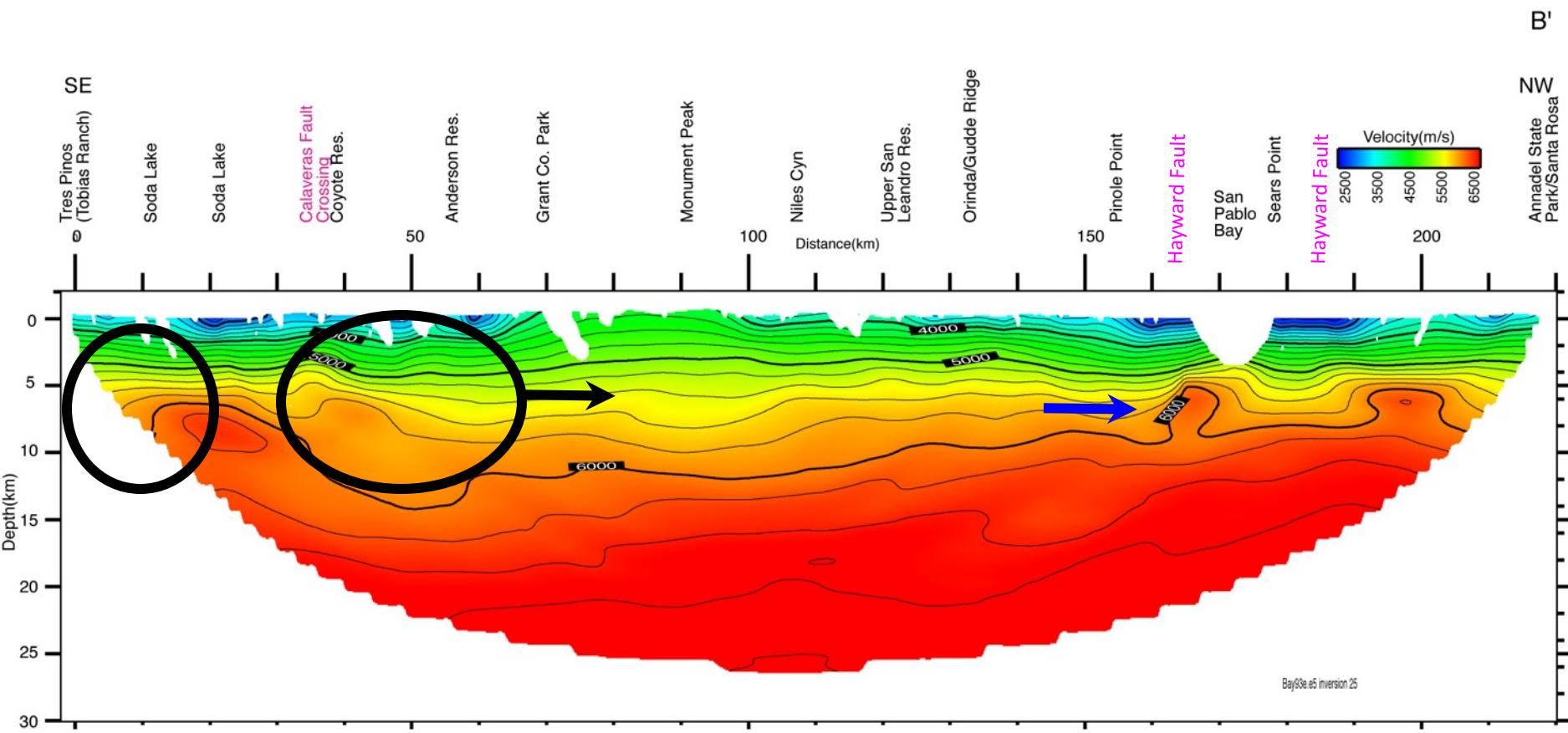
# Model Comparisons

## Deep Seismic Profiles

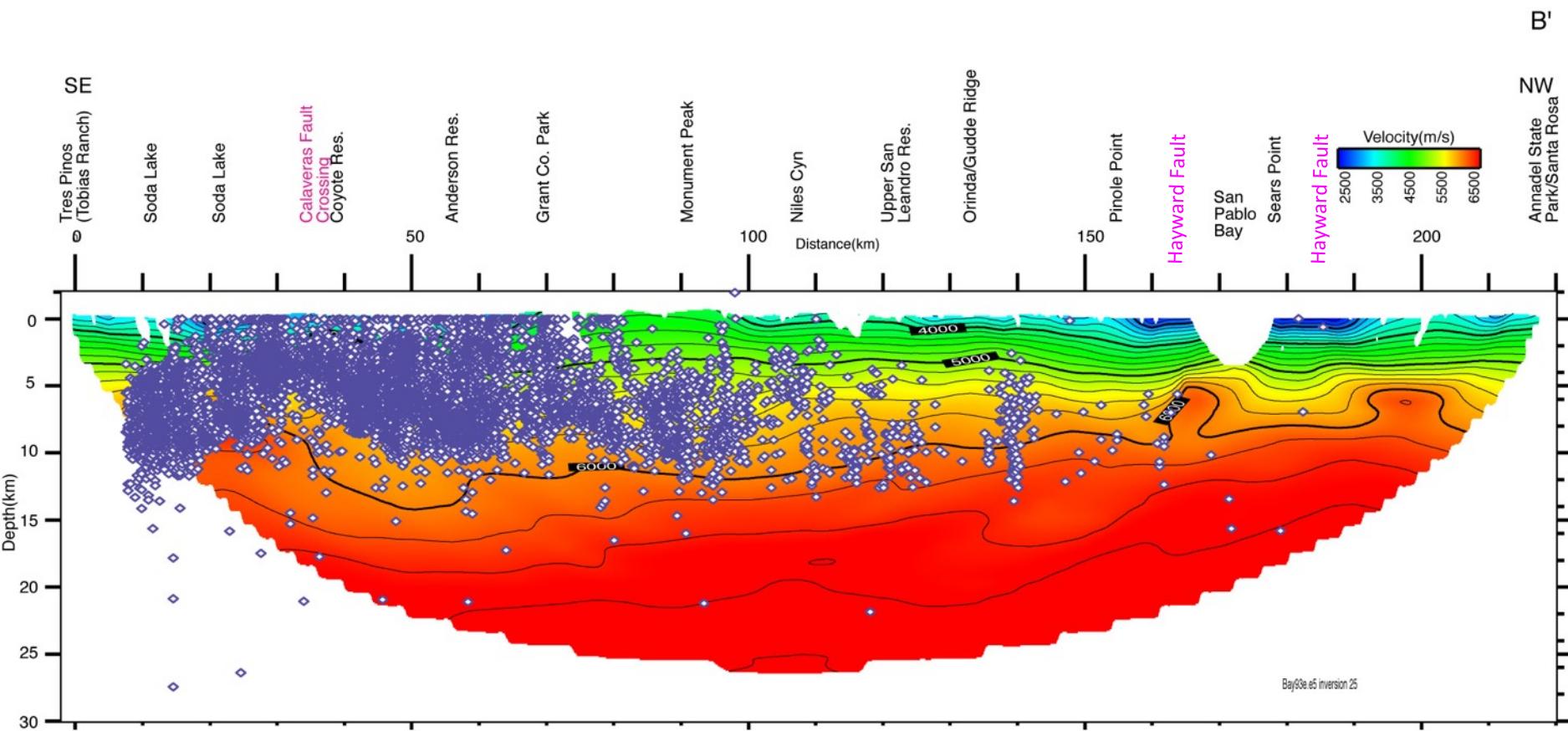
### East and South Bay Profile



# East and South Bay Refraction Tomography Model



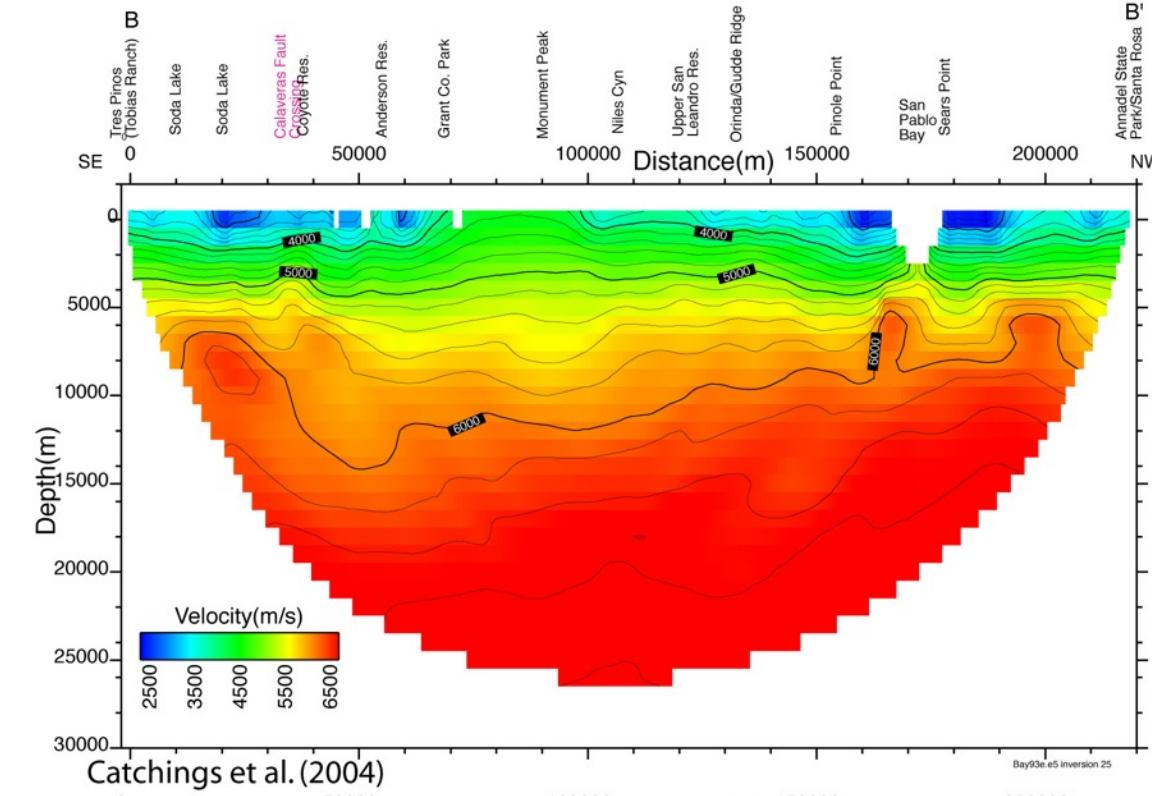
# East and South Bay Refraction Tomography Model With Seismicity



- Seismicity Tracks Low Velocity Zones
- Little Seismicity in Higher Velocity Areas

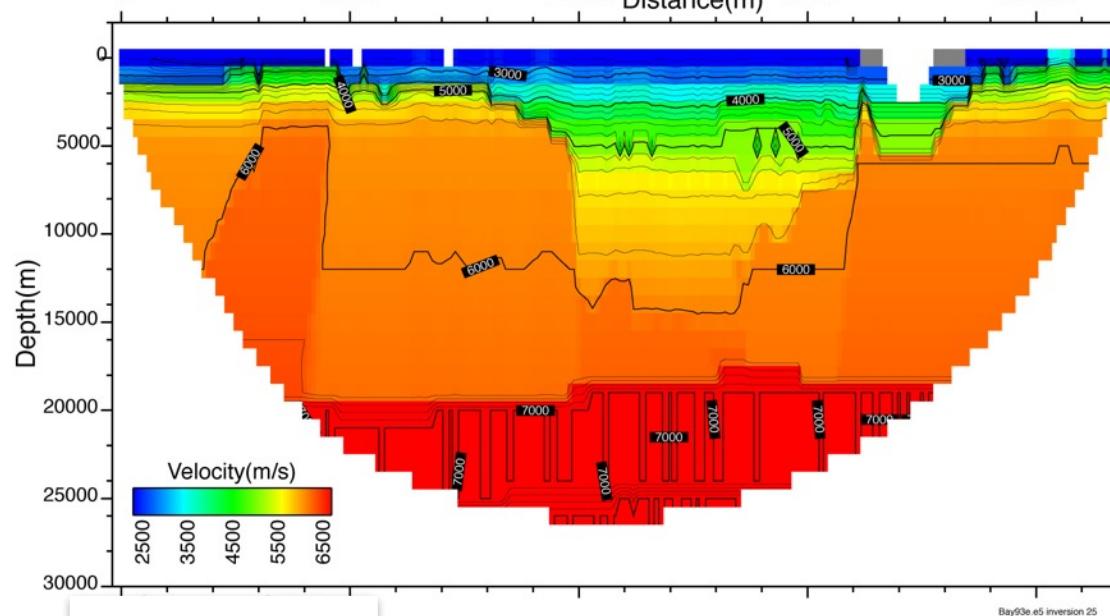
# Comparison of East and South Bay Models

## Refraction Tomography Model



Velocity Differences Up to 1000 m/s

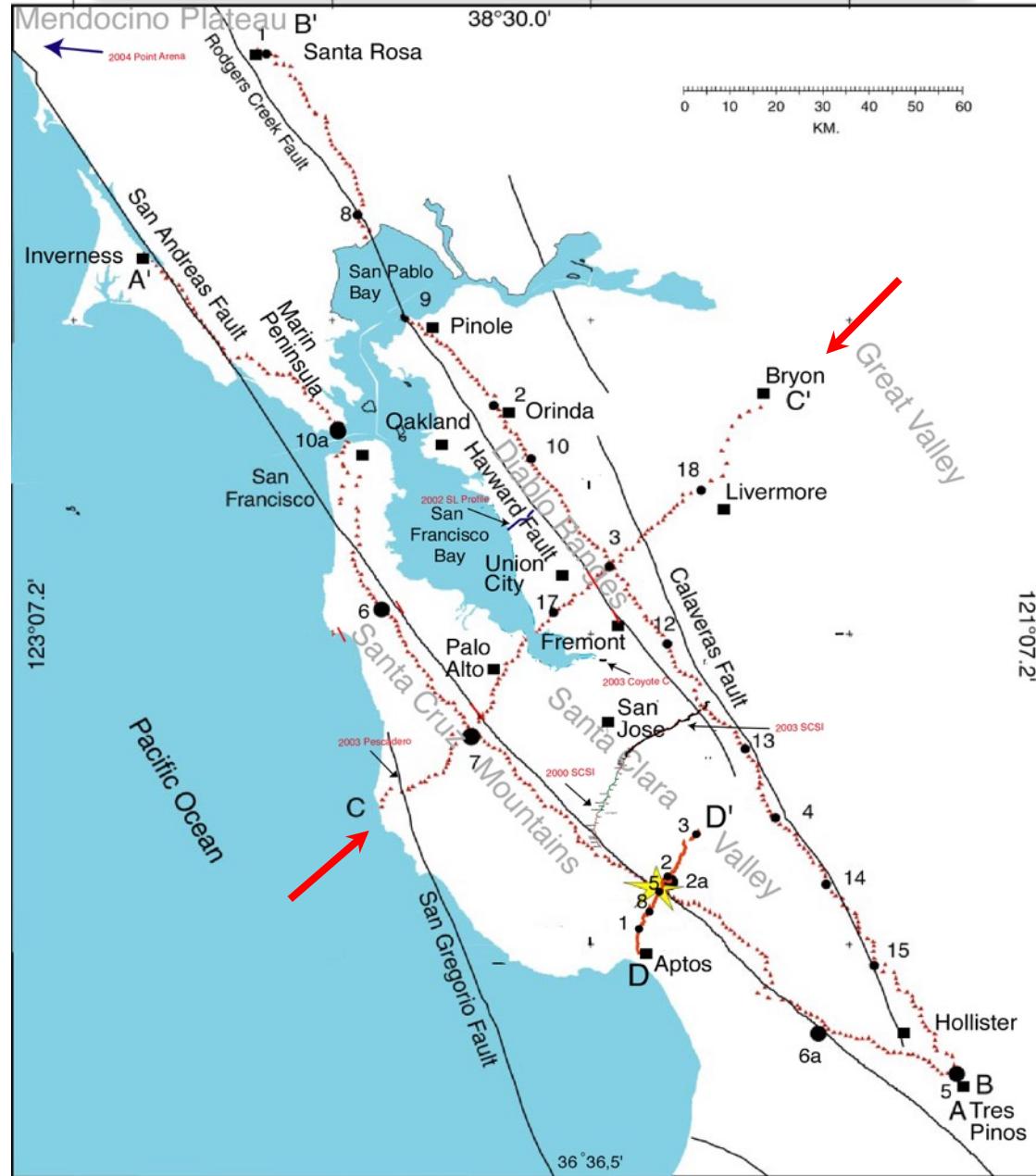
## Existing 3-D Velocity Model



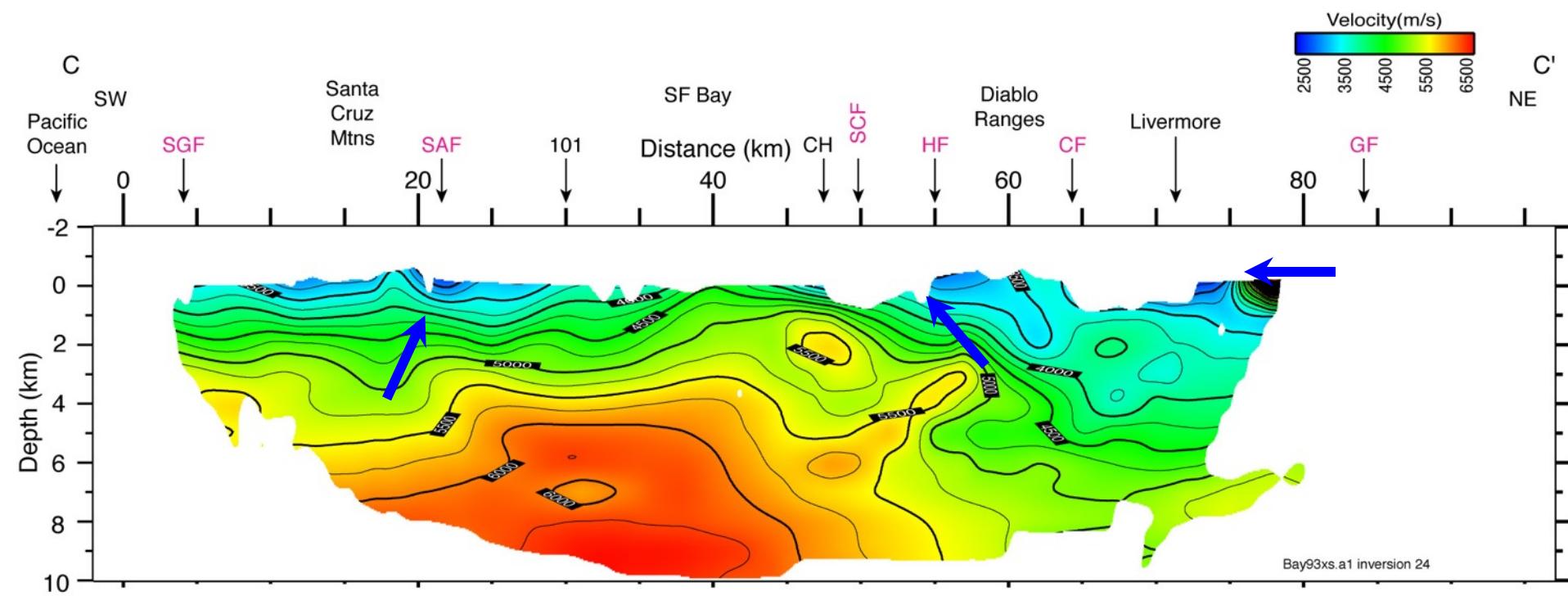
# Deep Seismic Profiles

# Model Comparisons

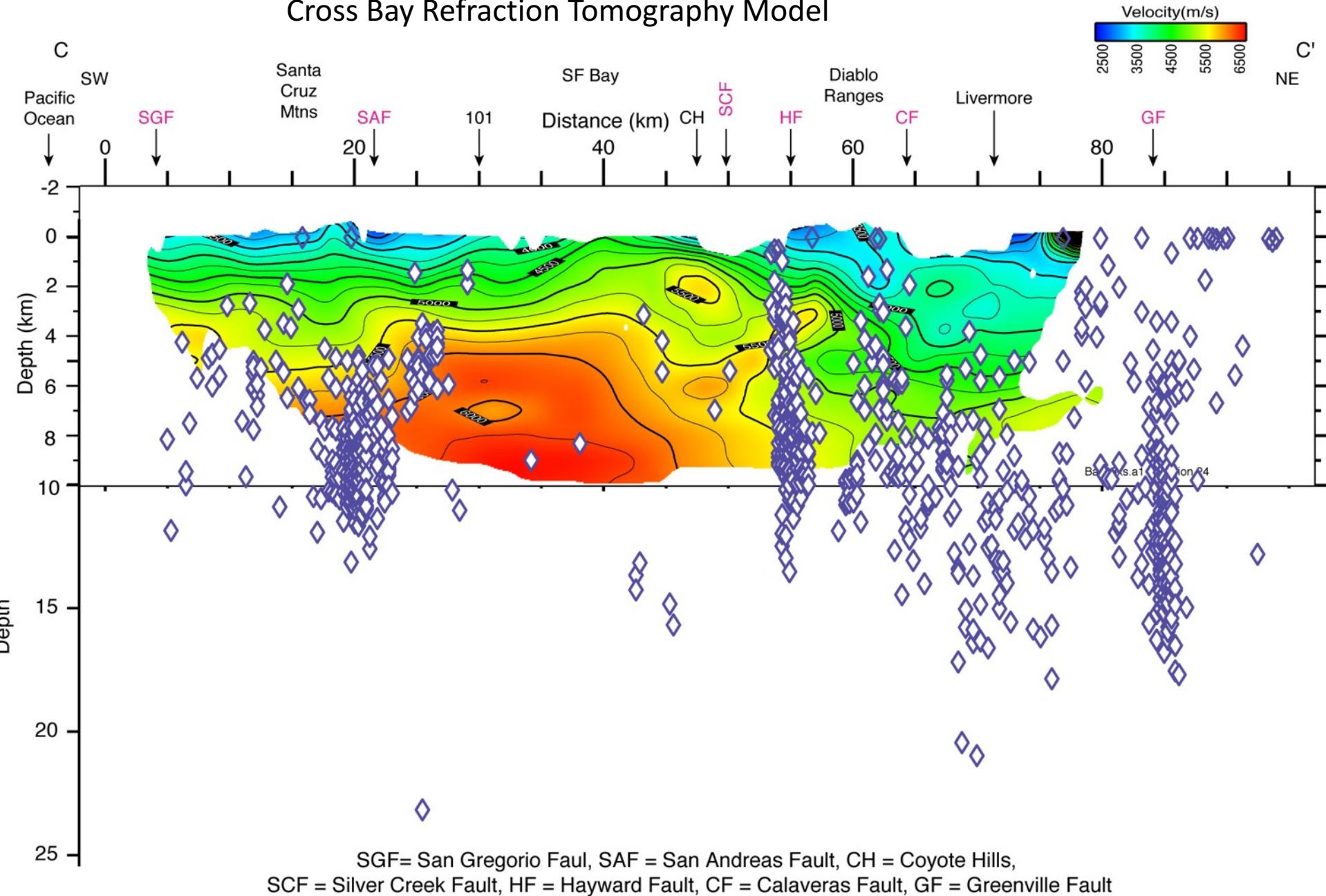
# Cross Bay Profile



# Cross Bay Refraction Tomography Model



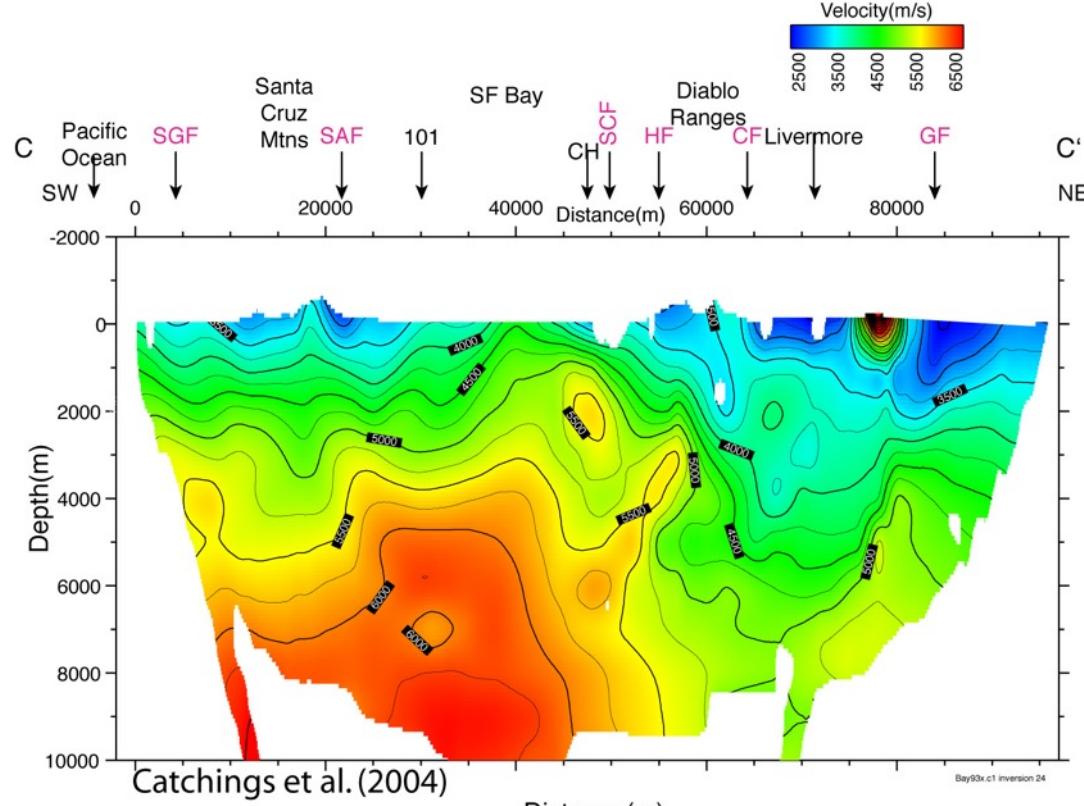
# Cross Bay Refraction Tomography Model



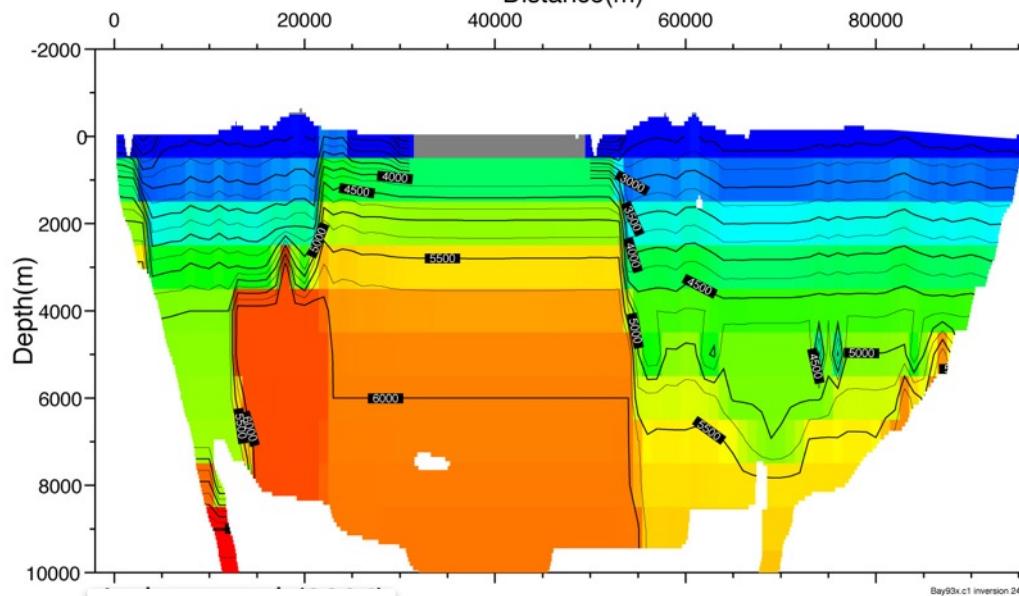
# Comparison

## Refraction Tomography Model

## Existing 3-D Velocity Model



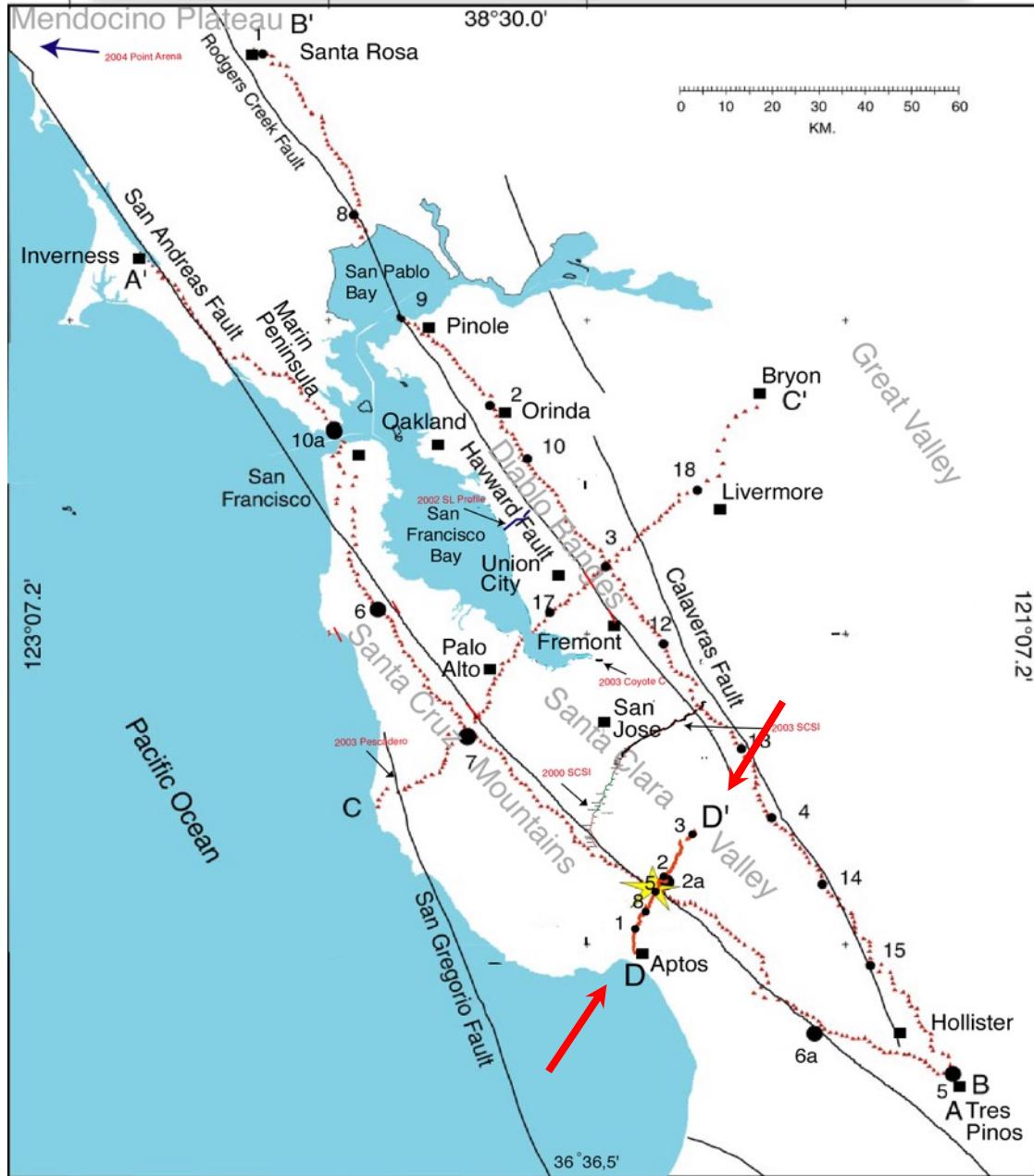
Velocity Differences Up to 1500 m/s



# Model Comparisons

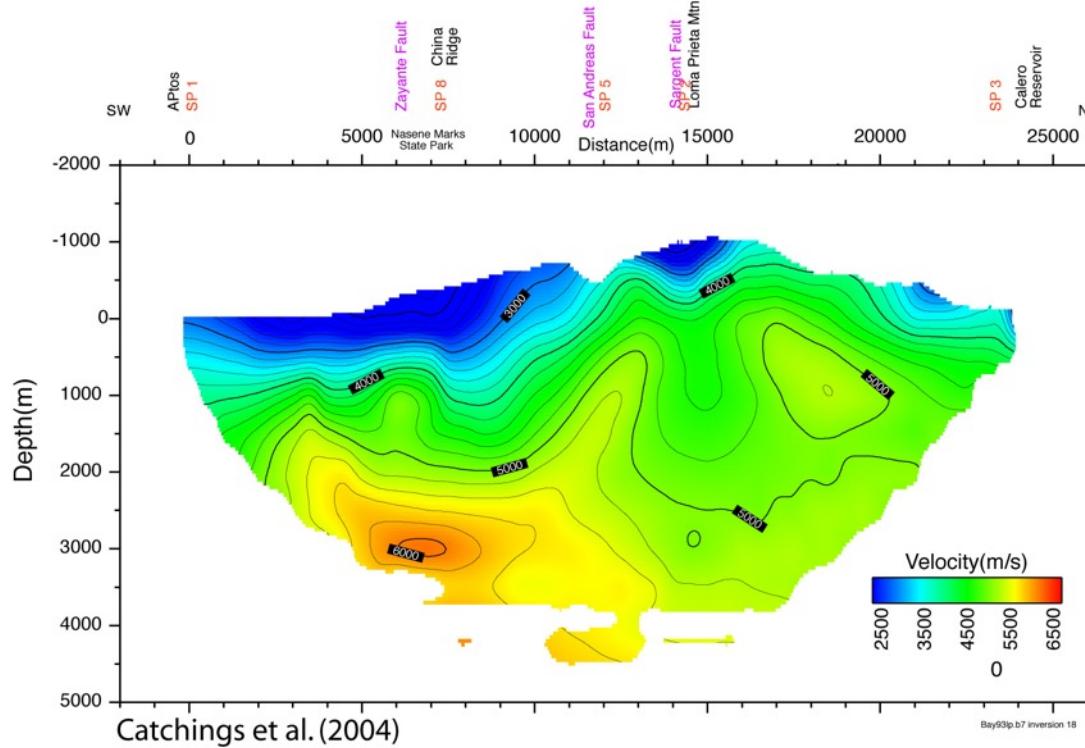
## Deep Seismic Profiles

### Loma Prieta Profile

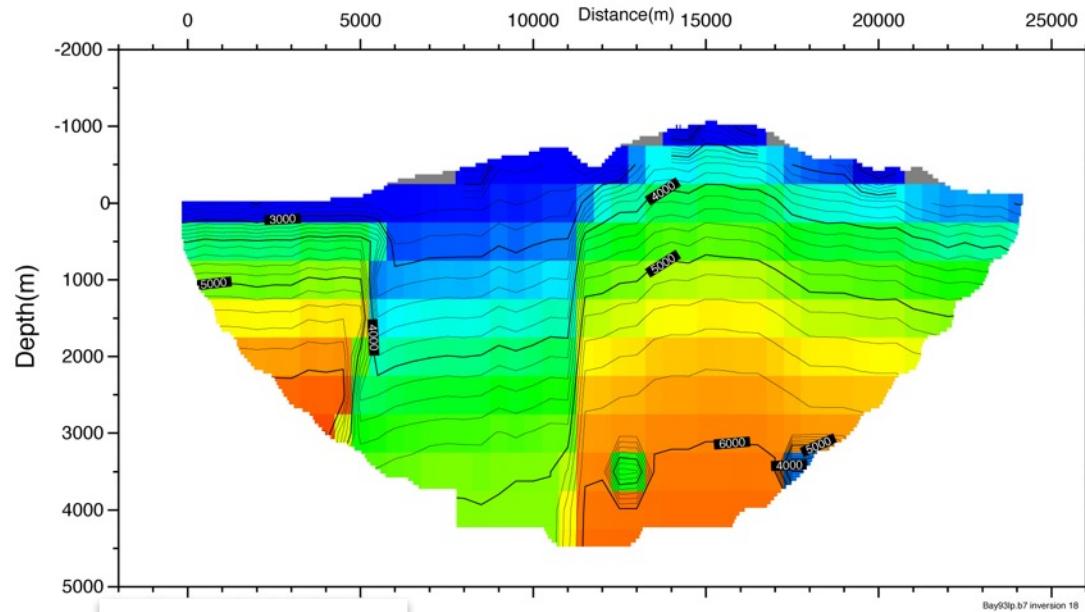


# Comparison

## Refraction Tomography Model



## Existing 3-D Velocity Model



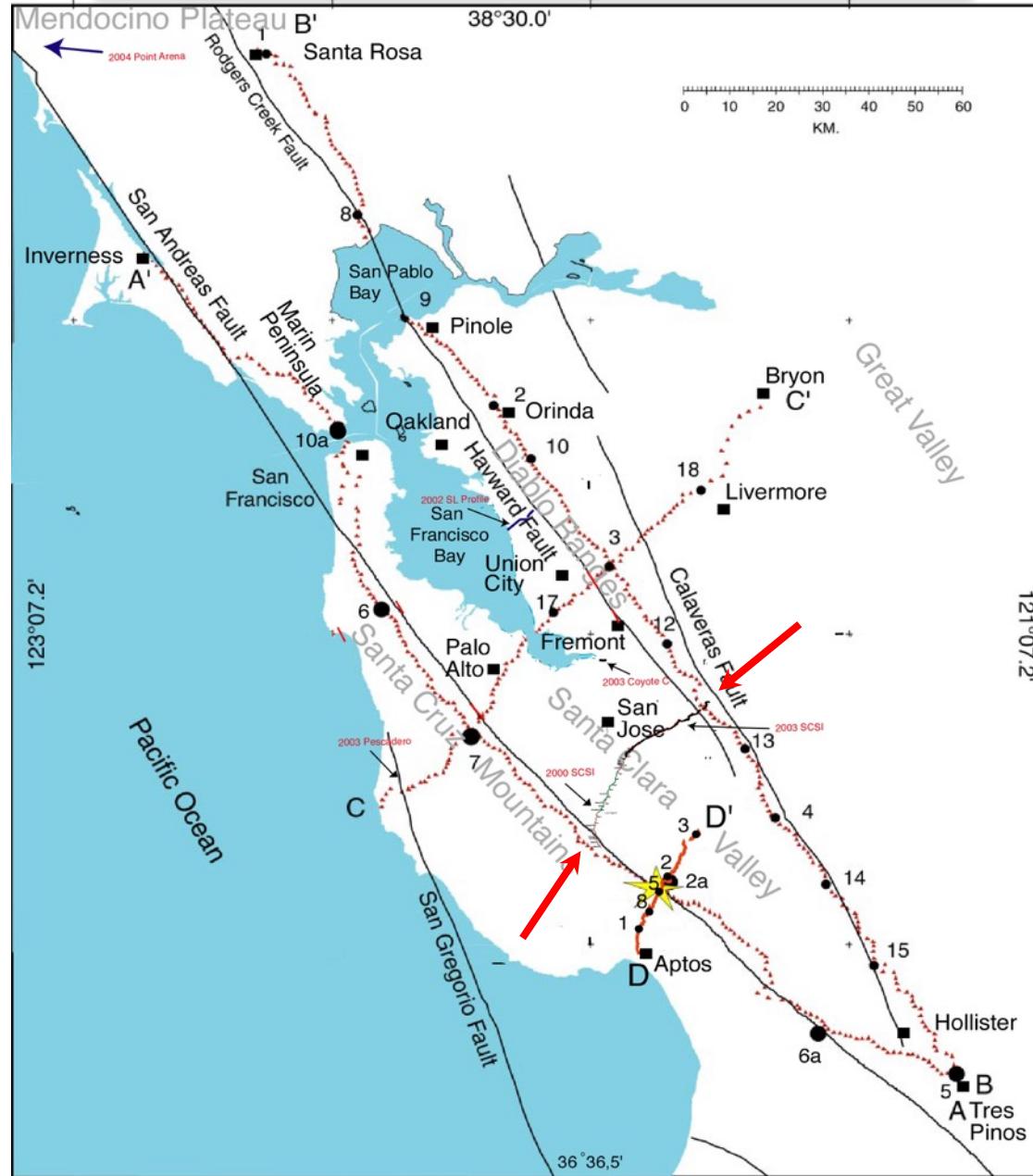
Velocity  
Differences Up  
to 1700 m/s

-Fault Structure

# Deep Seismic Profiles

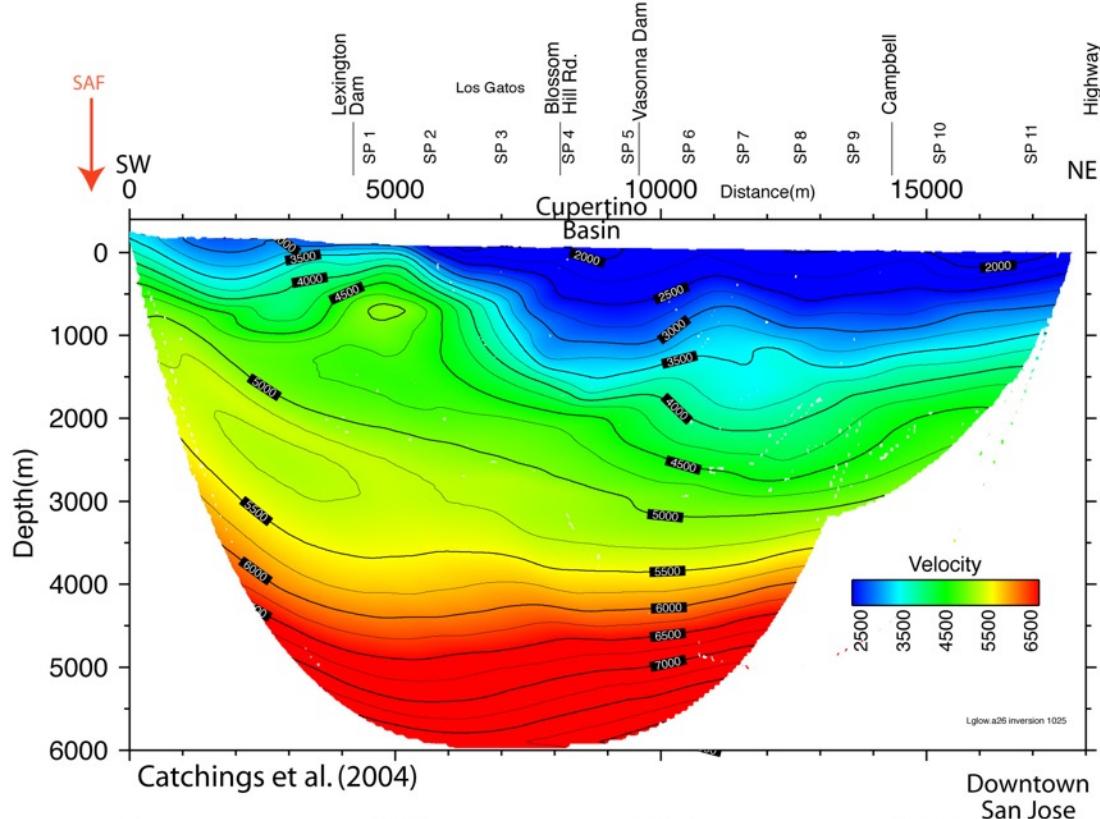
# Model Comparisons

# Santa Clara Valley Profiles

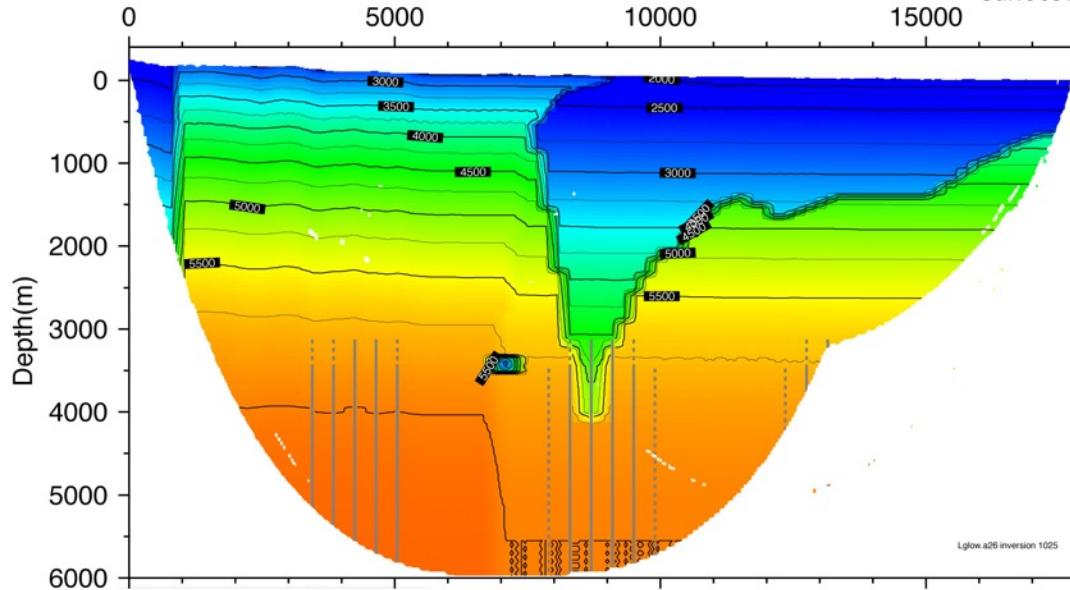


# Comparison of Western Santa Clara Valley Models

## Refraction Tomography Model



## Existing 3-D Velocity Model

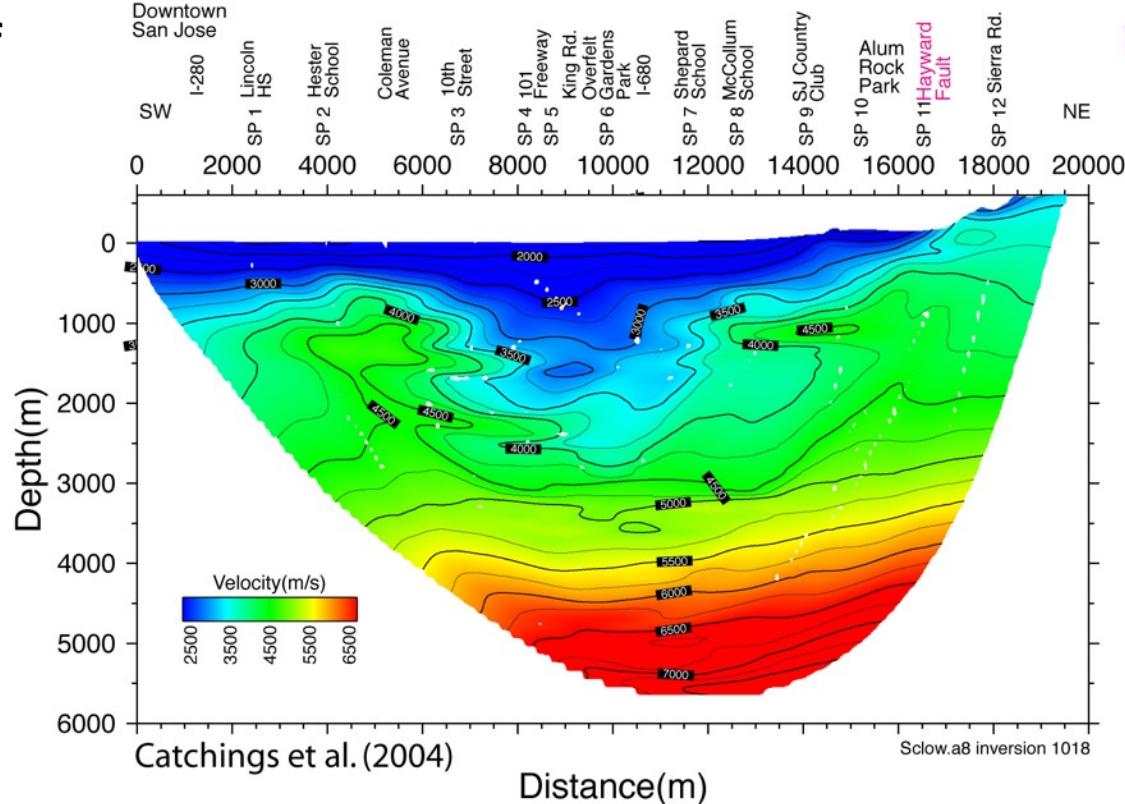


Velocity Differences Up to 2000 m/s

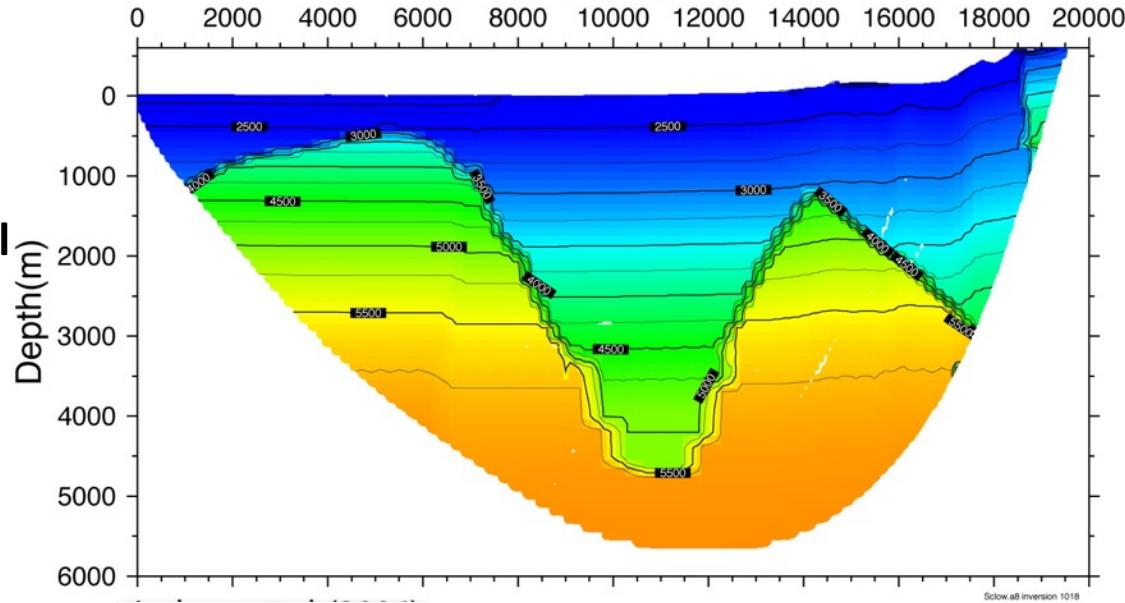
-Fault Structure

# Comparison of Eastern Santa Clara Valley Models

## Refraction Tomography Model



## Existing 3-D Velocity Model



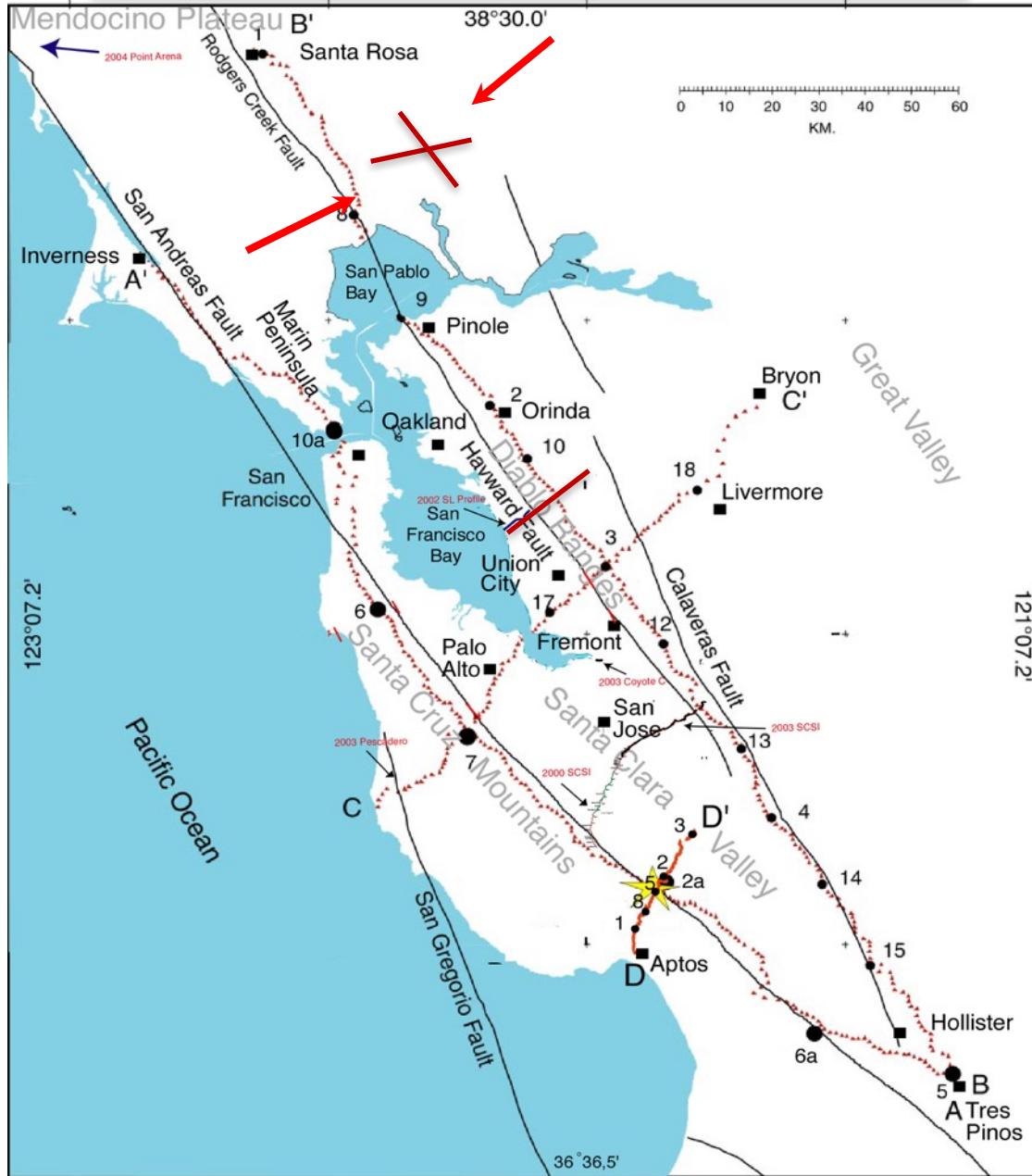
Velocity Differences Up to 1200 m/s

-Fault Structure

# Model Comparisons

## Deep Seismic Profiles

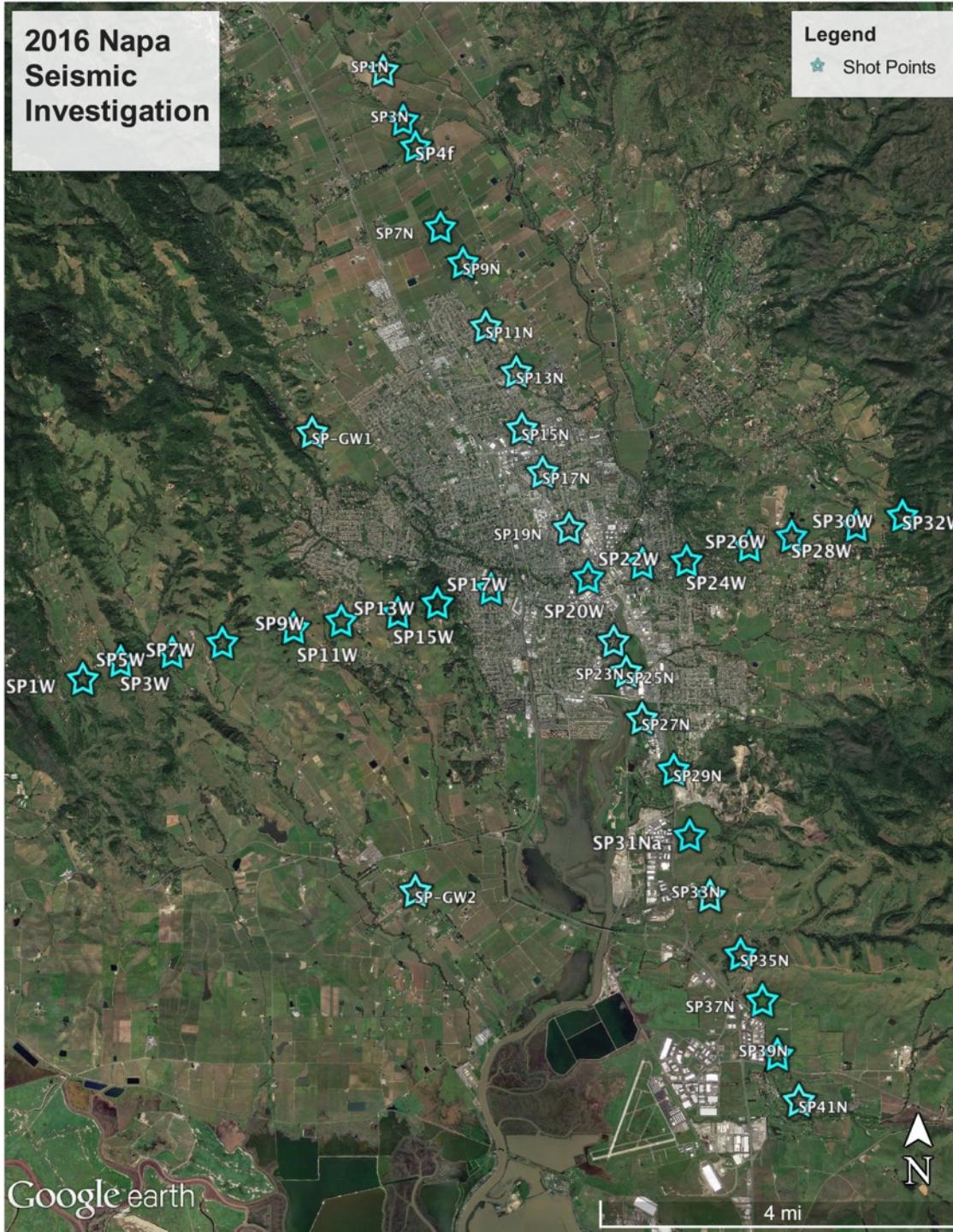
### Napa Profiles



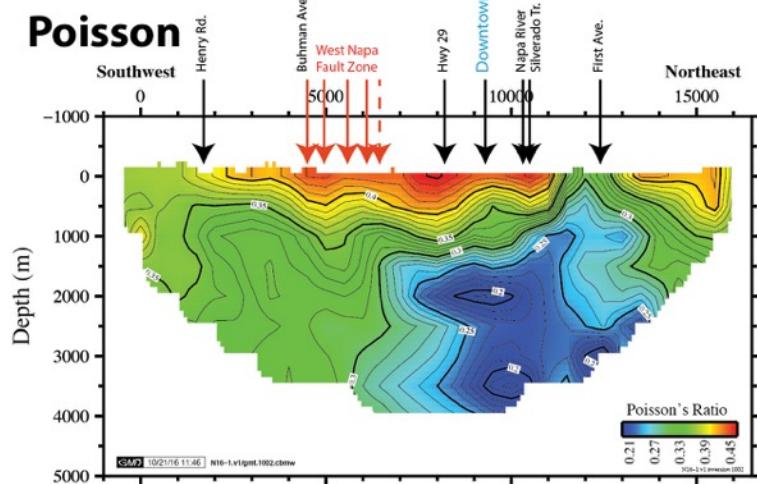
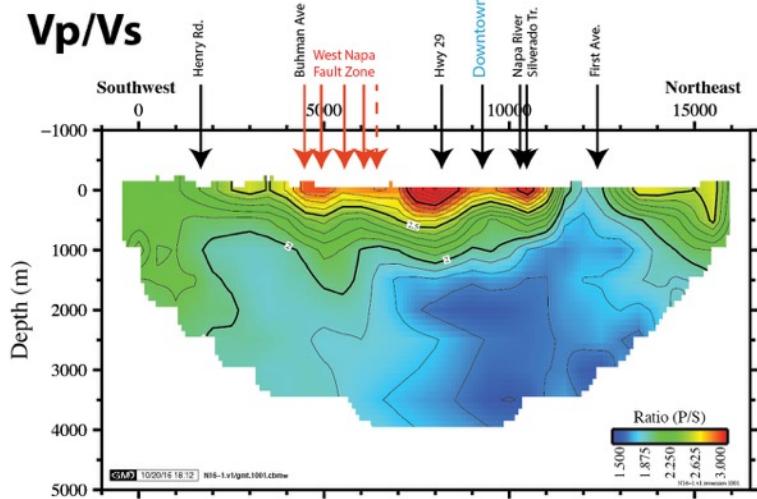
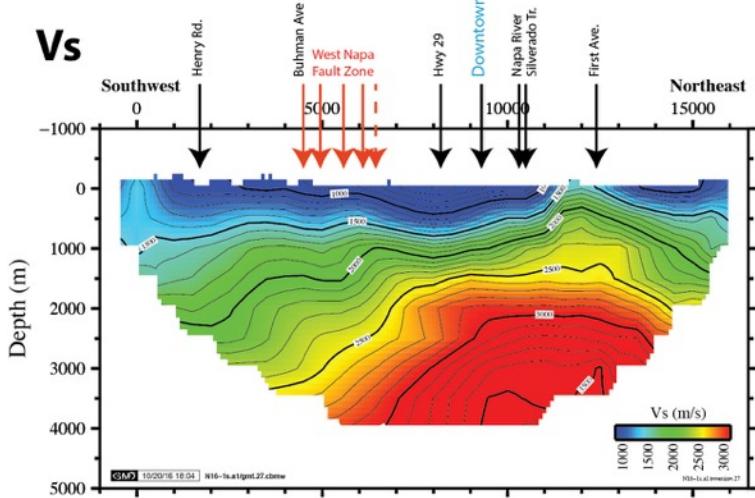
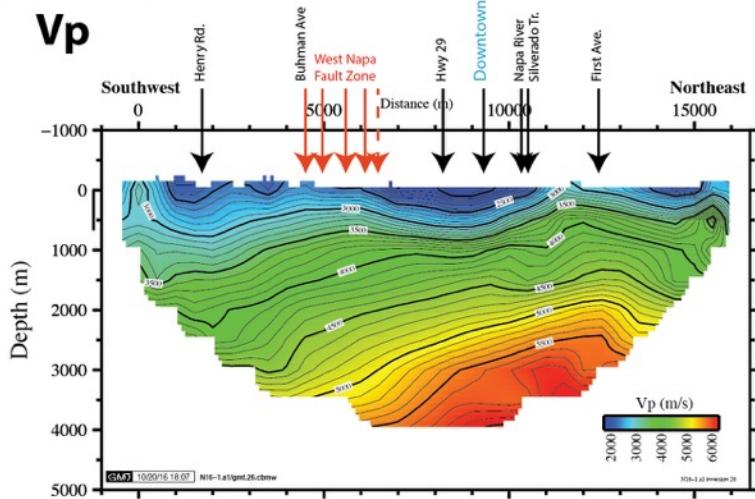
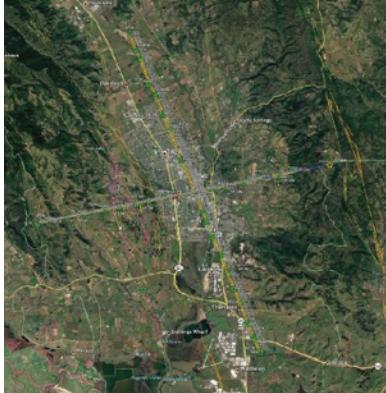
# 2016 Napa Seismic Investigation

Legend

★ Shot Points



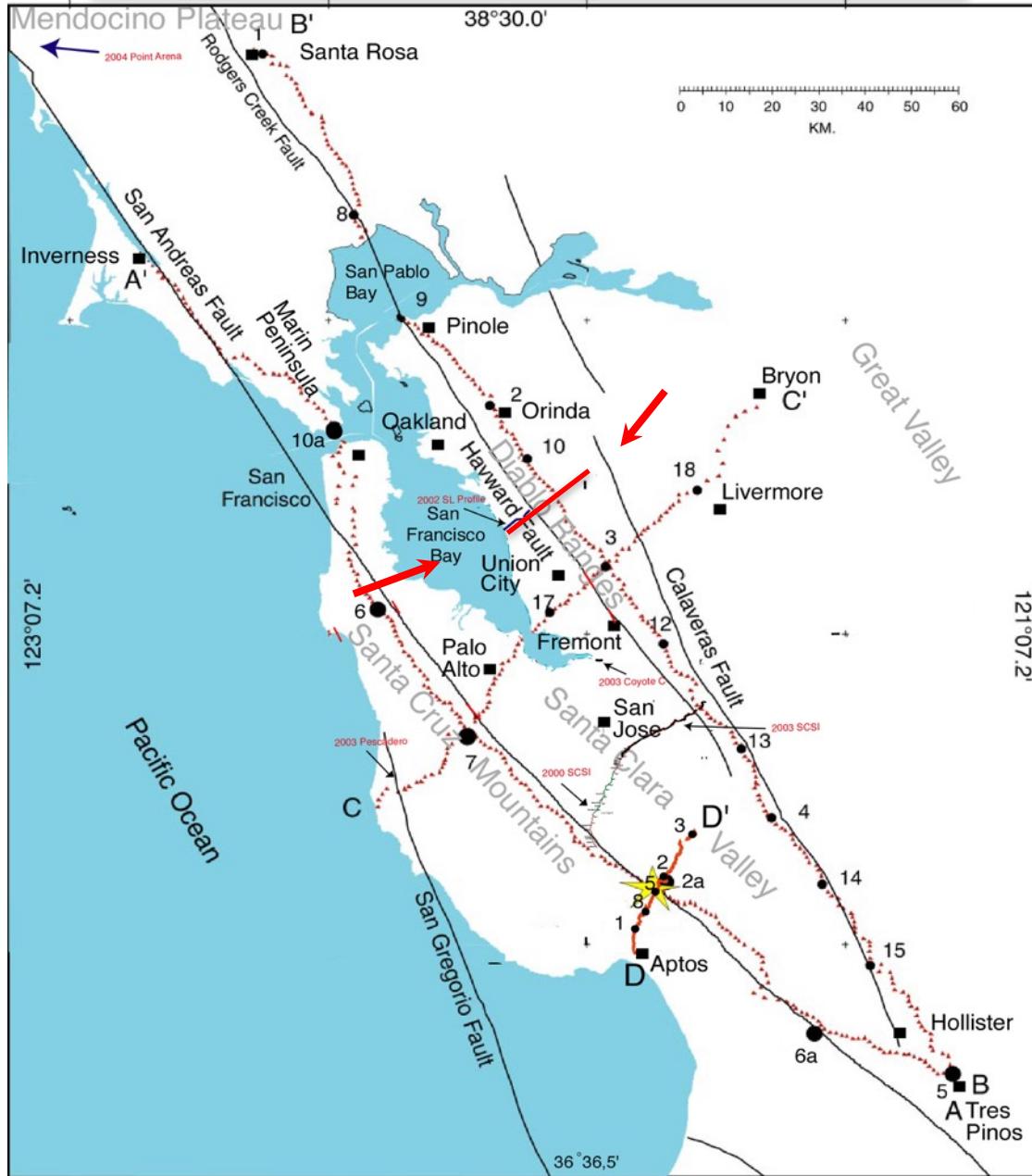
# Napa Valley 2016 Vp, Vs, Vp/Vs, PR Models

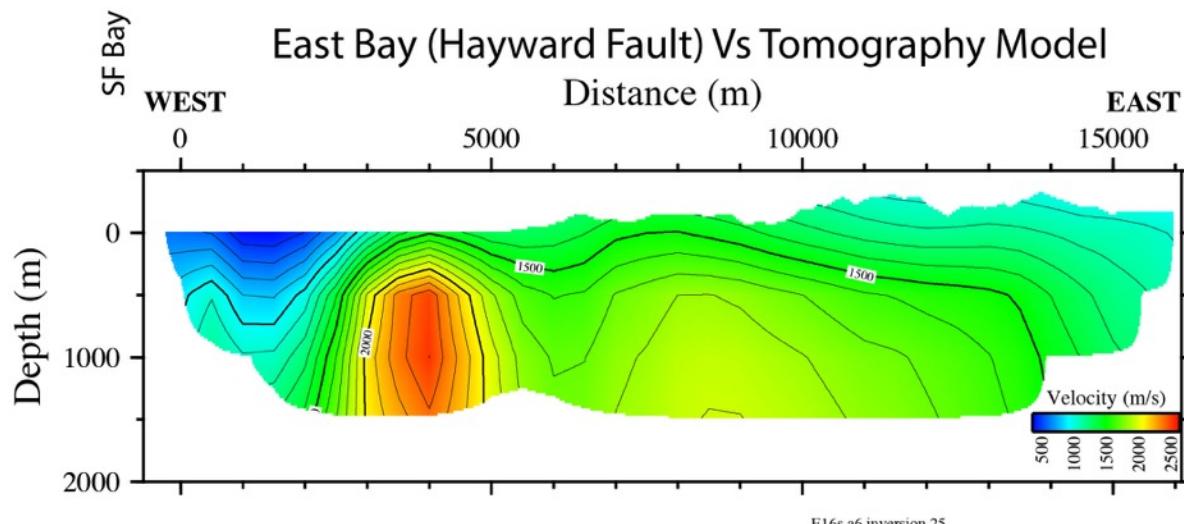
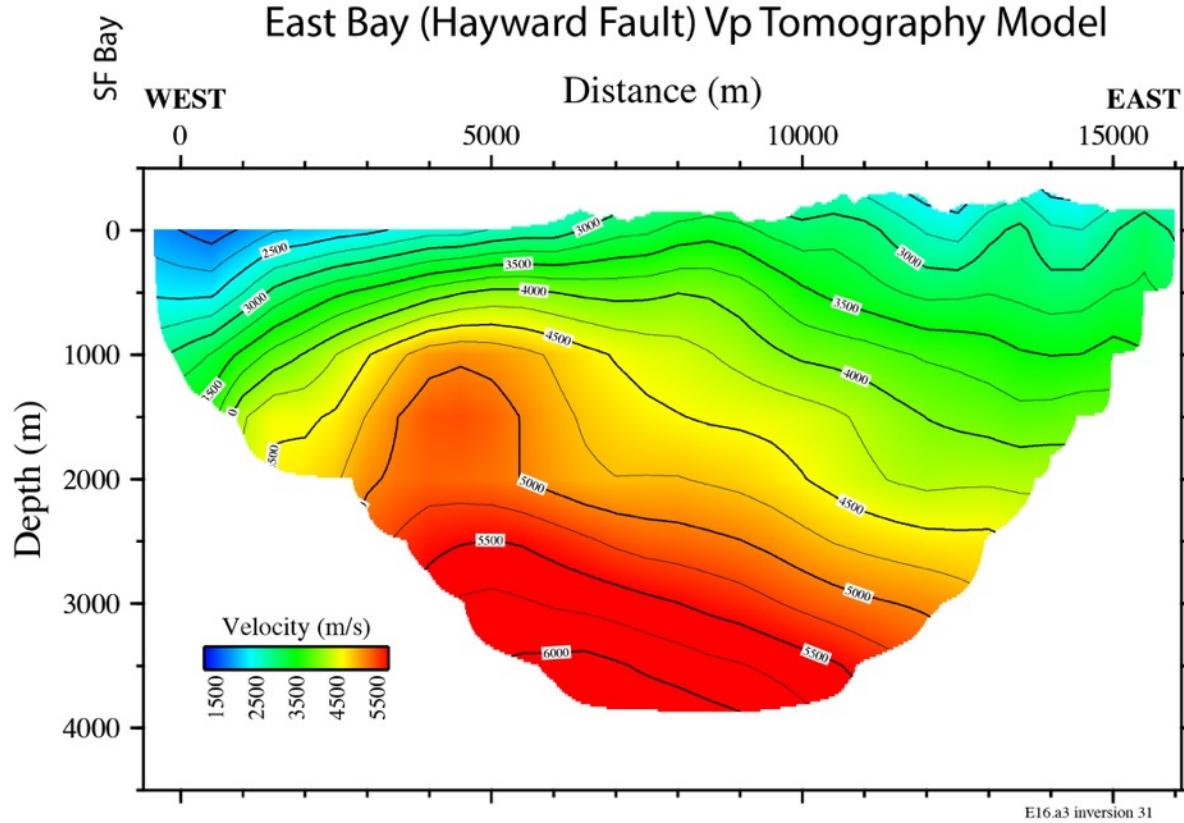


# Model Comparisons

## Deep Seismic Profiles

### Hayward Fault Profile





# **Shallow Vp and Vs models**

# Improving the Existing Bay Area 3-D Velocity Model

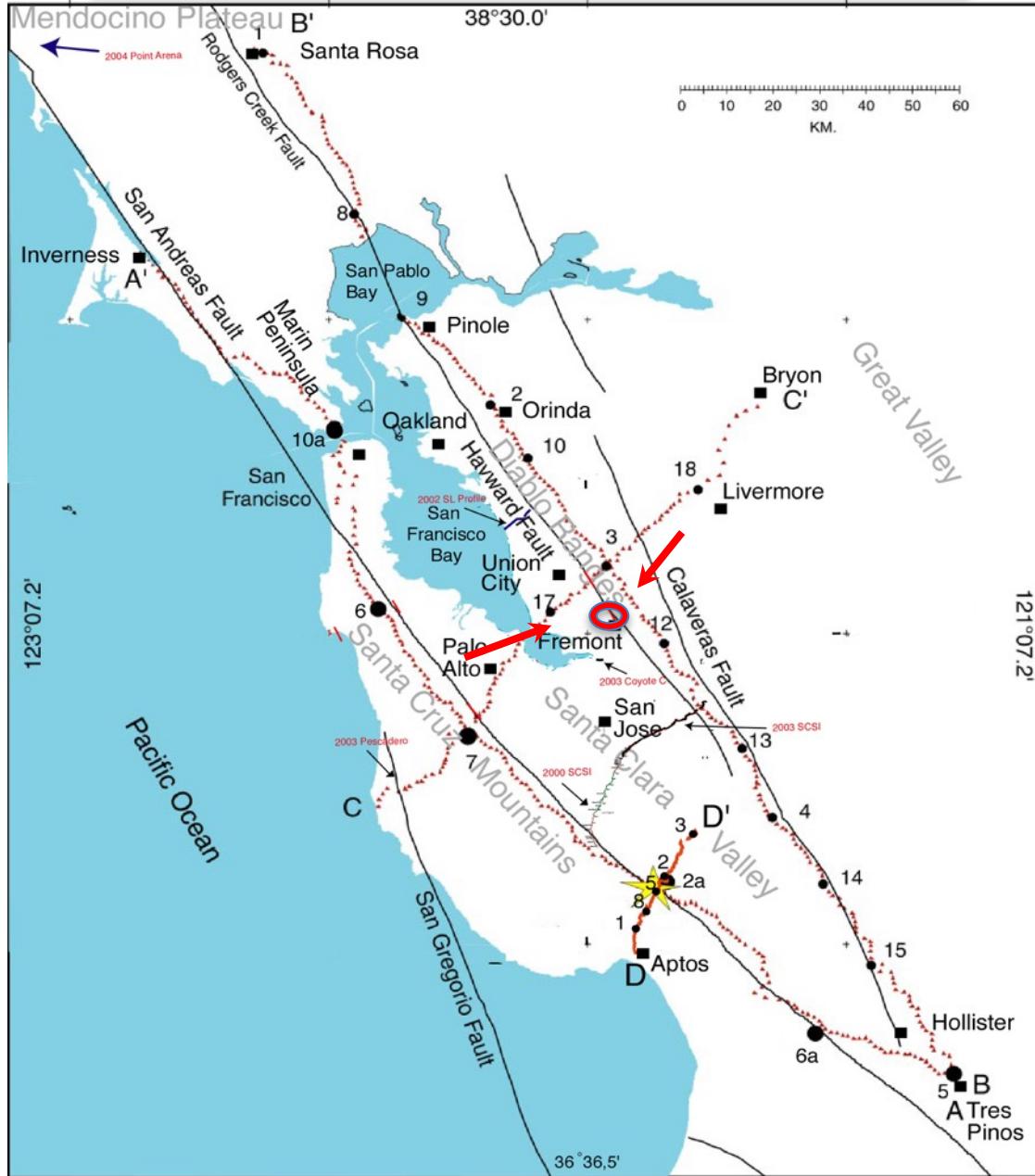
**Shallow V<sub>p</sub> and V<sub>s</sub> models, where available, should be incorporated into the 3-D model.**

- Accurate deep models require accurate shallow-depth models.
  - Especially for gravity modeling
- Ground motion modeling is strongly influenced by shallow velocities (for example, Vs30).
- There are large differences (some 100%) between the existing shallow-depth 3-D models and the shallow seismic models.

# Model Comparisons

## Shallow Seismic Profiles

### Fremont Hayward Fault Profile



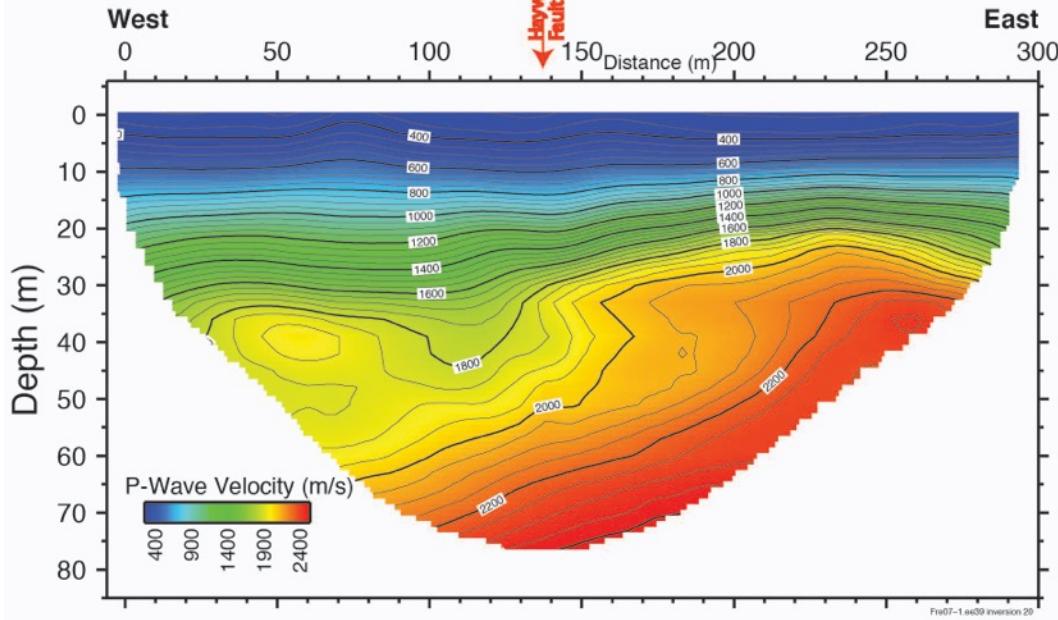
Dozens of  
Shallow-Depth  
Seismic Profiles

# Comparison

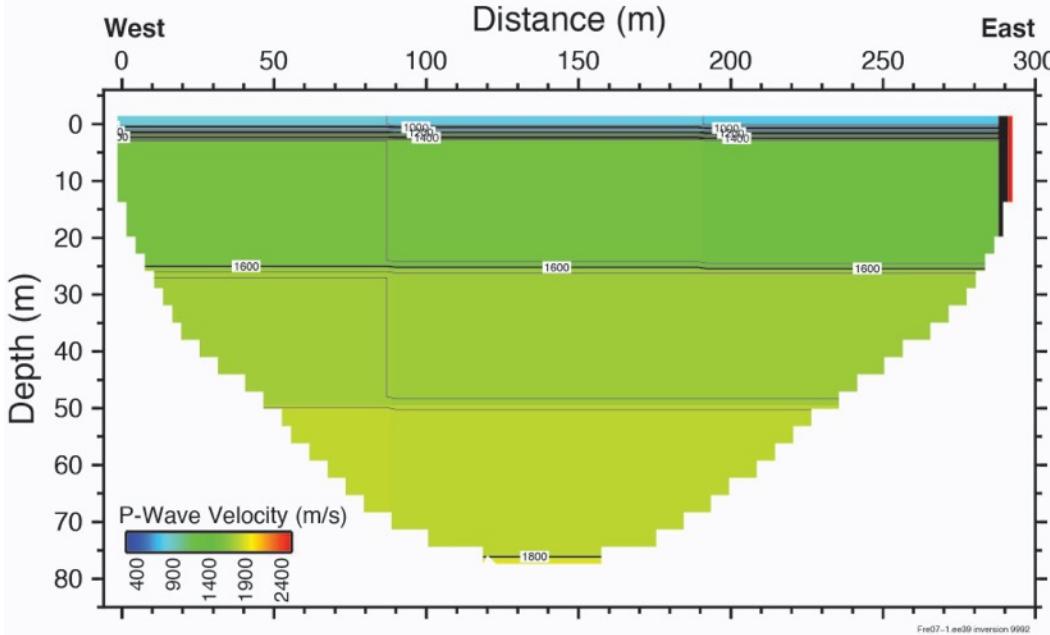
Refraction  
Tomography  
Model

Existing 3-D  
Velocity Model

High-Res. P-wave Model - Hayward Fault - Fremont



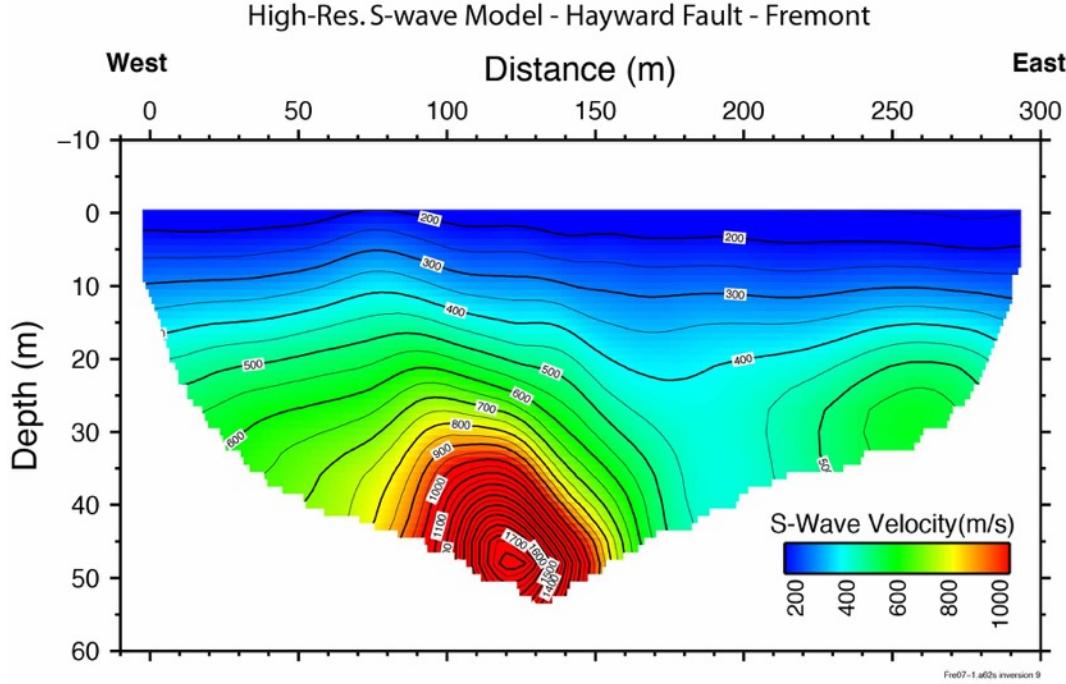
Bay Area 3D P-Wave Model - Hayward Fault - Fremont



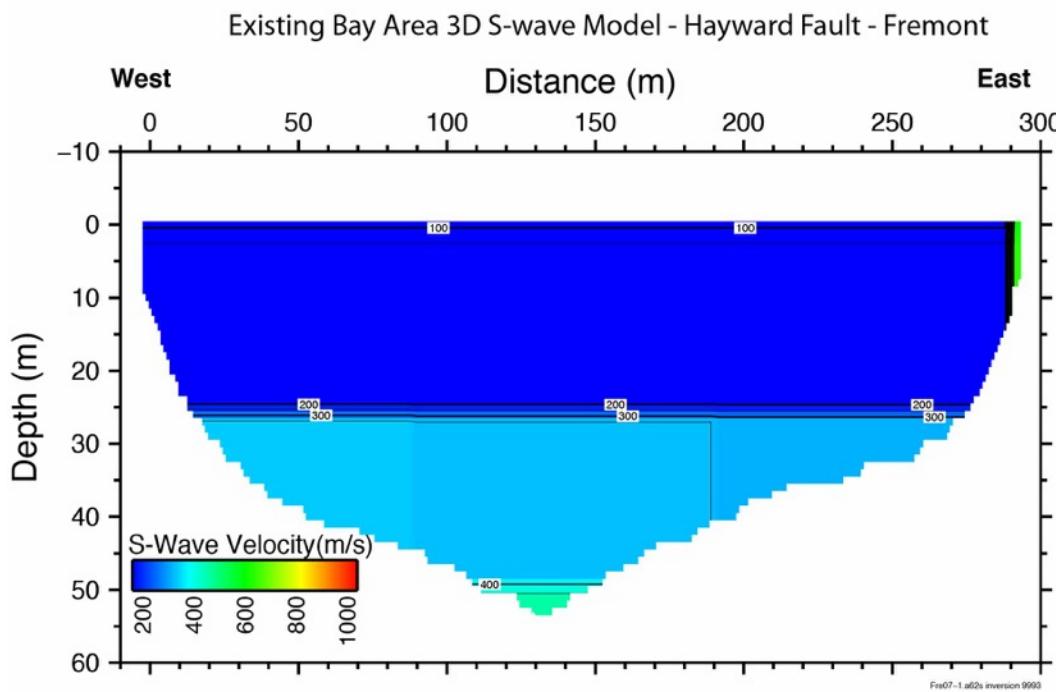
Velocity  
Differences Up  
to 800 m/s in  
upper 75 m

# Comparison

Refraction  
Tomography  
Model



Existing 3-D  
Velocity Model

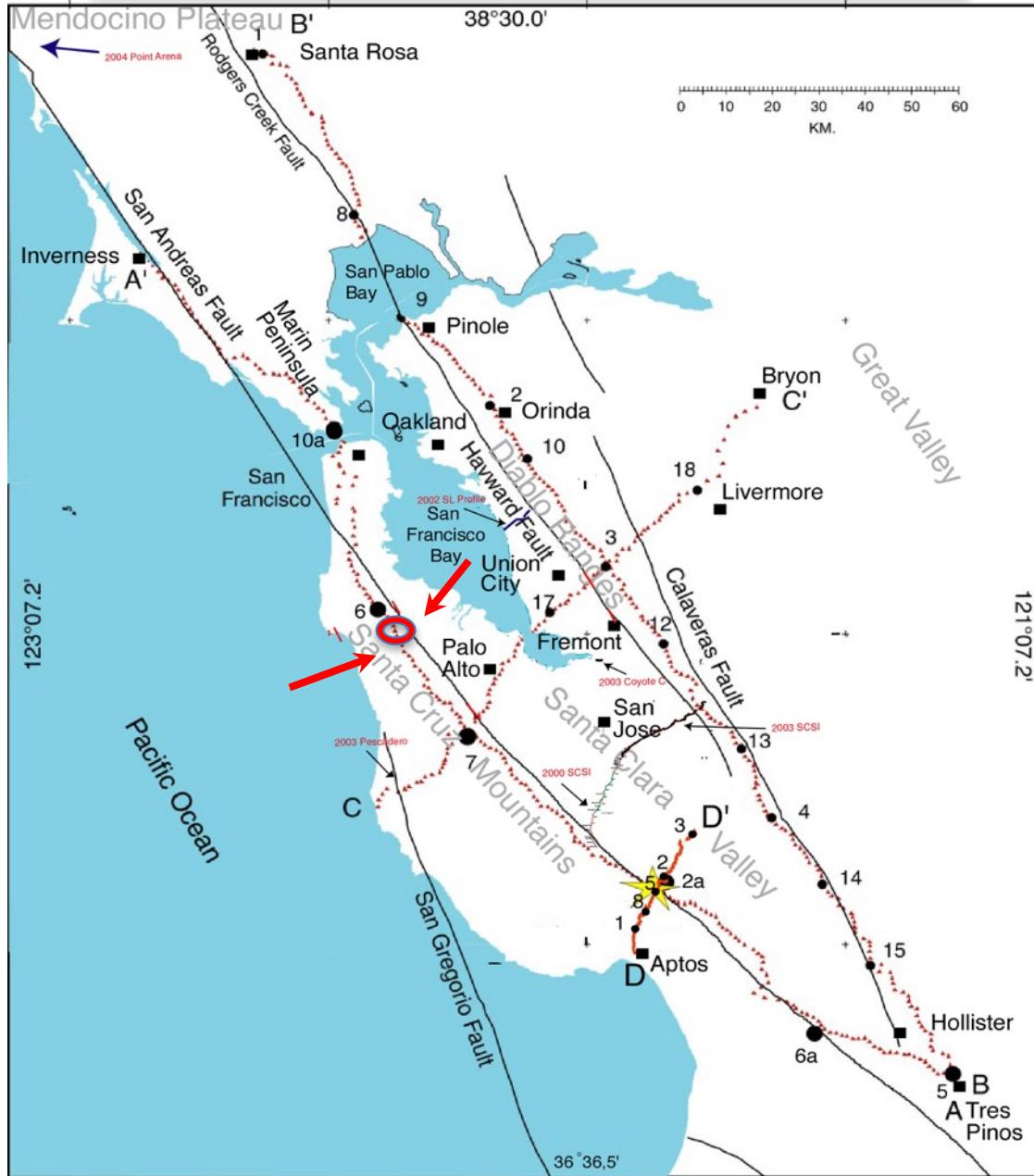


Vs Differences  
Up to 600 m/s in  
upper 50 m

# Model Comparisons

## Shallow Seismic Profiles

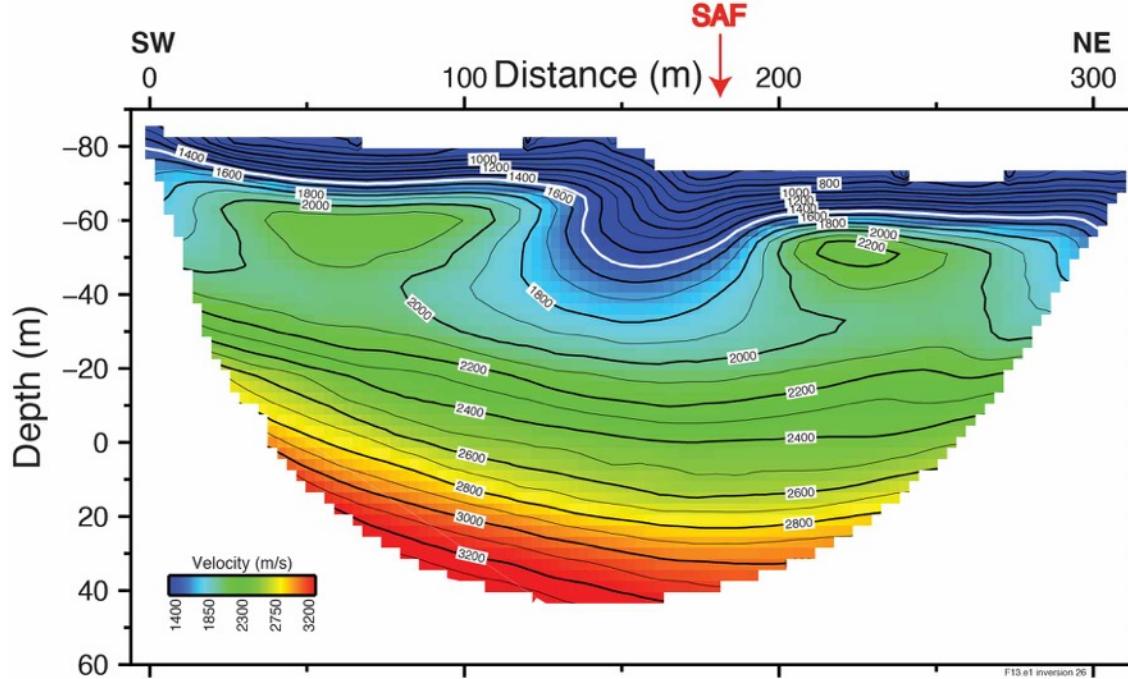
### Filoli San Andreas Fault Profile



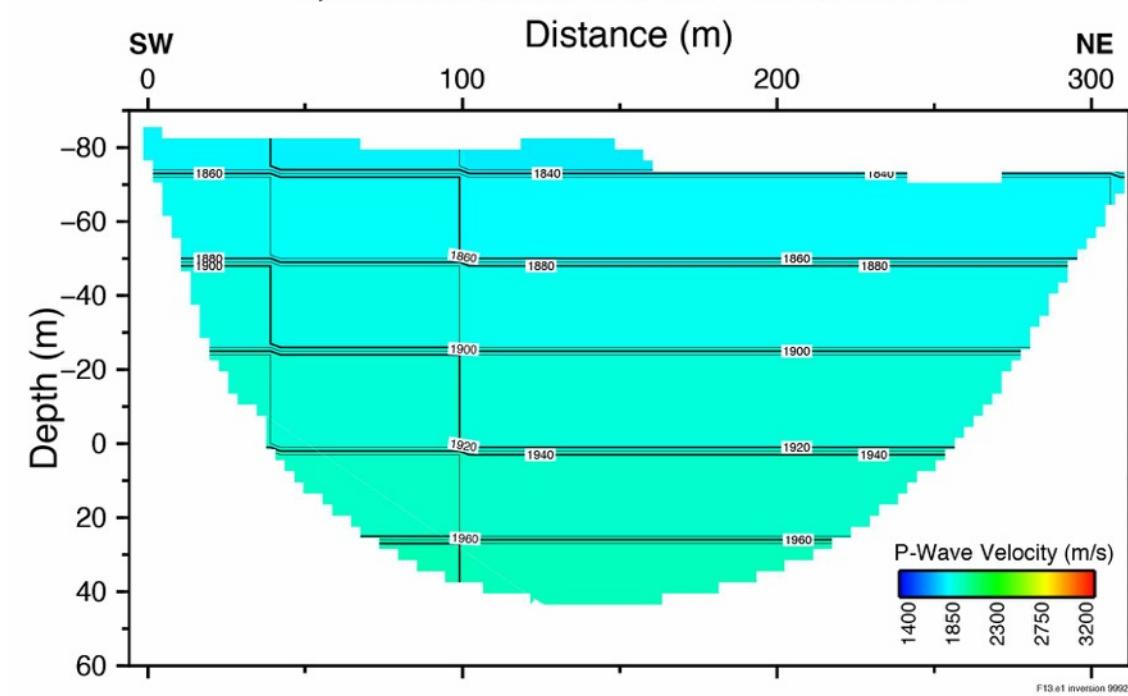
Dozens of  
Shallow-Depth  
Seismic Profiles

# Comparison

Refraction  
Tomography  
Model



Existing 3-D  
Velocity Model



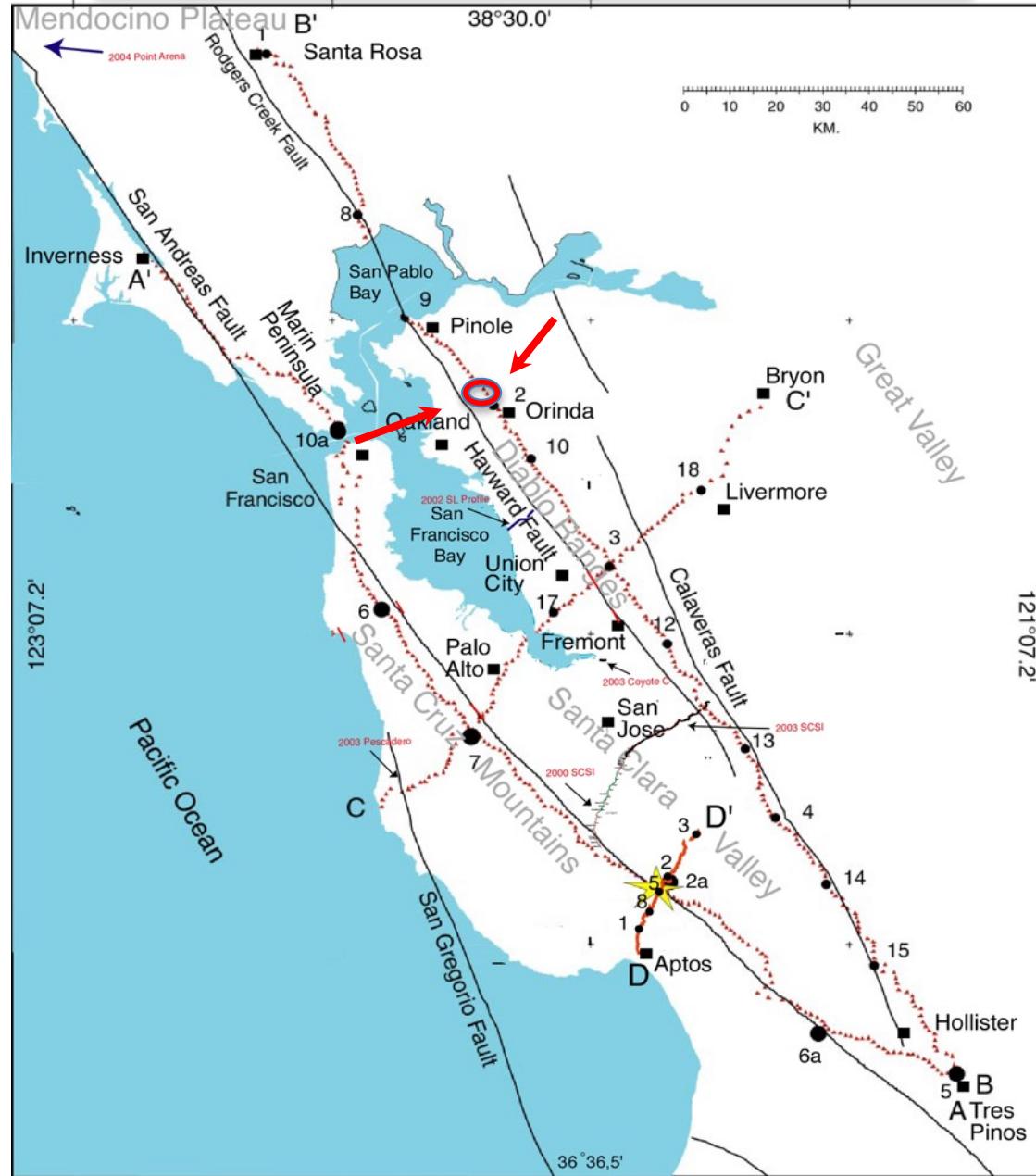
**Velocity  
Differences Up  
to 1300 m/s in  
upper 150 m**

# Model Comparisons

## Shallow Seismic Profiles

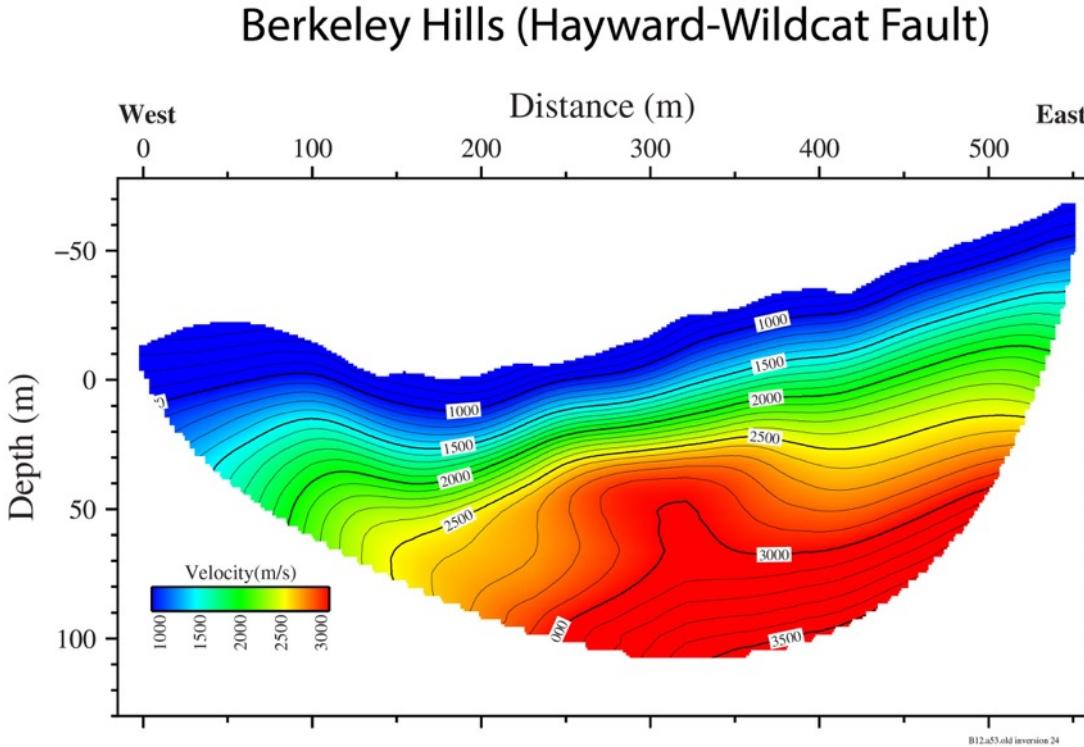
### Berkeley Hills Hayward Fault Profile

Dozens of  
Shallow-Depth  
Seismic Profiles

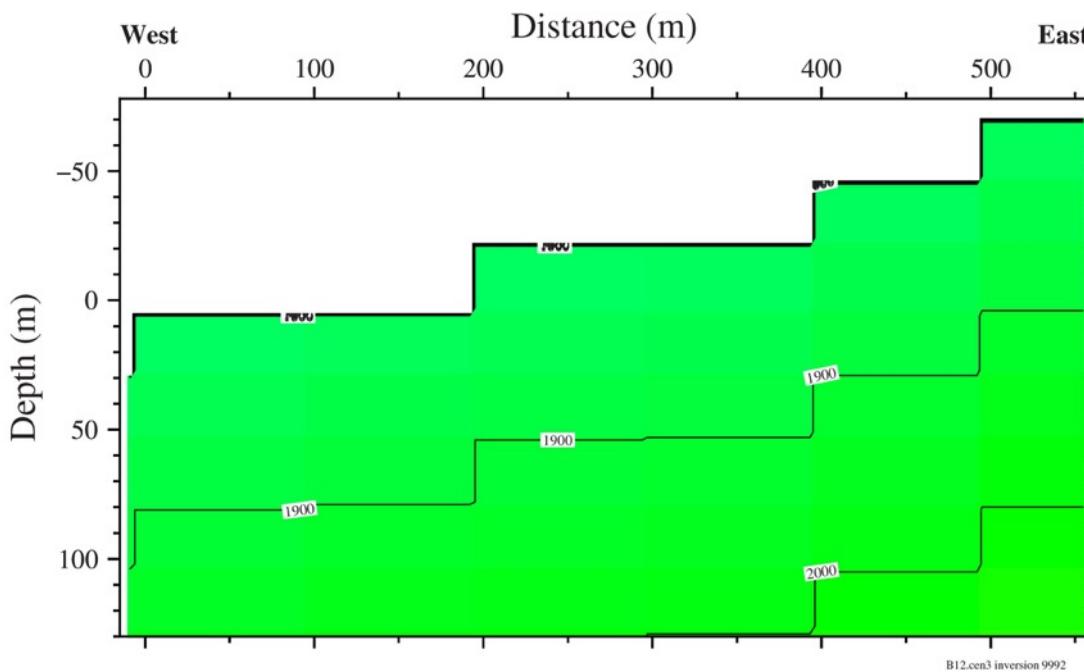


# Comparison

## Refraction Tomography Model



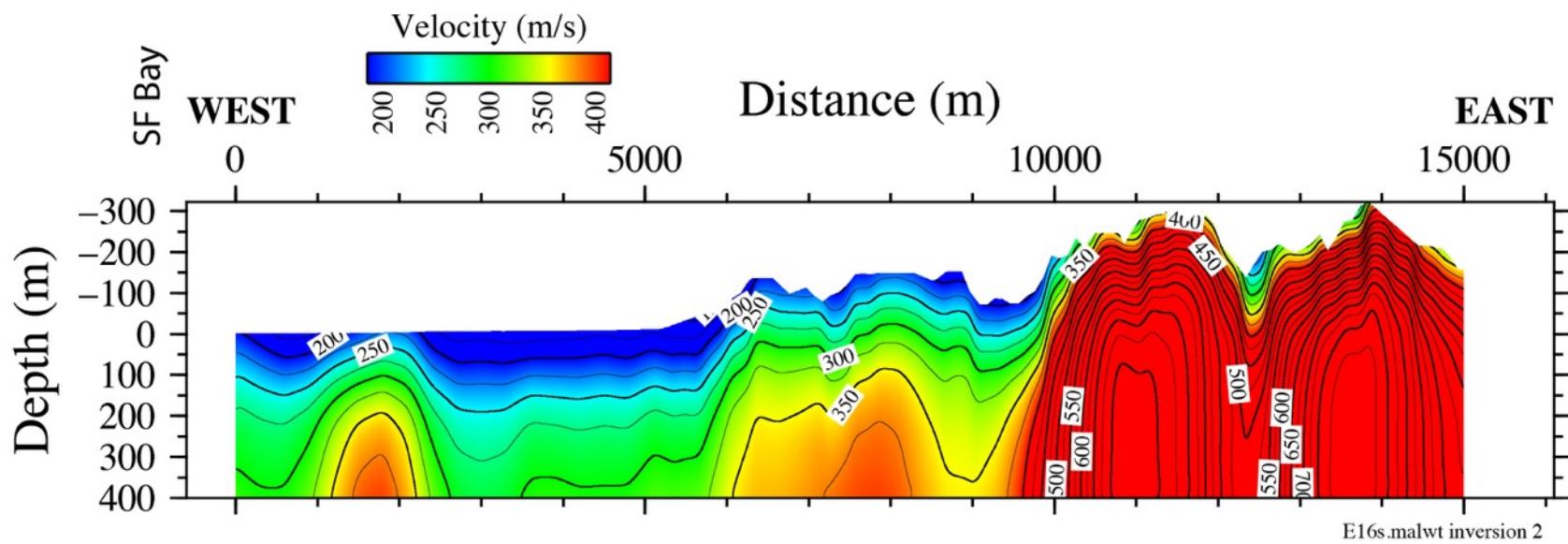
## Existing 3-D Velocity Model



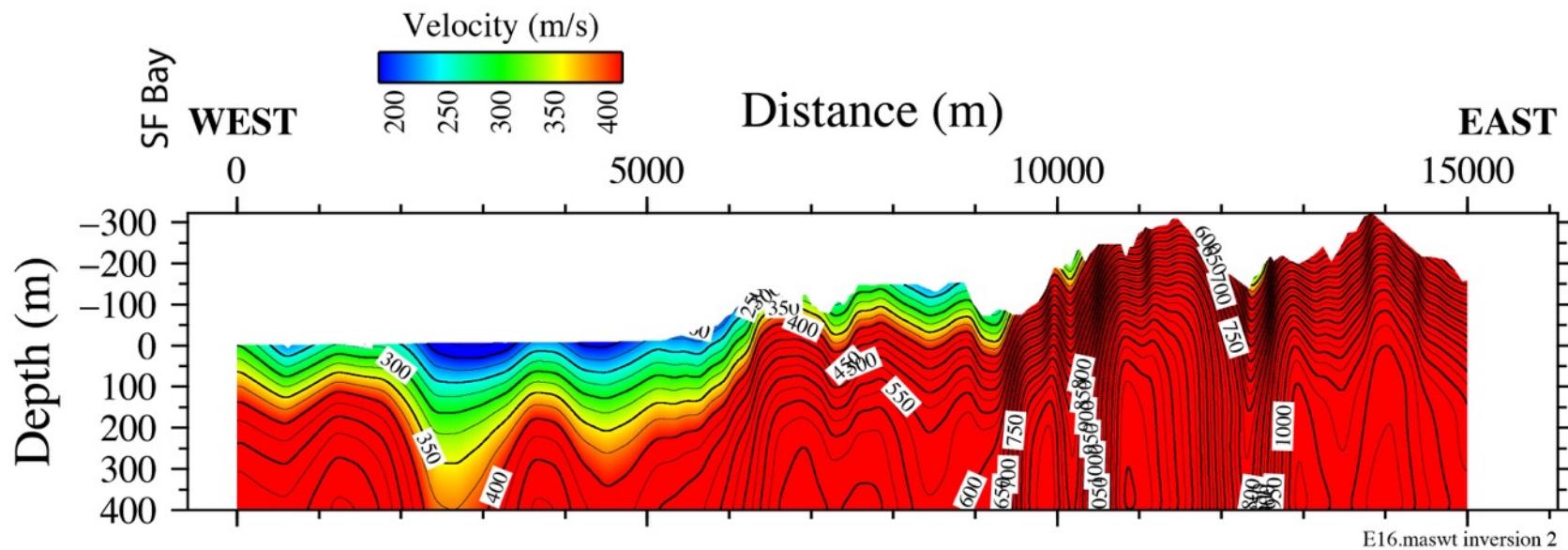
Velocity  
Differences Up  
to 1500 m/s in  
upper 150 m

# **Shallow Vs Models From Multi-Channel Analysis of Surface Waves**

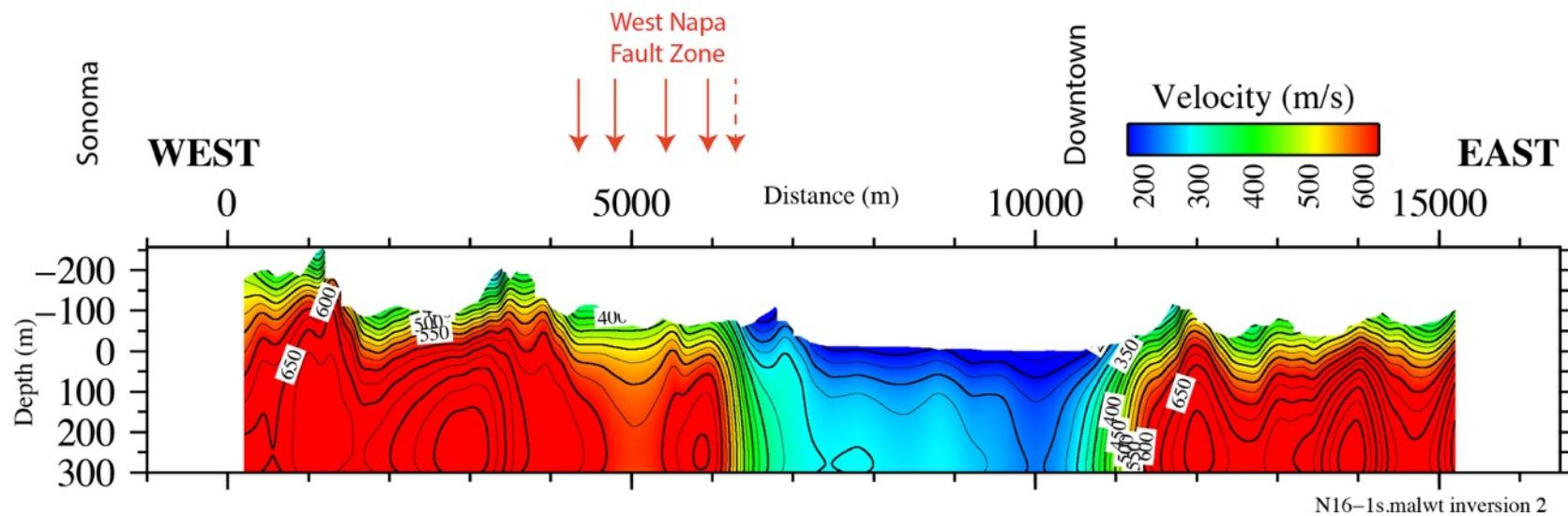
## East Bay (Hayward Fault) Vs MALW Model



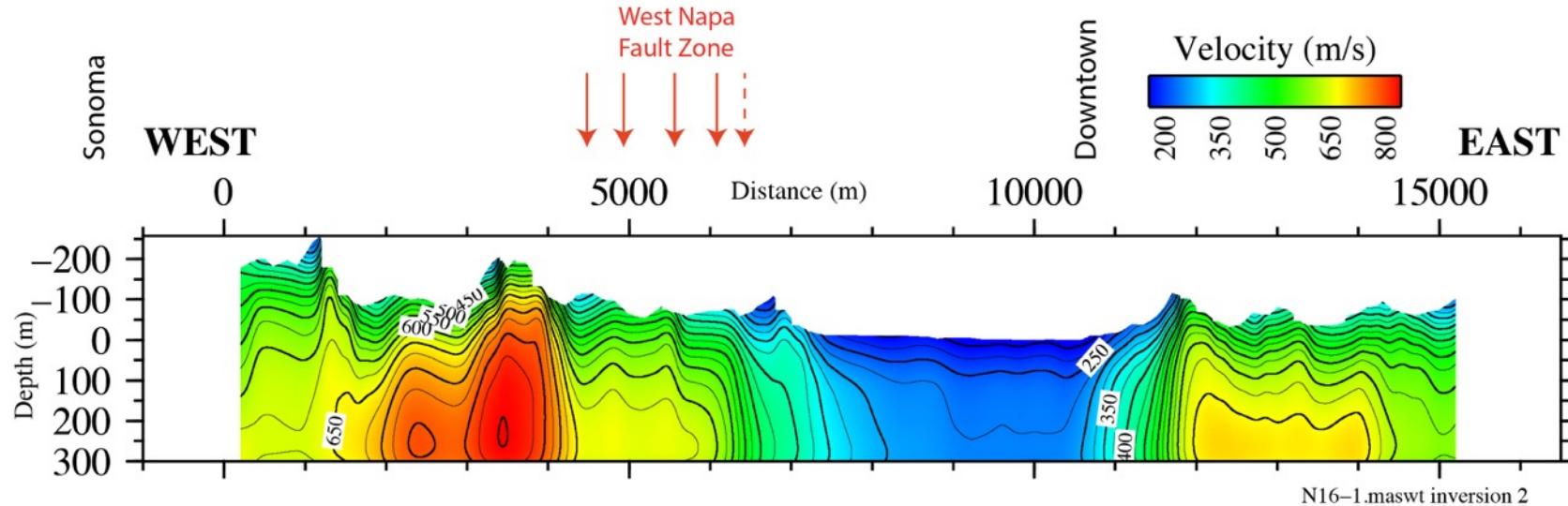
## East Bay (Hayward Fault) Vs MASW Model



## Napa Cross Valley Vs MALW Model

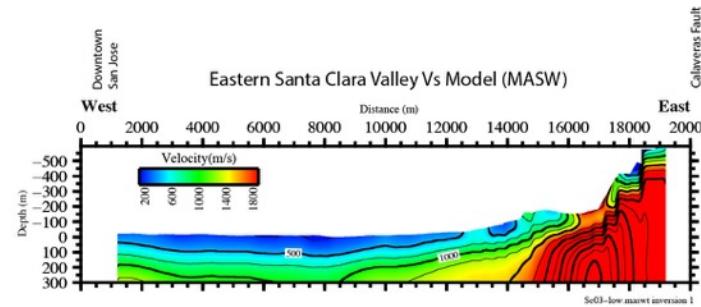


## Napa Cross Valley Vs MASW Model

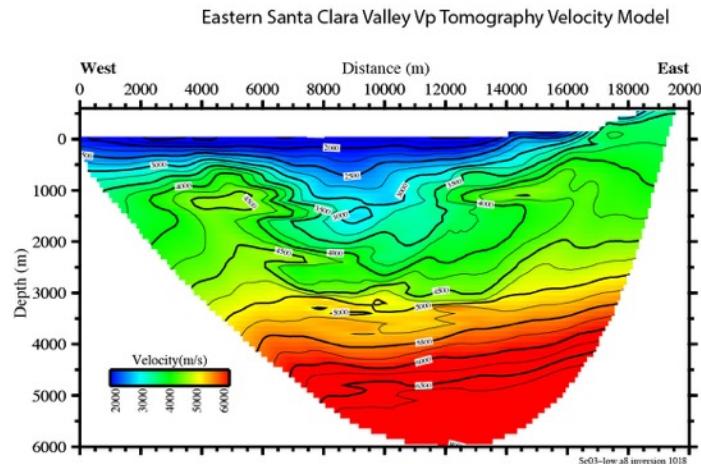


# Eastern Santa Clara Models

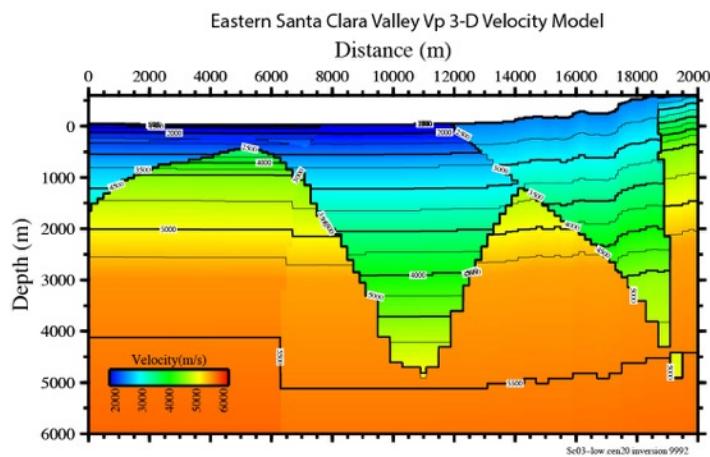
MASW (Vs)



Refraction Tomography (Vp)



Existing 3-D Model (Vp)



# **V<sub>s</sub> from V<sub>p</sub> Assuming with V<sub>p</sub>/V<sub>s</sub> Ratios**

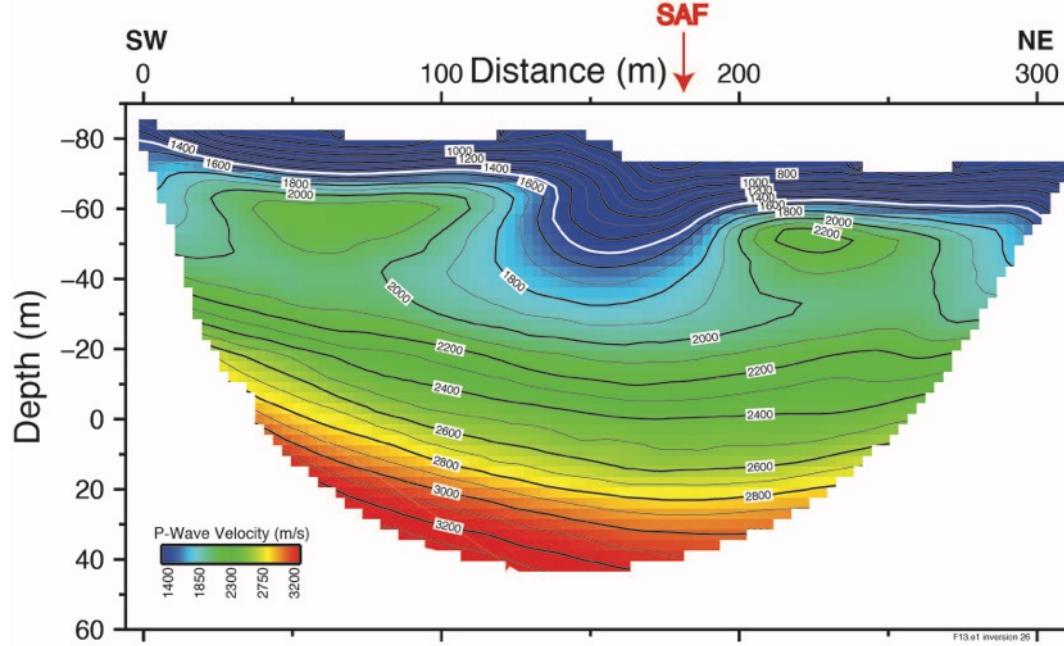
# Improving the Existing Bay Area 3-D Velocity Model

**Highly variable Vp/Vs ratios make extrapolation of Vs models from Vp models difficult.**

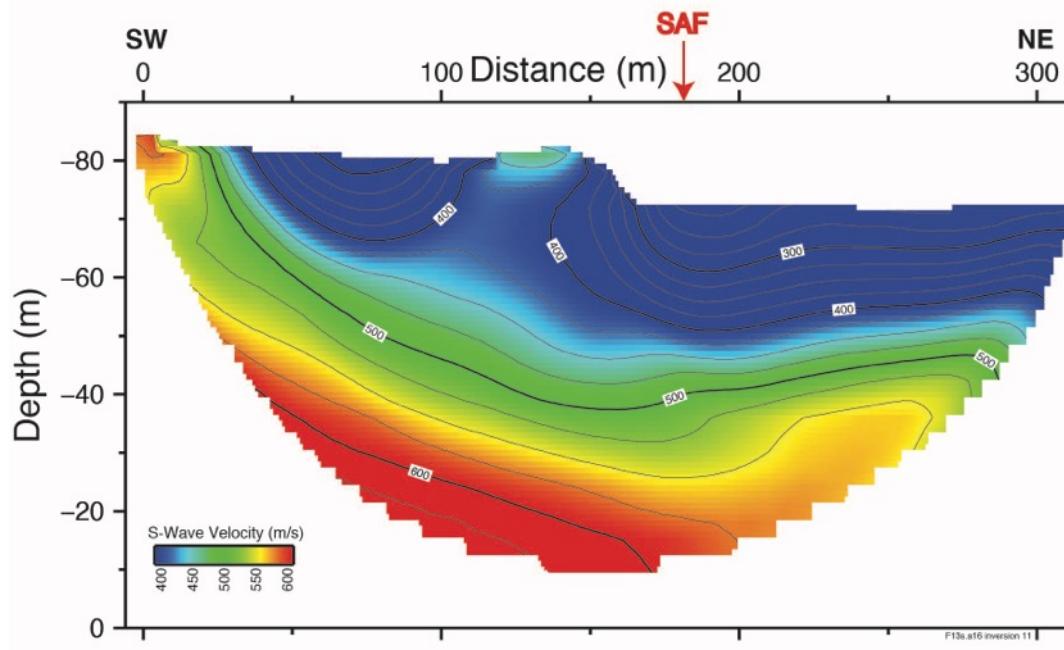
- For many rocks, Vp/Vs ratios assumed to be ~1.7 to ~2.0
- Vp/Vs ratios can vary significantly (up to 10) for  $V_p < 2500$  m/s in the subsurface of the Bay Area.
  - Serpentinite
  - Faulting
  - Saturated Sediments

# Peninsula San Andreas Fault

Vp Tomography Model



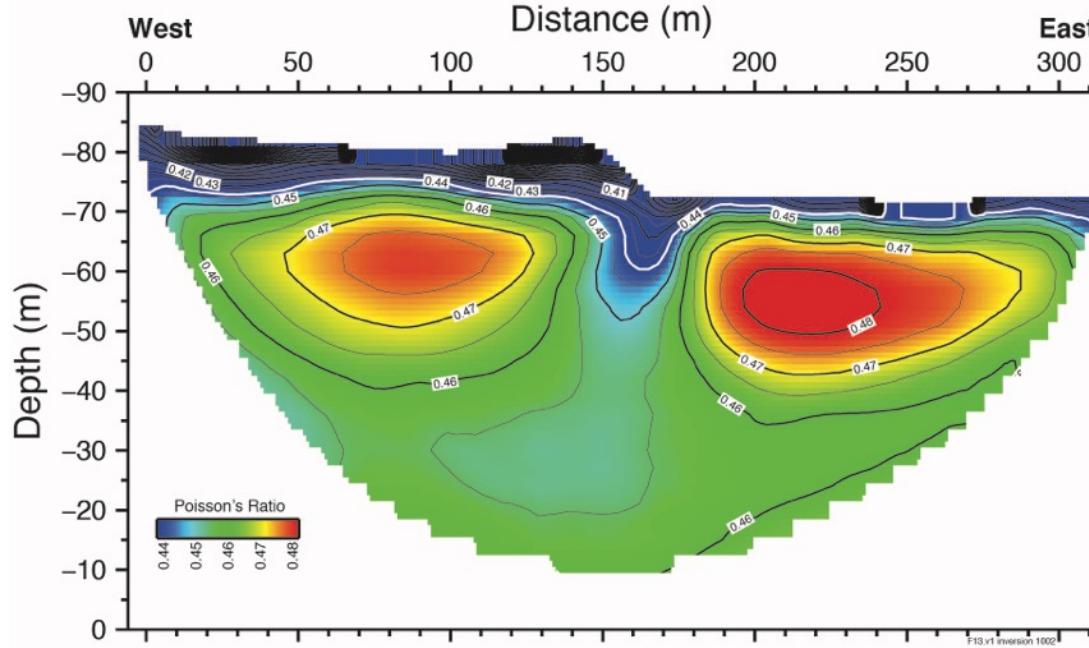
Vs Tomography Model



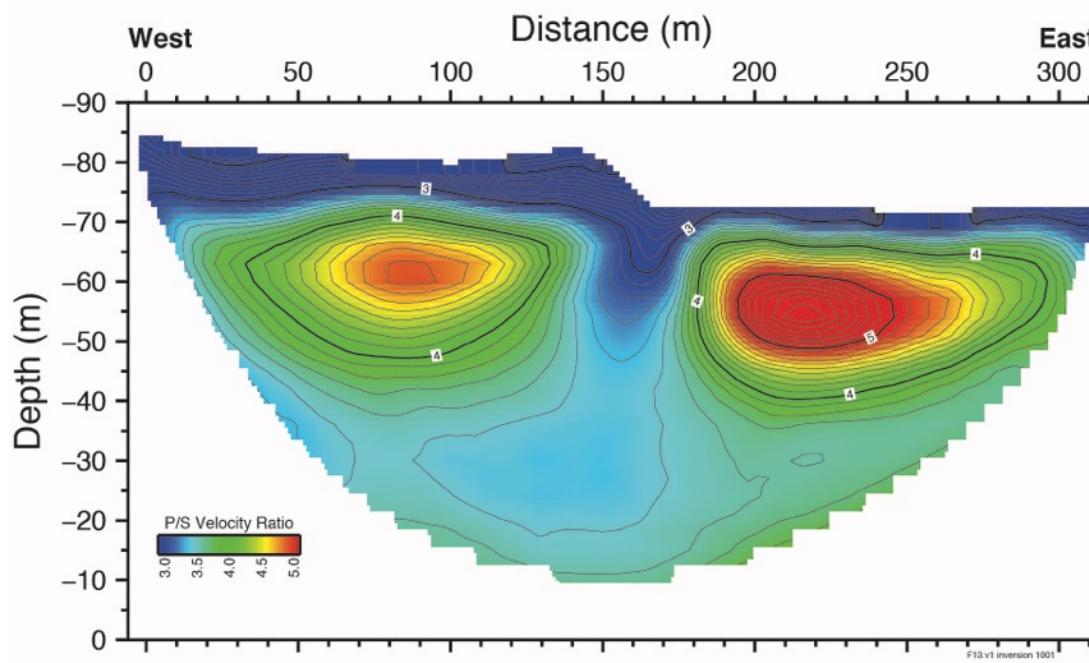
Differences in Structure

# Peninsula San Andreas Fault

Poisson's Ratio



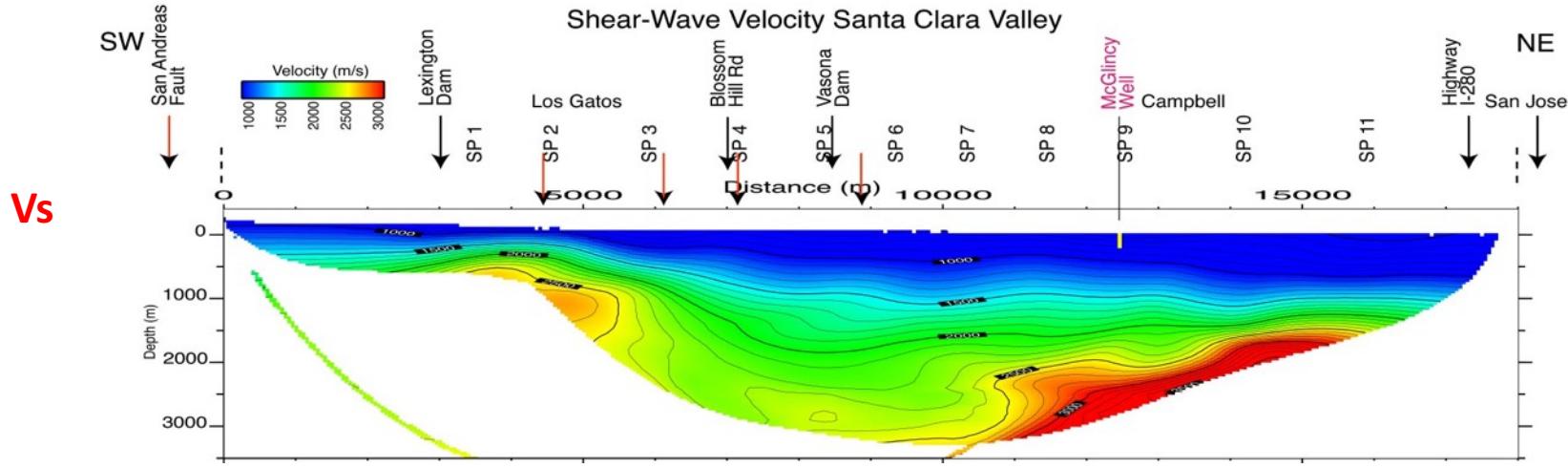
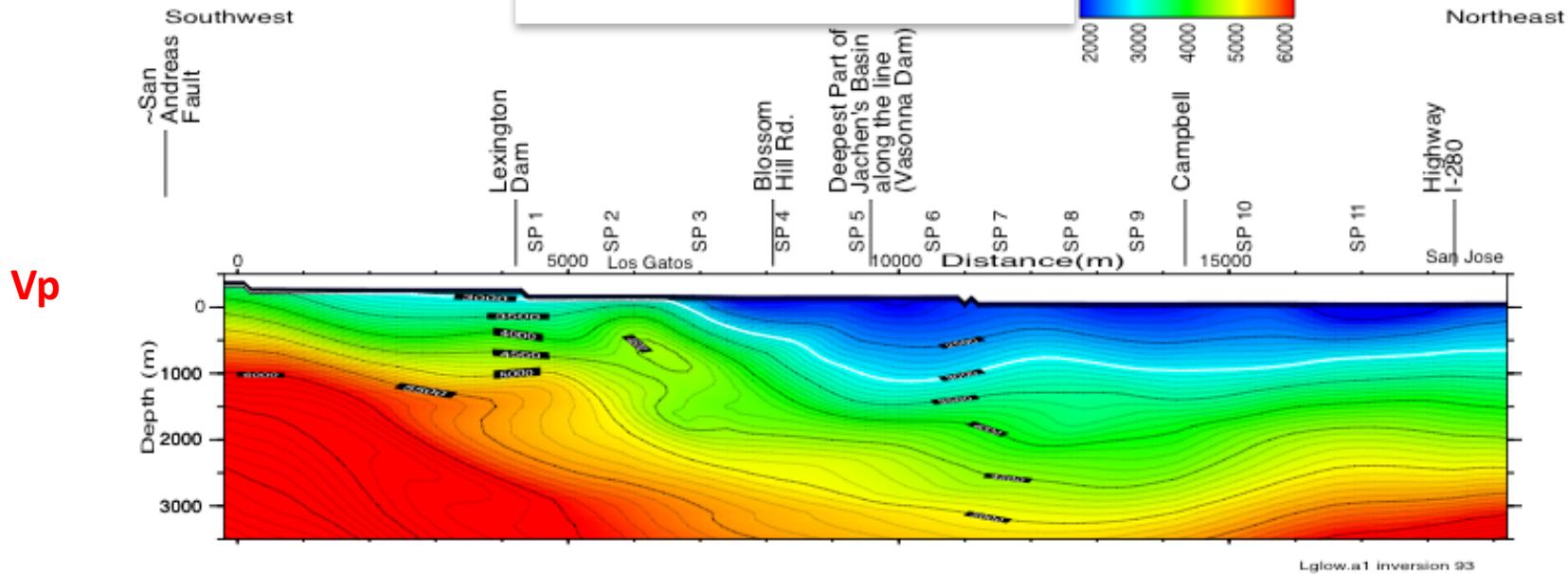
Vp/Vs Ratio

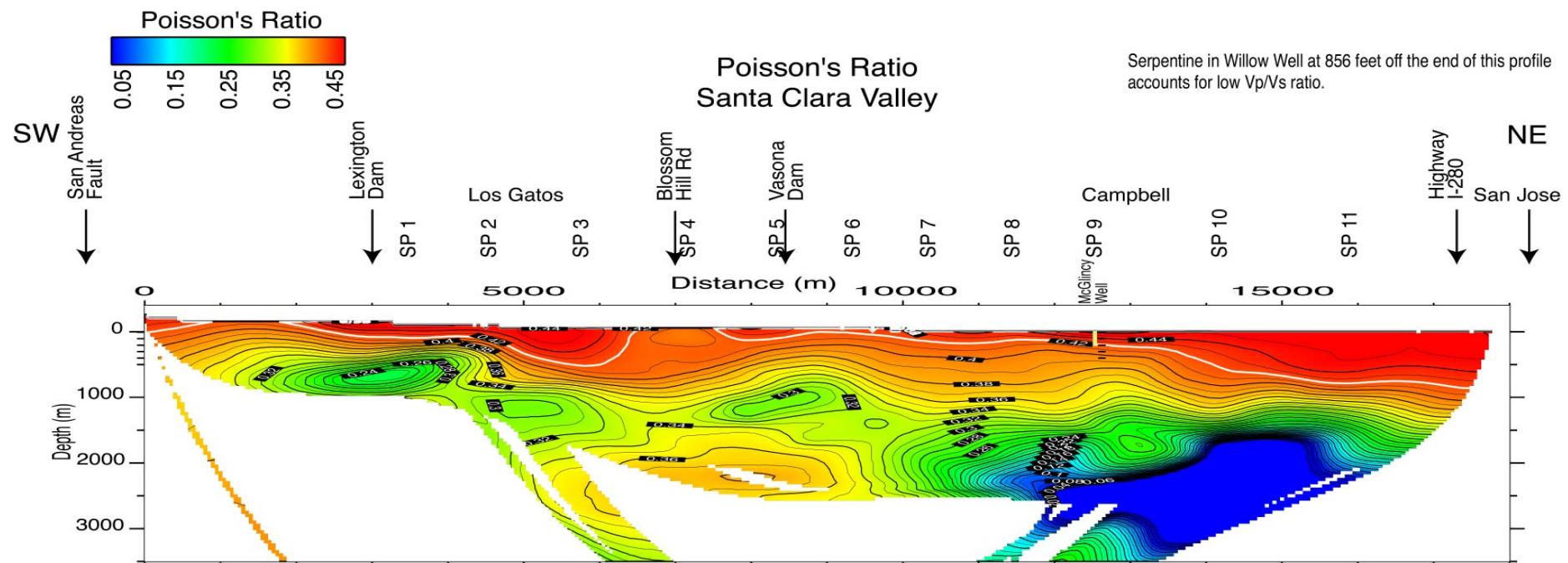
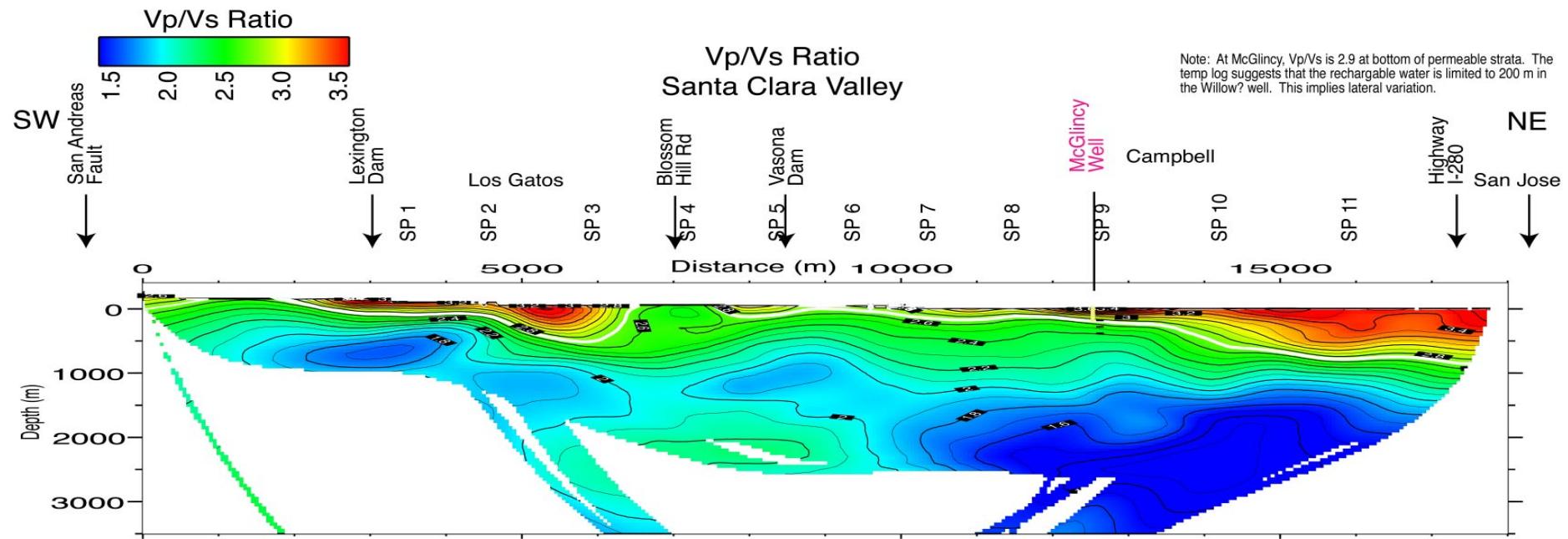


High Vp/Vs  
Ratios

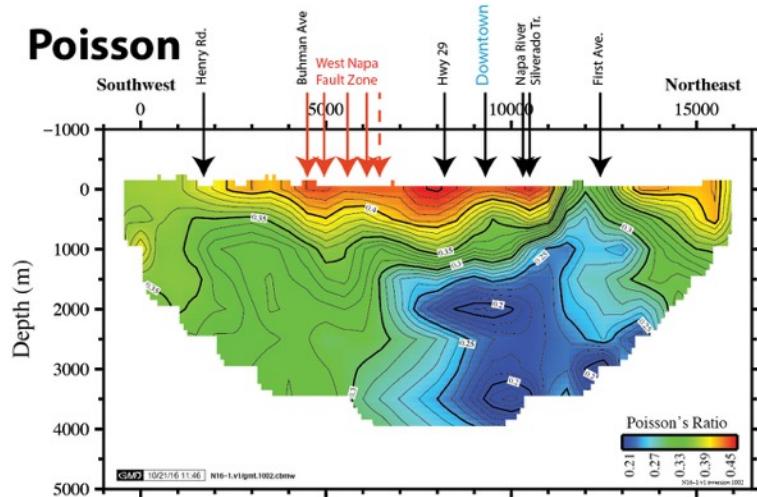
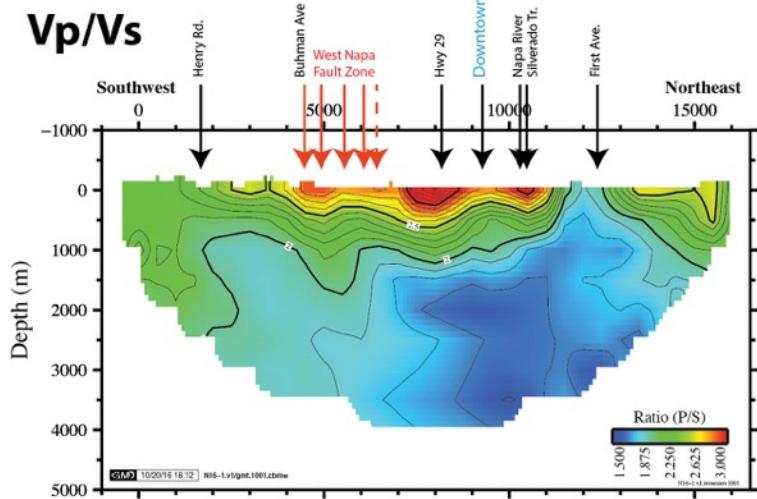
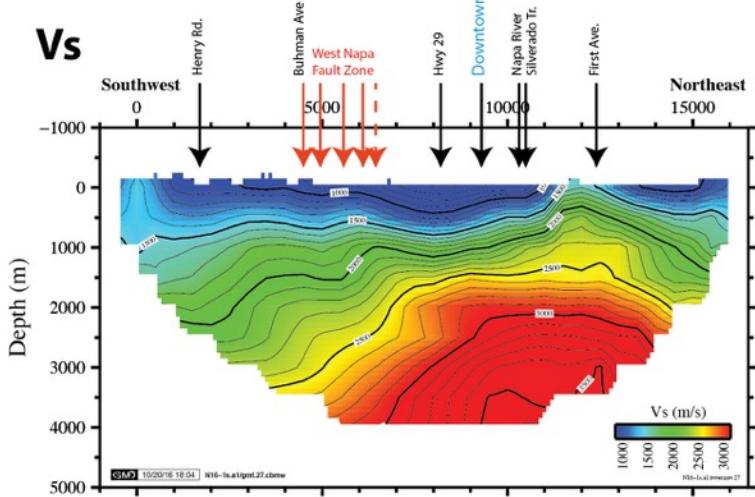
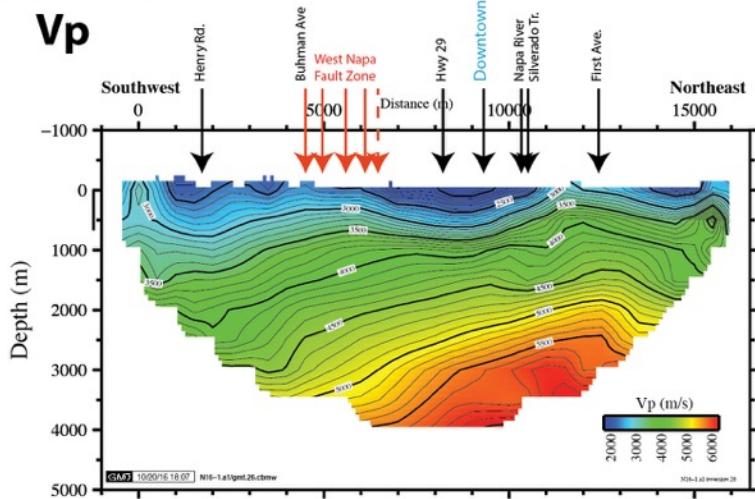
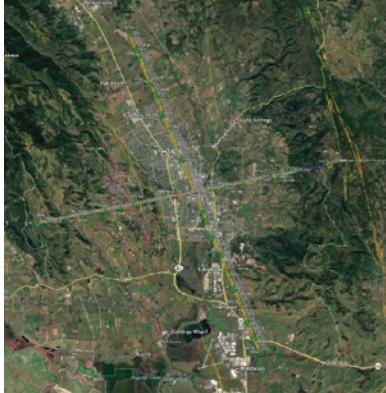
# Western Santa Clara Valley

## V<sub>p</sub> and V<sub>s</sub>





# Napa Valley 2016 Vp, Vs, Vp/Vs, PR Models



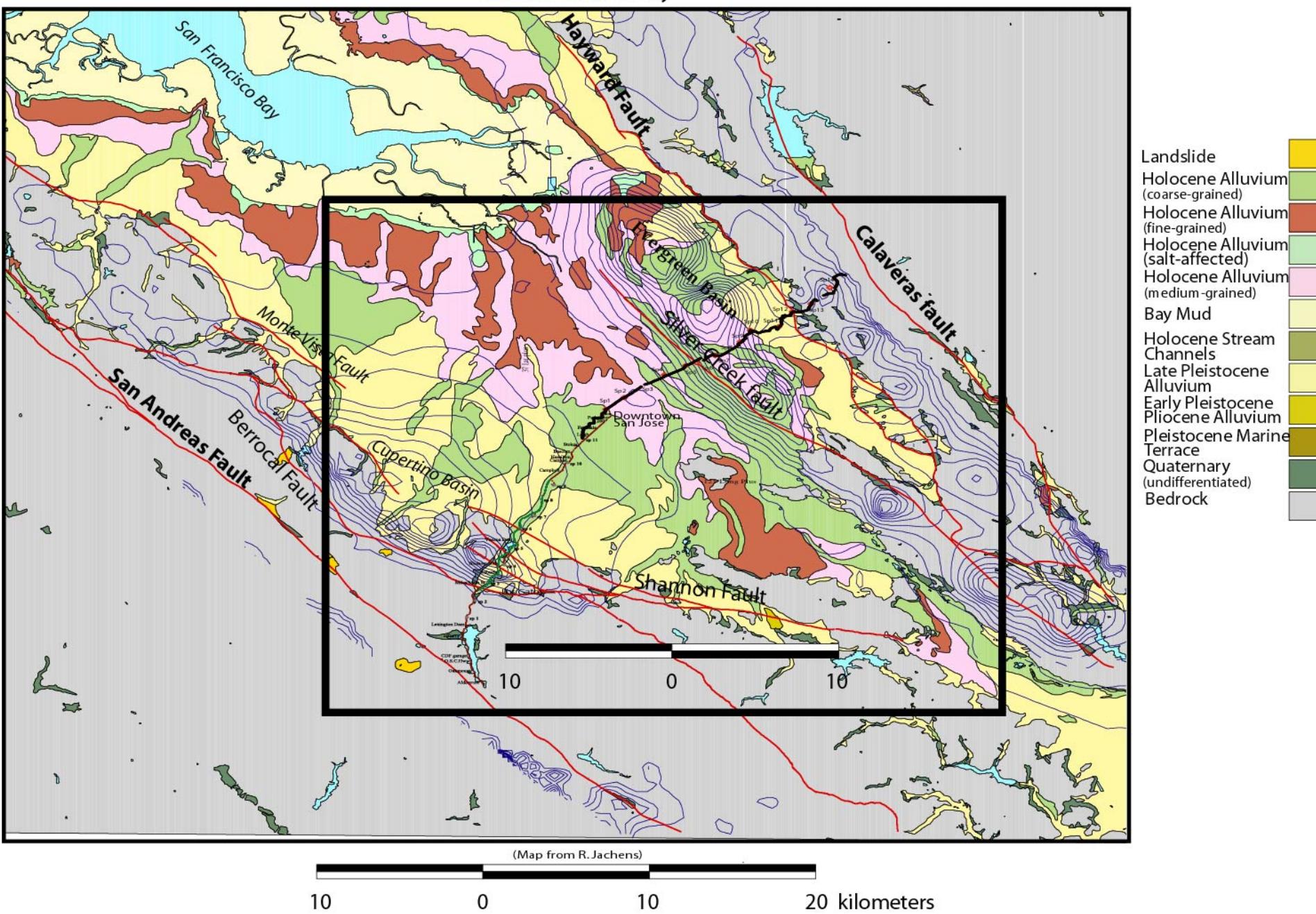
# Summary Suggestions

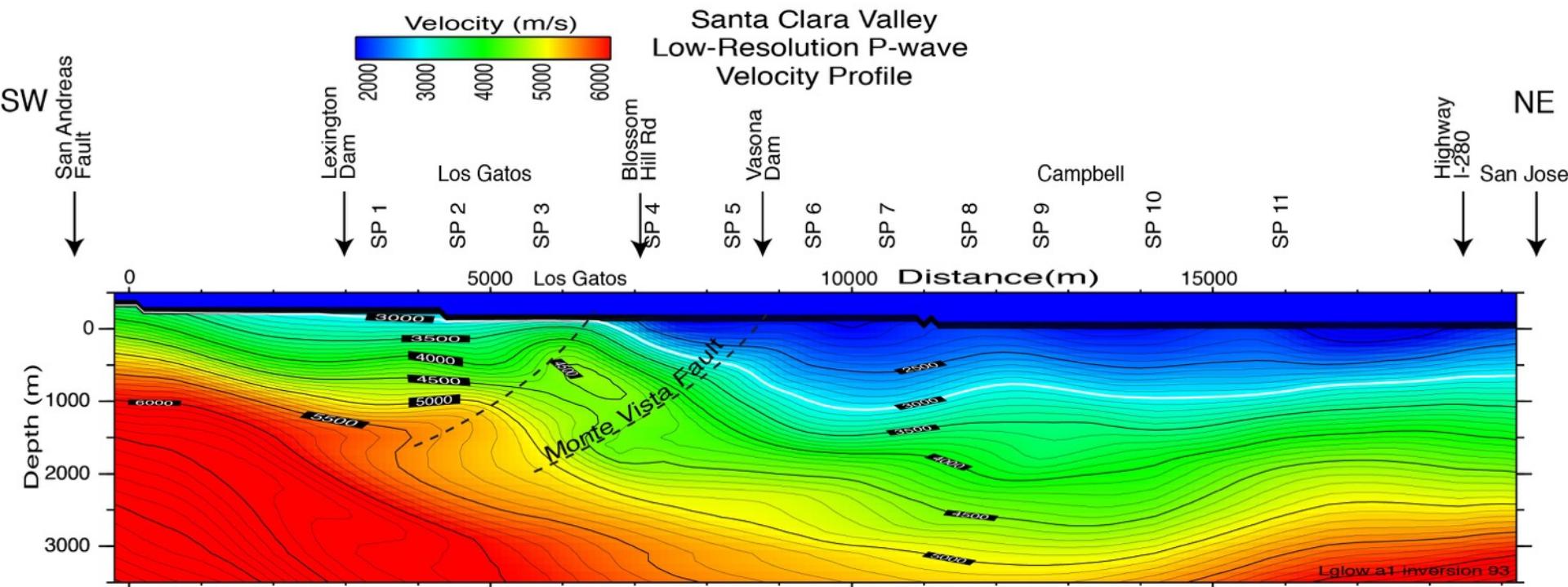
- Existing 3-D models should incorporate more of the seismic models where possible.
- Where the seismic models and the existing 3-D models differ, seismic models should be more heavily weighted.
- Shallow Vp and Vs models, where available, should be incorporated into the 3-D model.
- Highly variable Vp/Vs ratios make it difficult to extrapolate 3-D Vs models from Vp models.

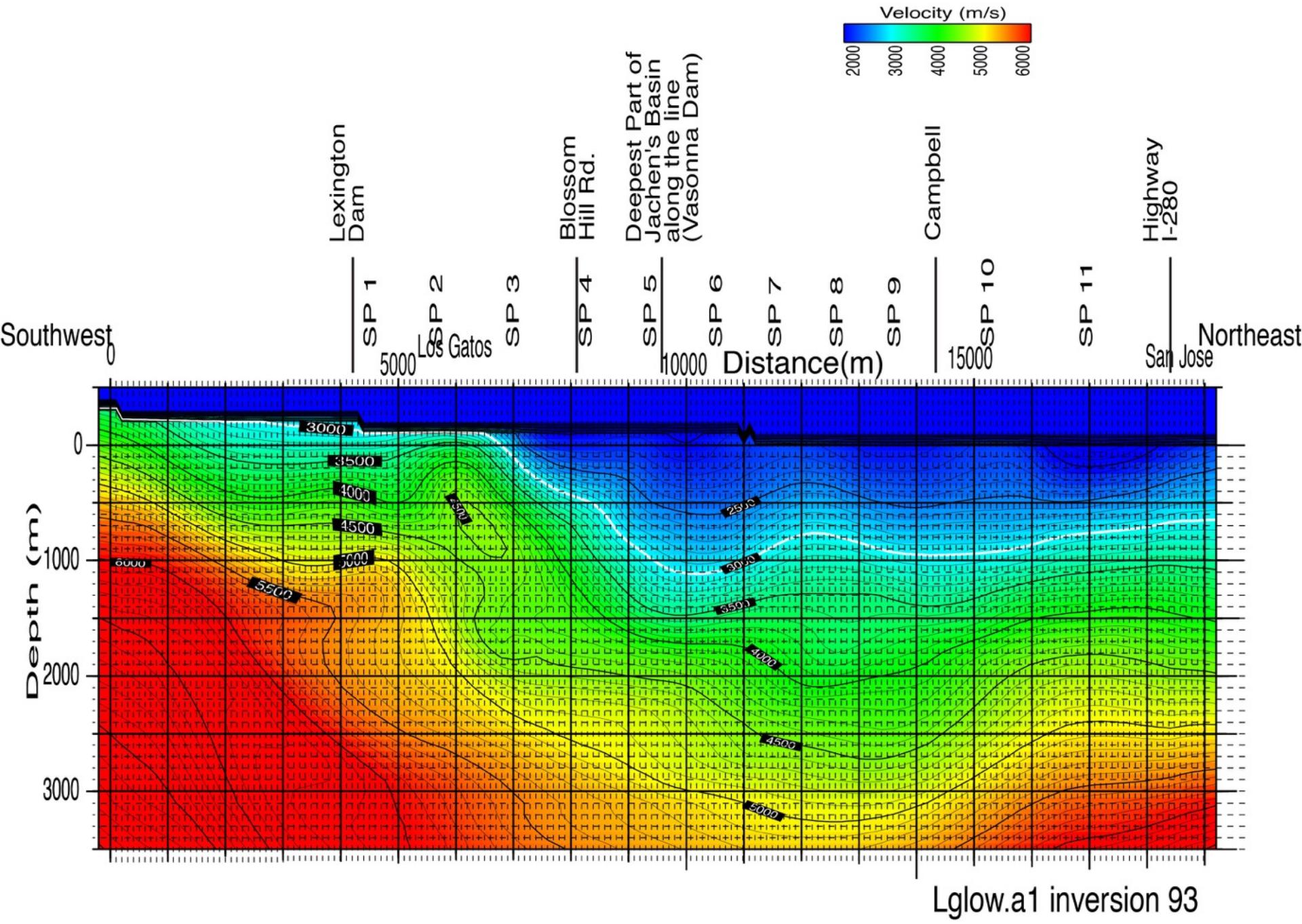


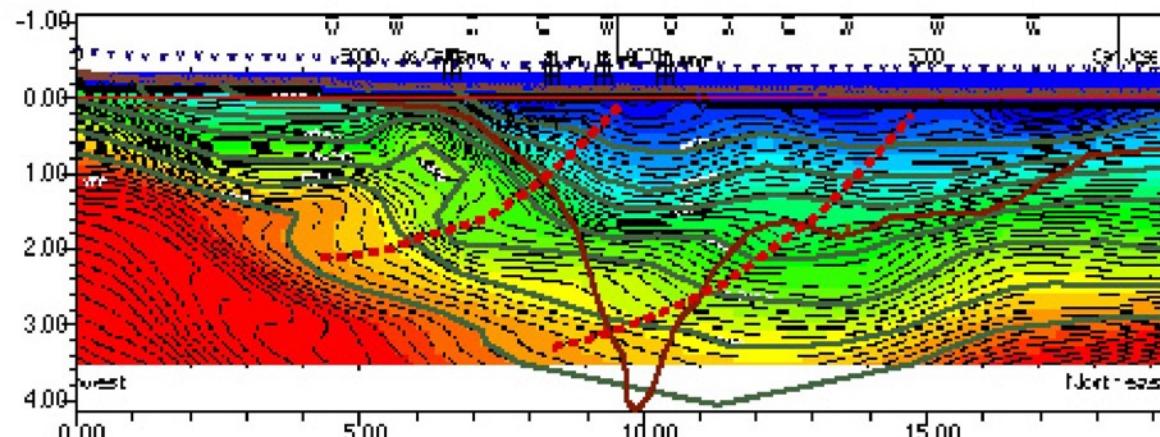
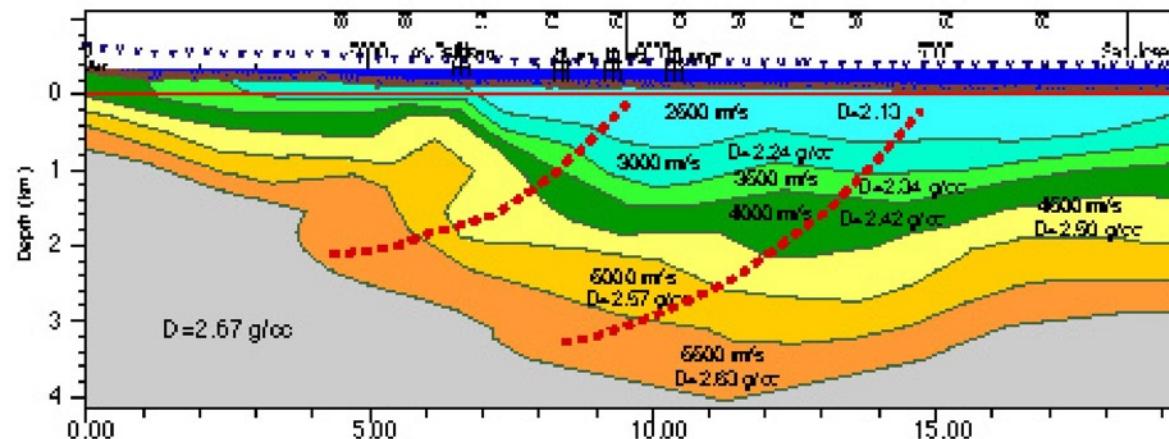
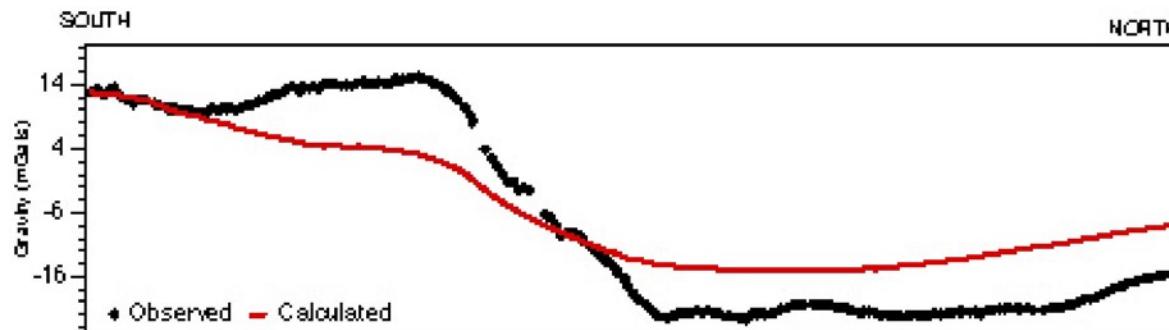


## Santa Clara Valley







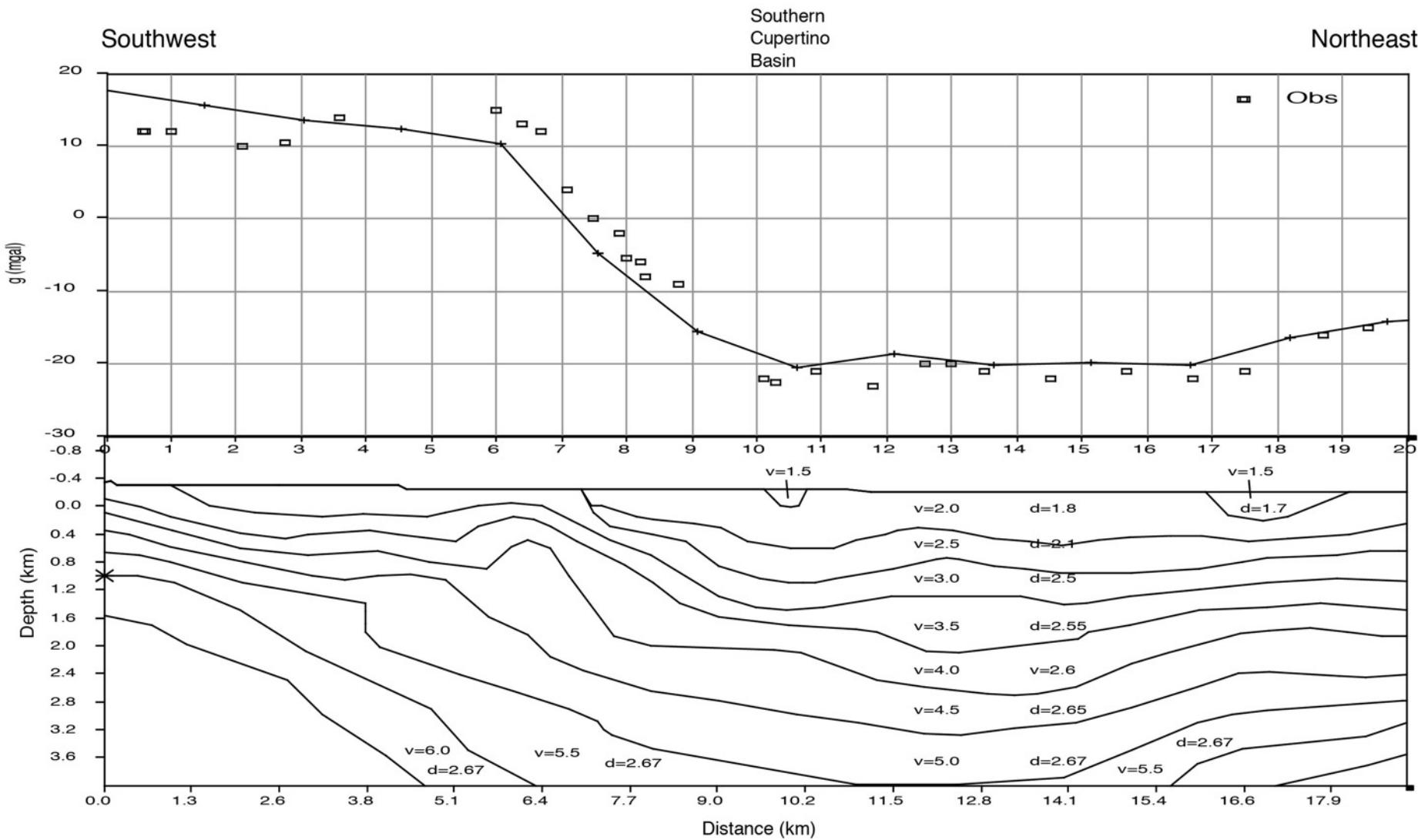


VE=1

Southwest

Southern  
Cupertino  
Basin

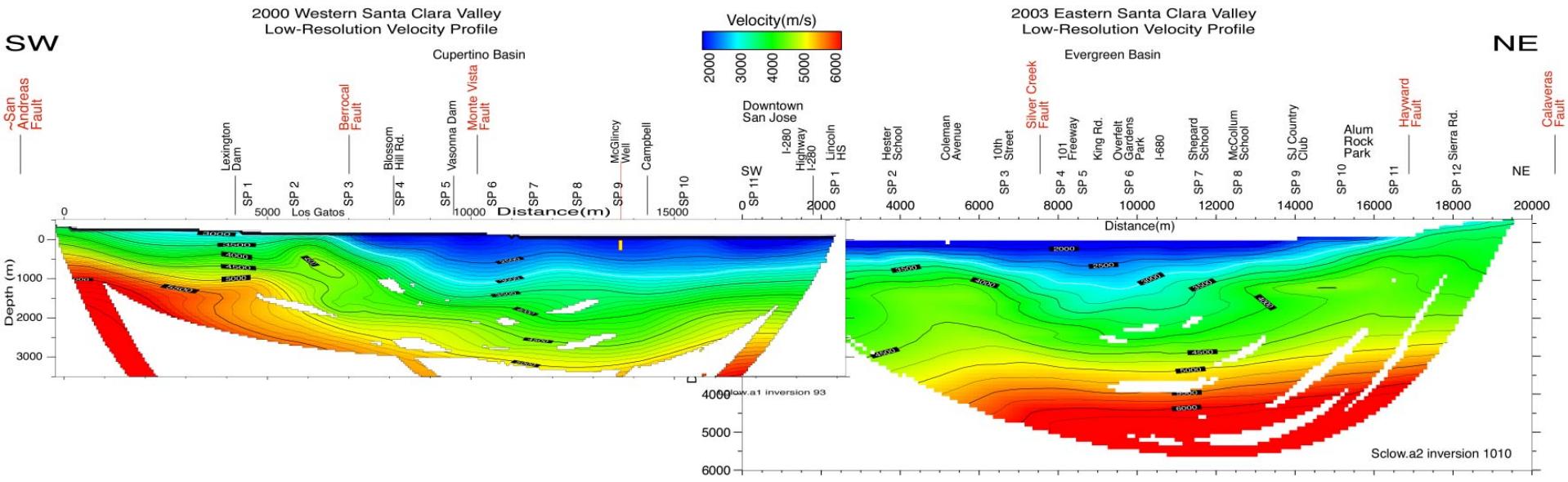
Northeast

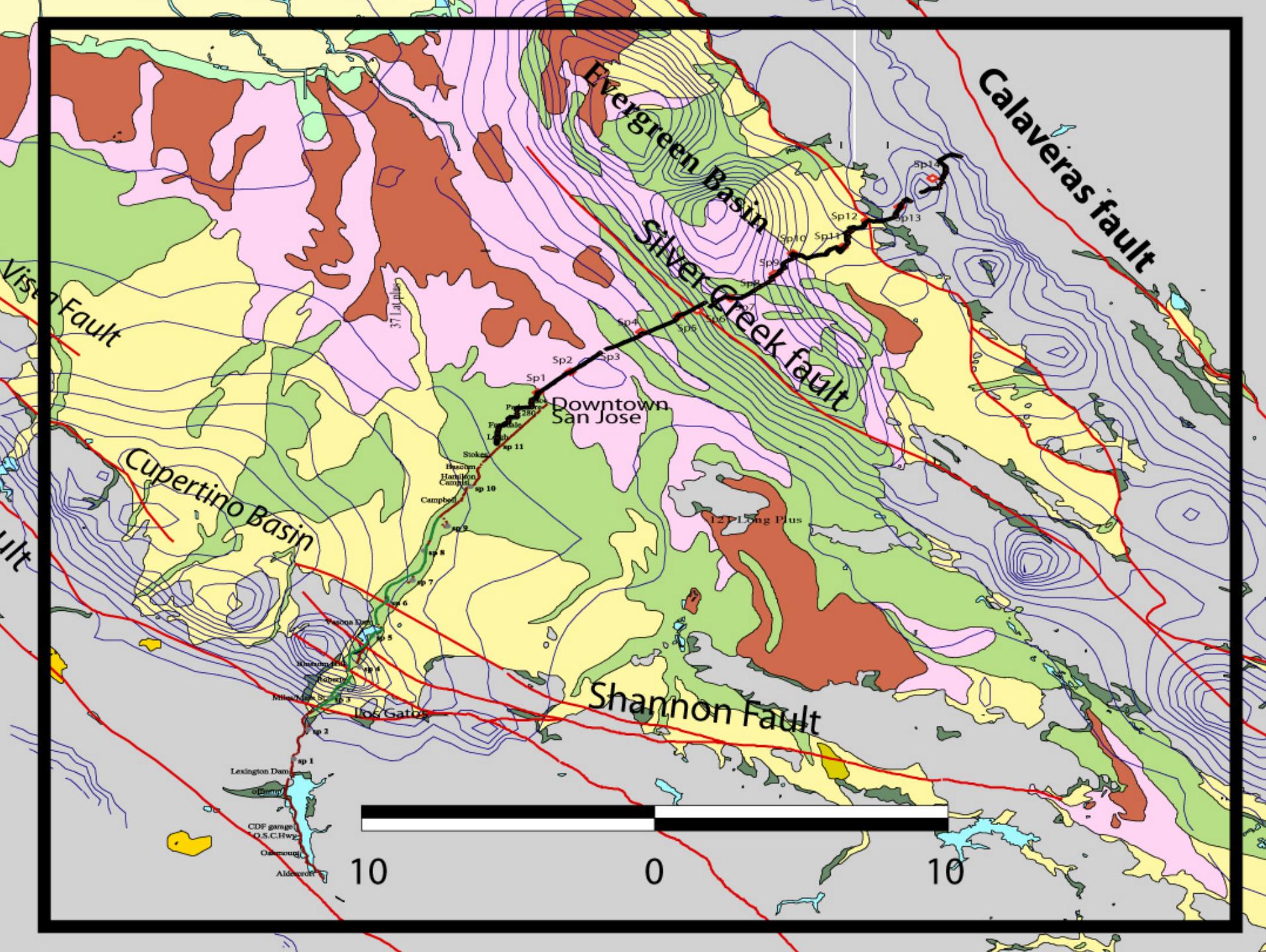


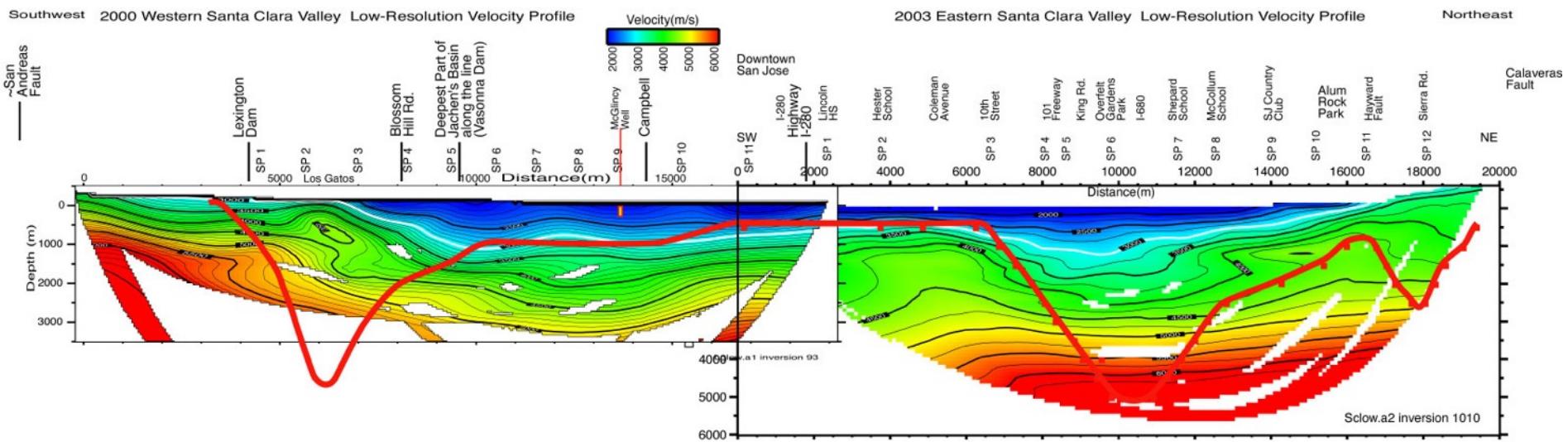






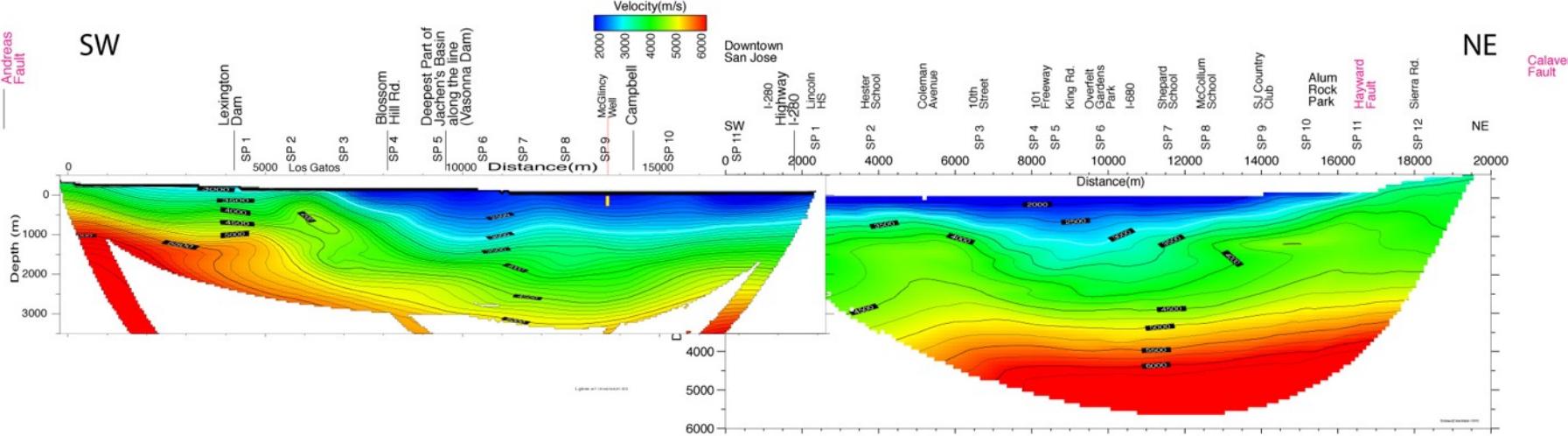






~San Andreas Fault

SW

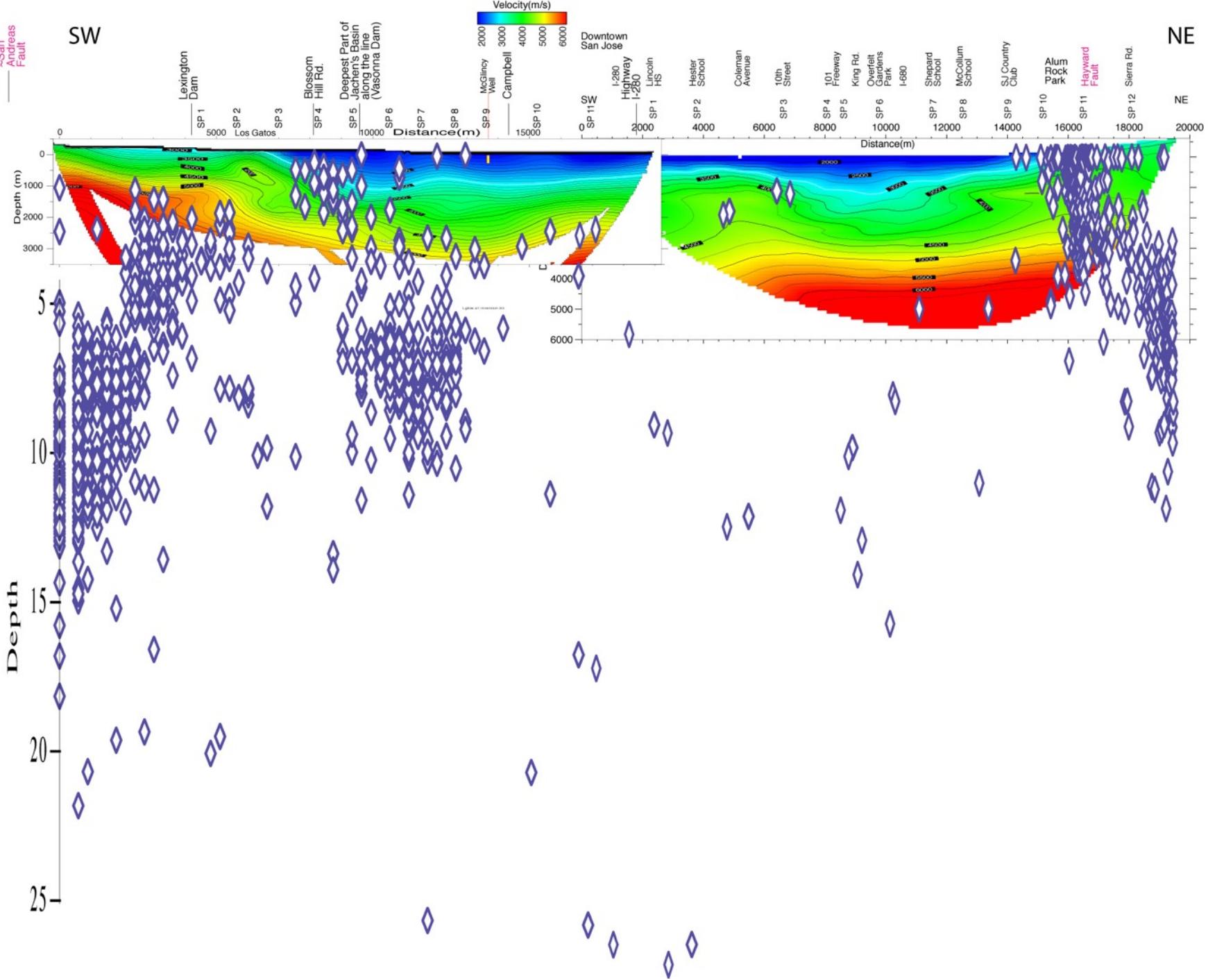


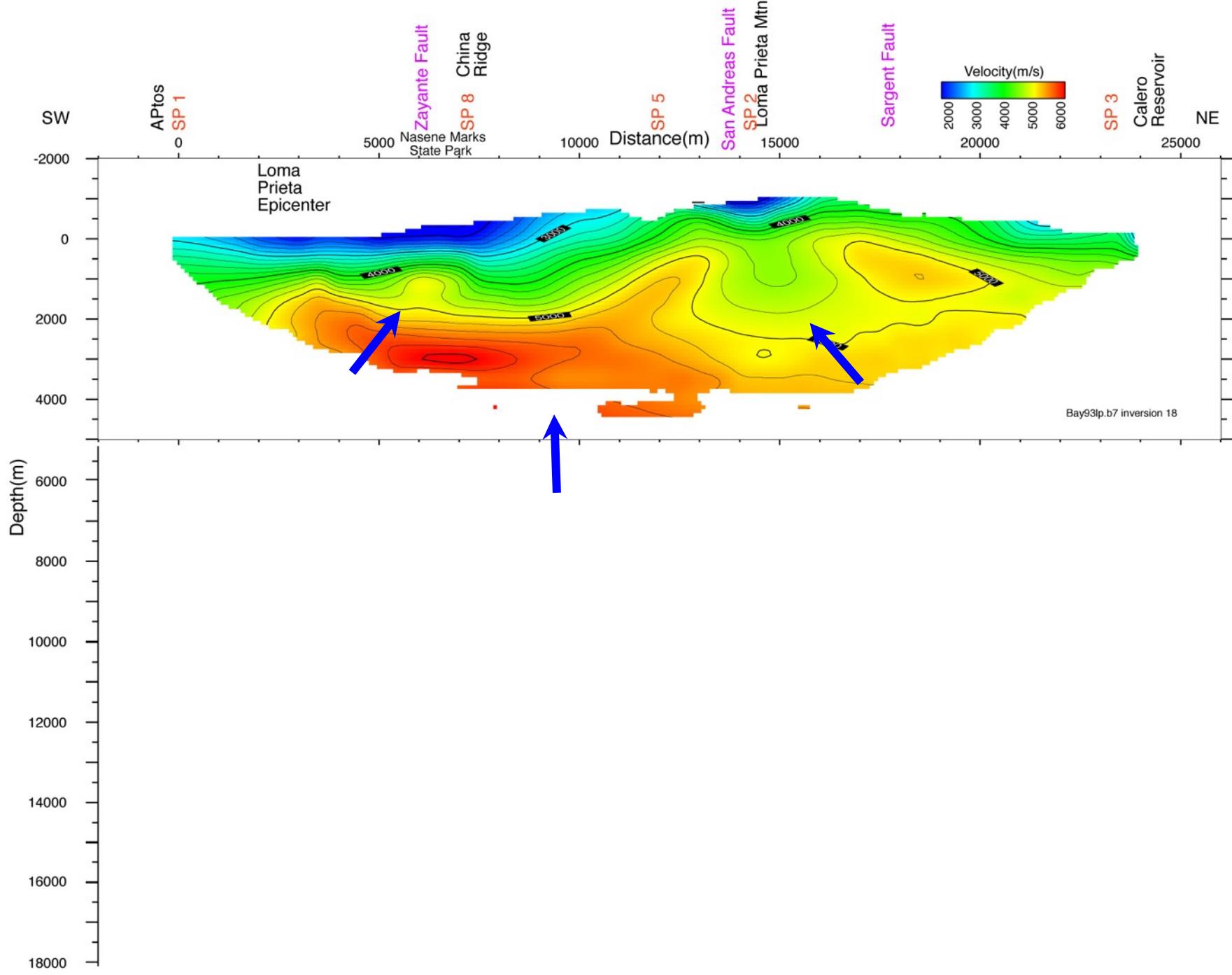
—San Andreas Fault

SW

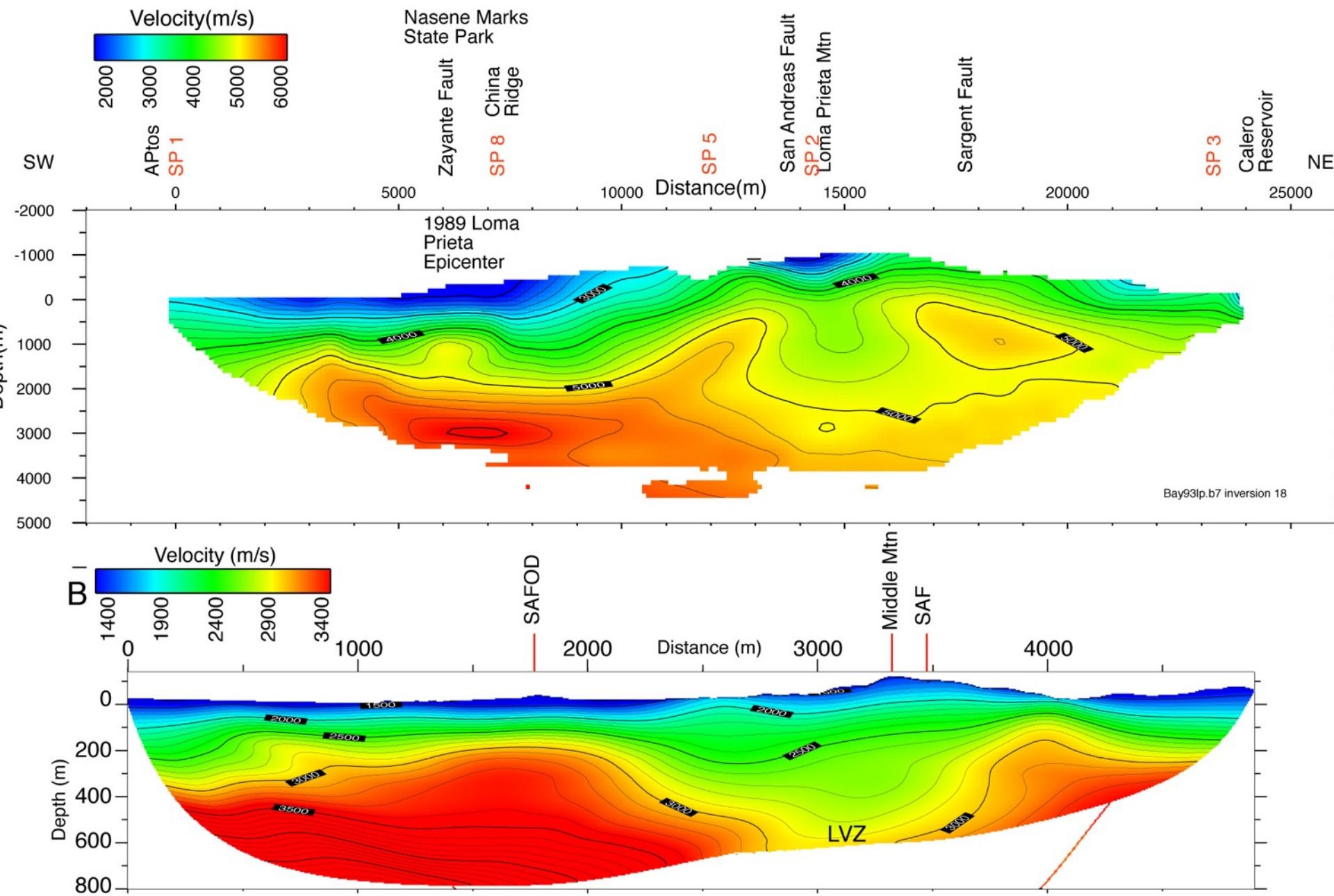
NE

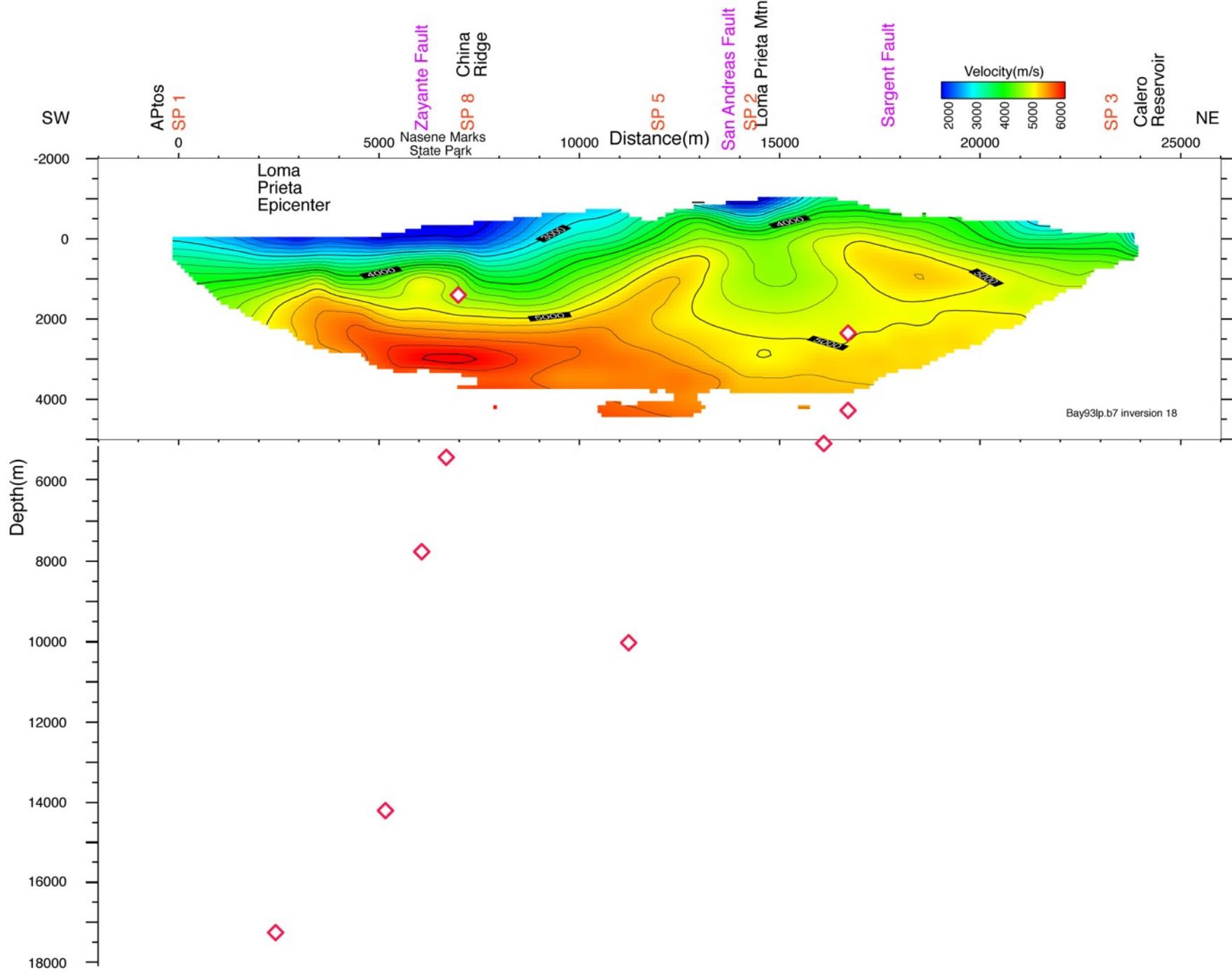
Calaveras Fault

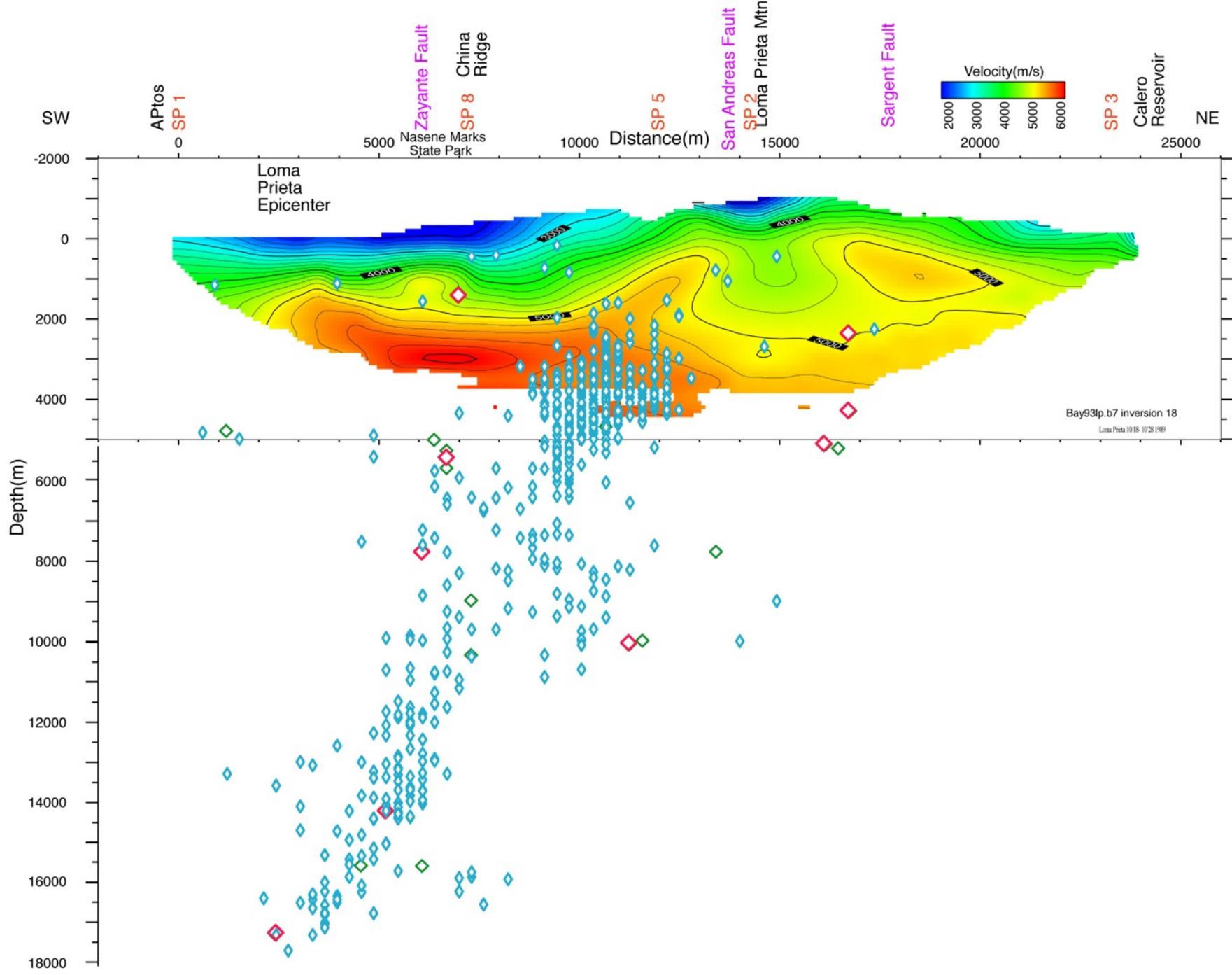


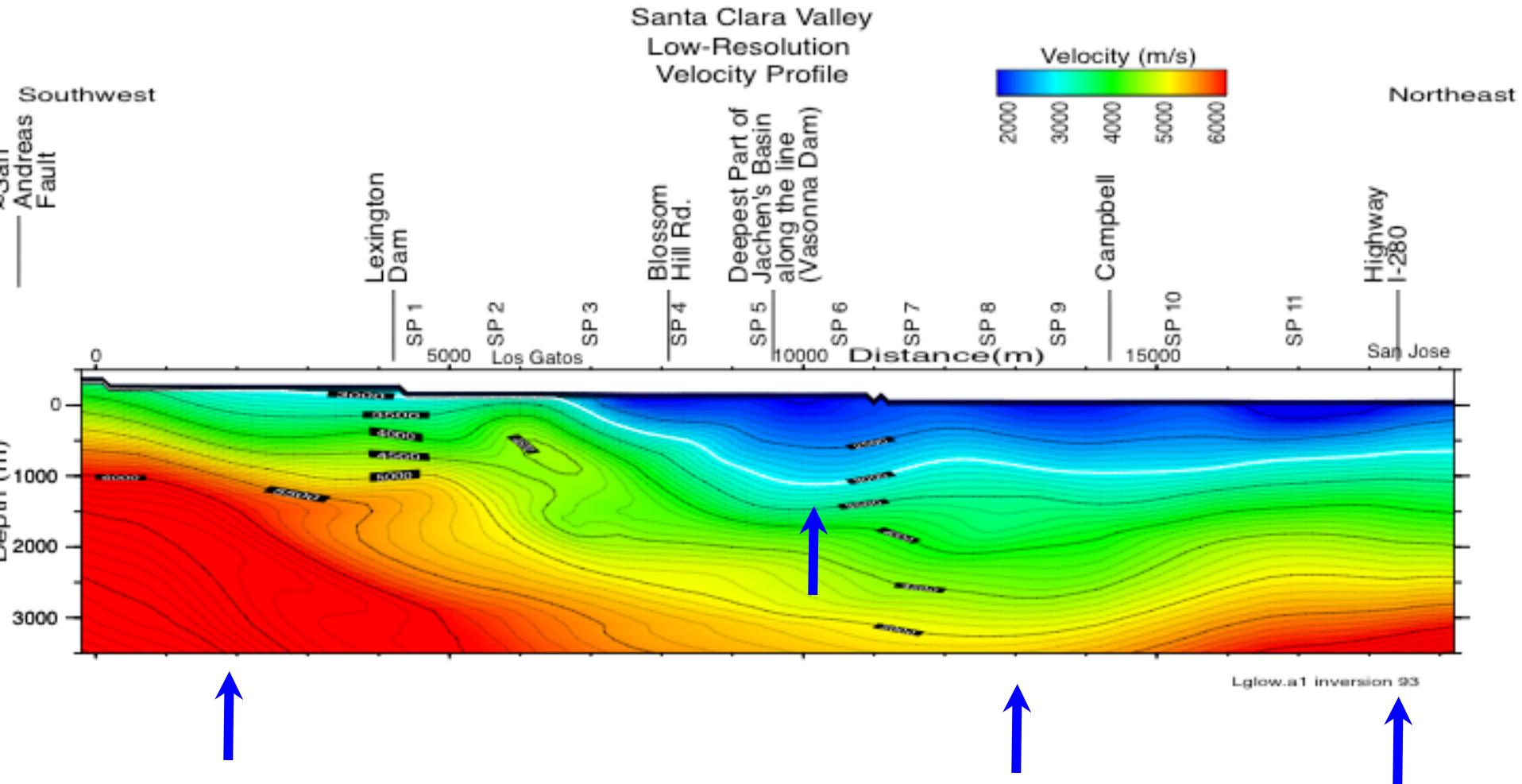


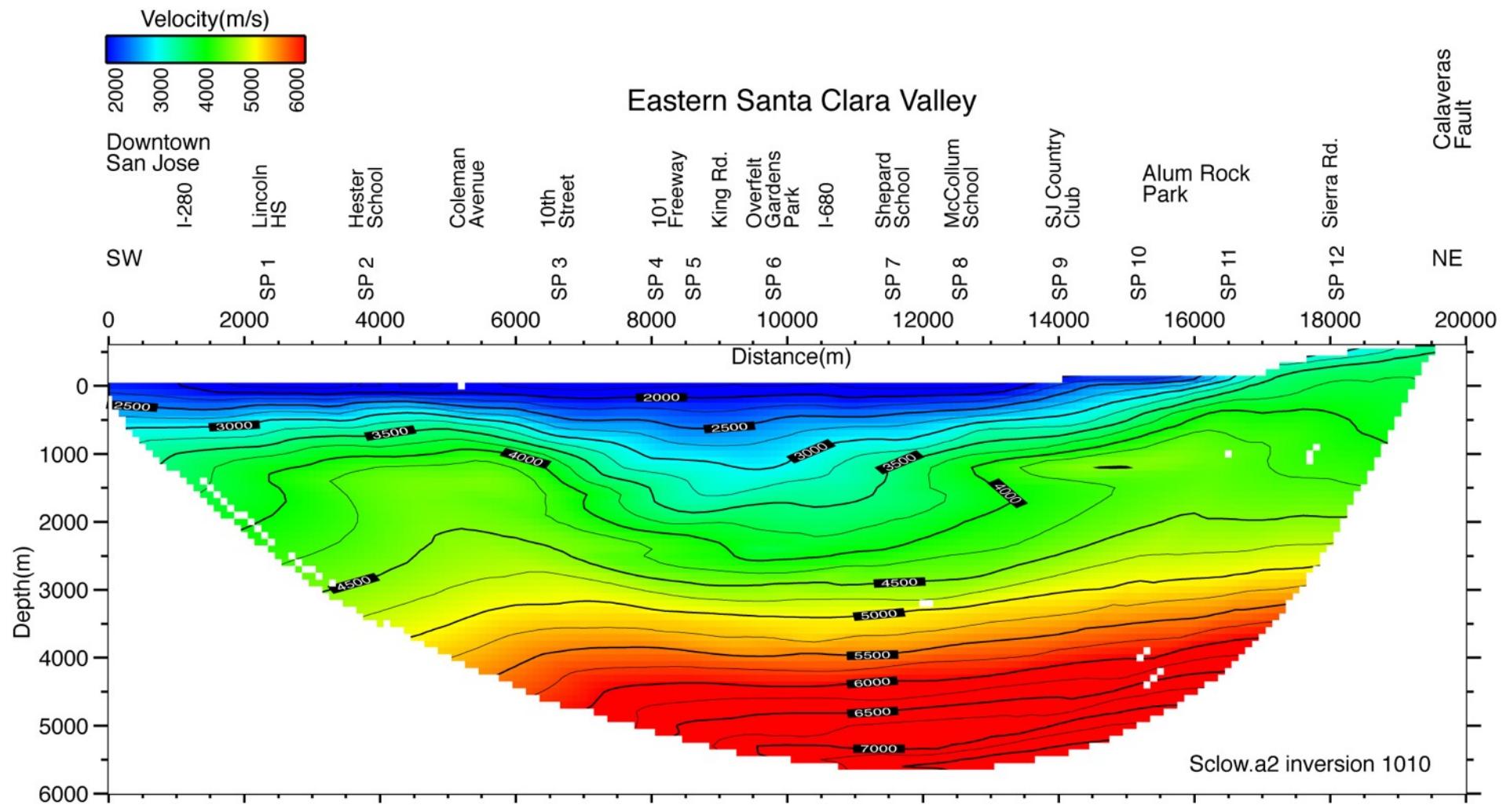
# Comparisons of Seismic Velocity Profiles Across The San Andreas Fault At Loma Prieta and SAFOD



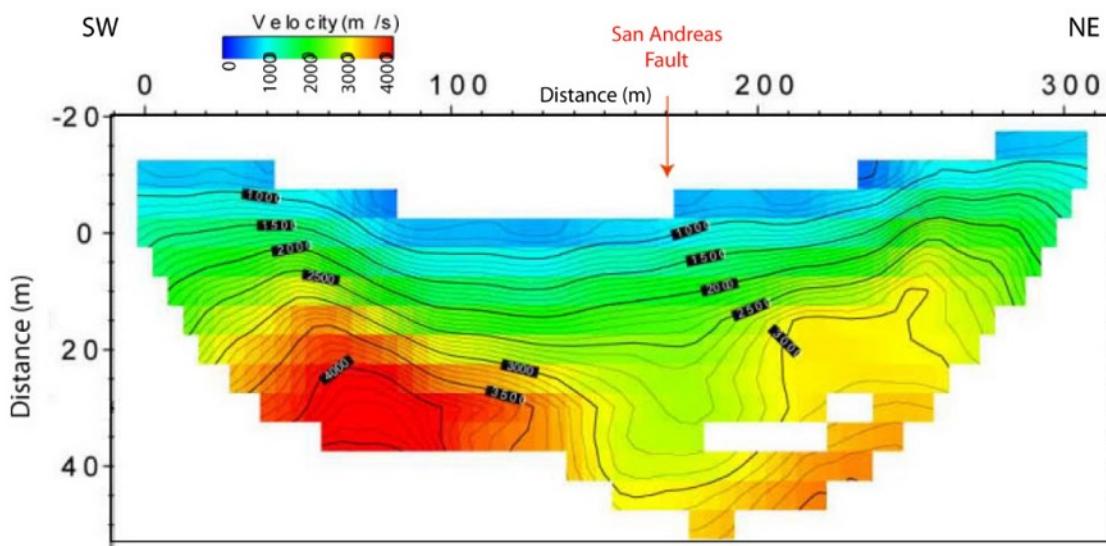
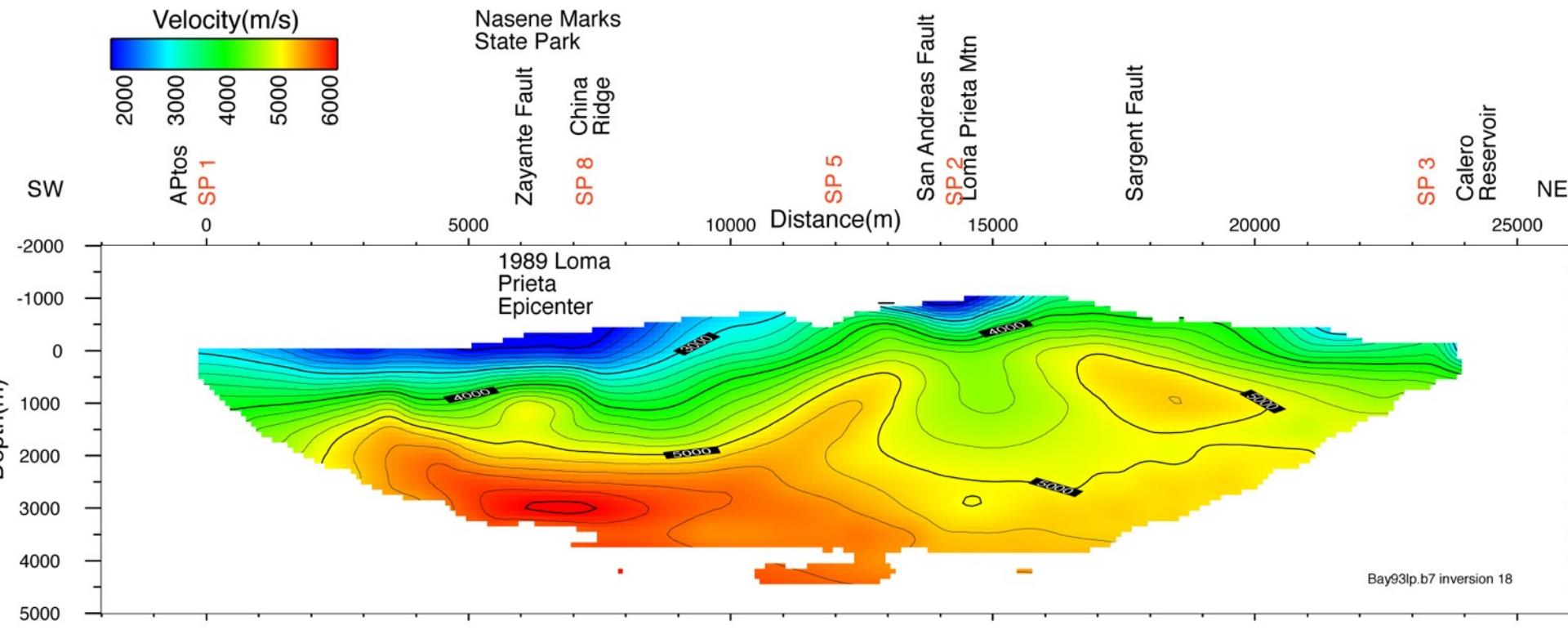


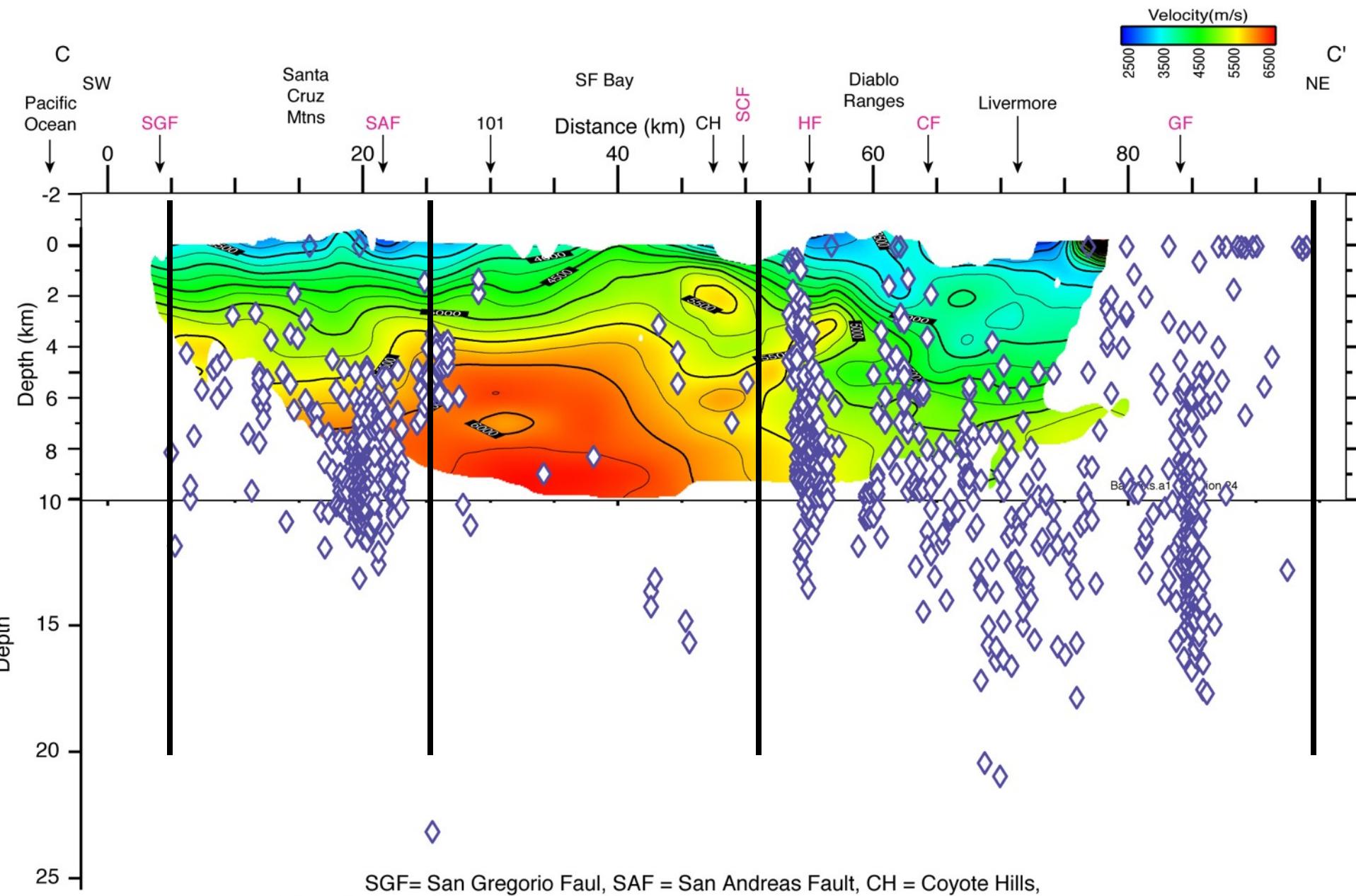




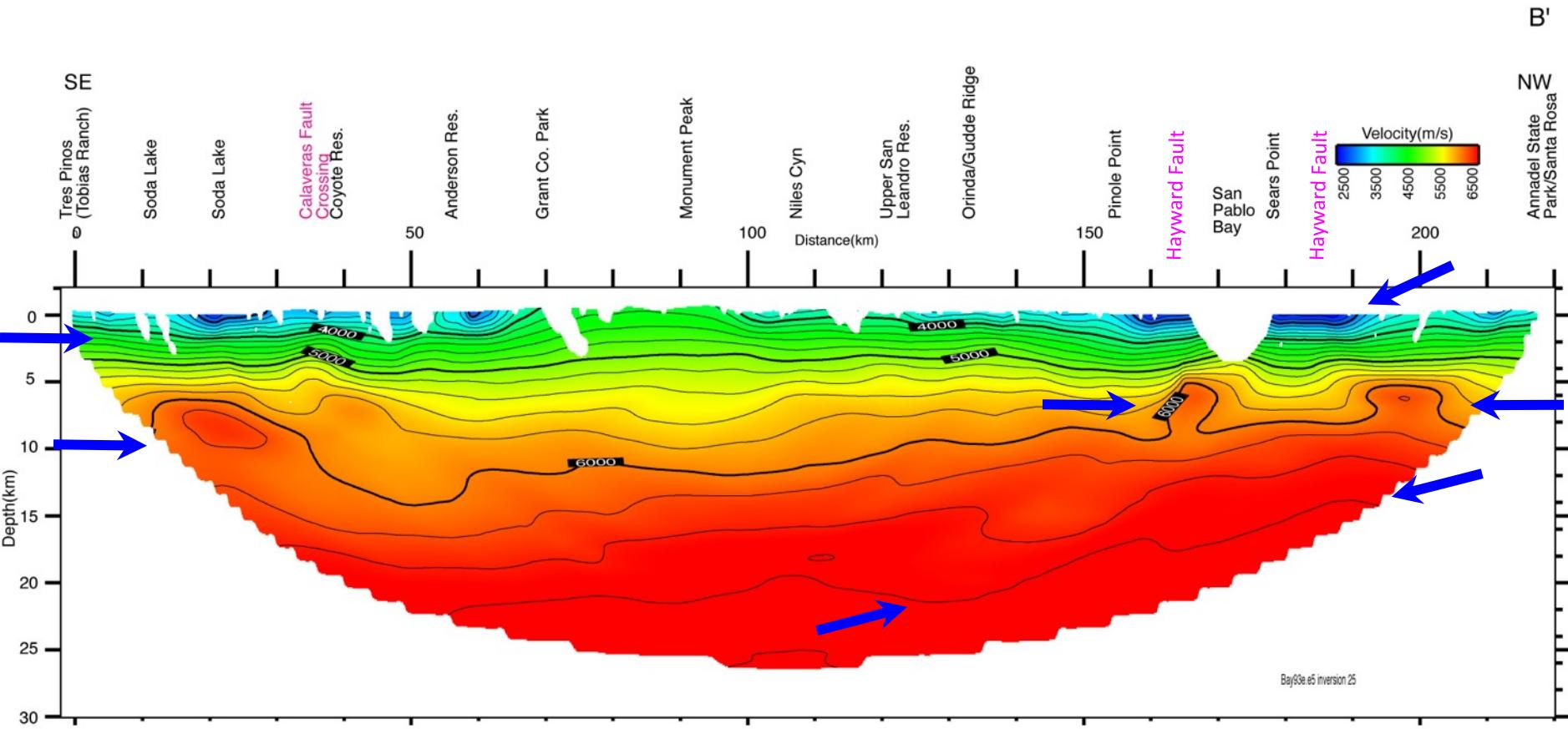


# Comparisons of Seismic Velocity Profiles Across The San Andreas Fault At Loma Prieta and Palo Alto





SGF= San Gregorio Fault, SAF = San Andreas Fault, CH = Coyote Hills,  
SCF = Silver Creek Fault, HF = Hayward Fault, CF = Calaveras Fault, GF = Greenville Fault

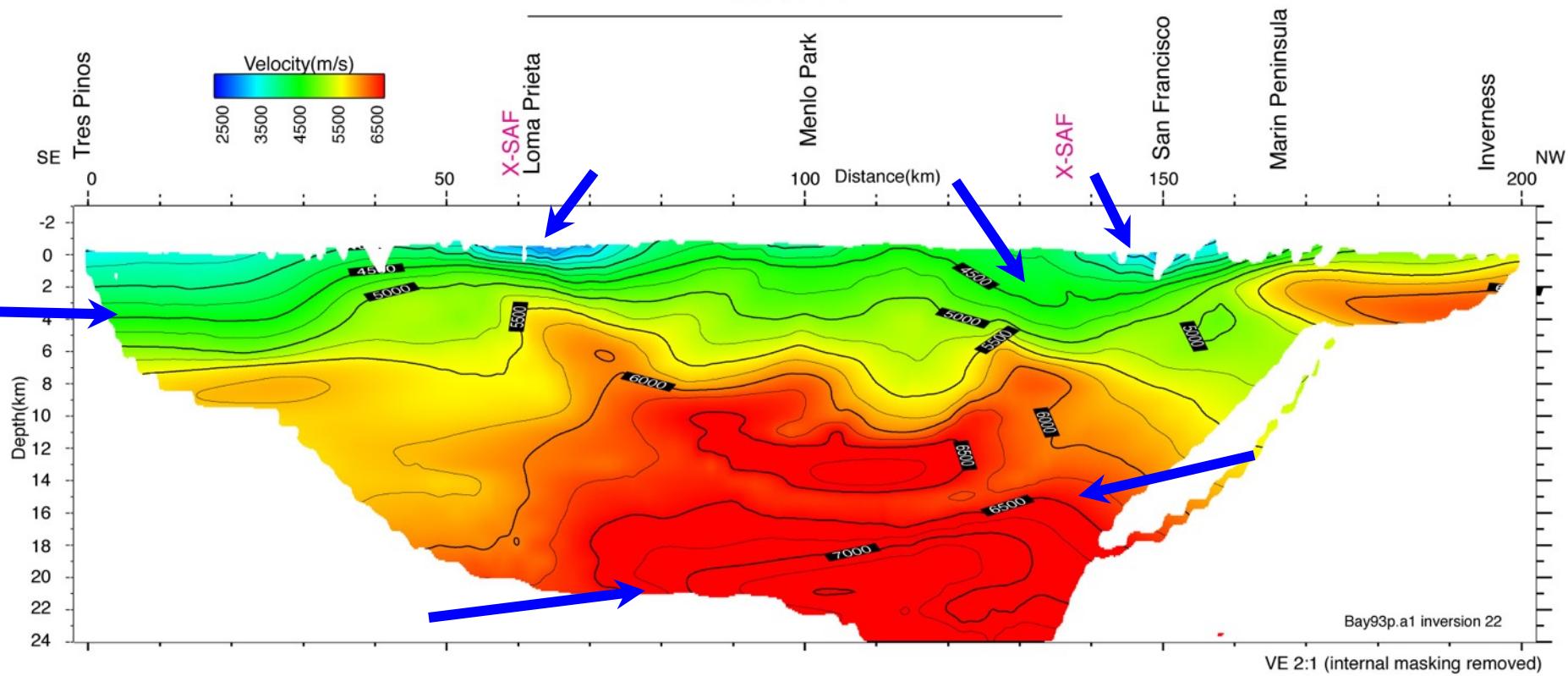


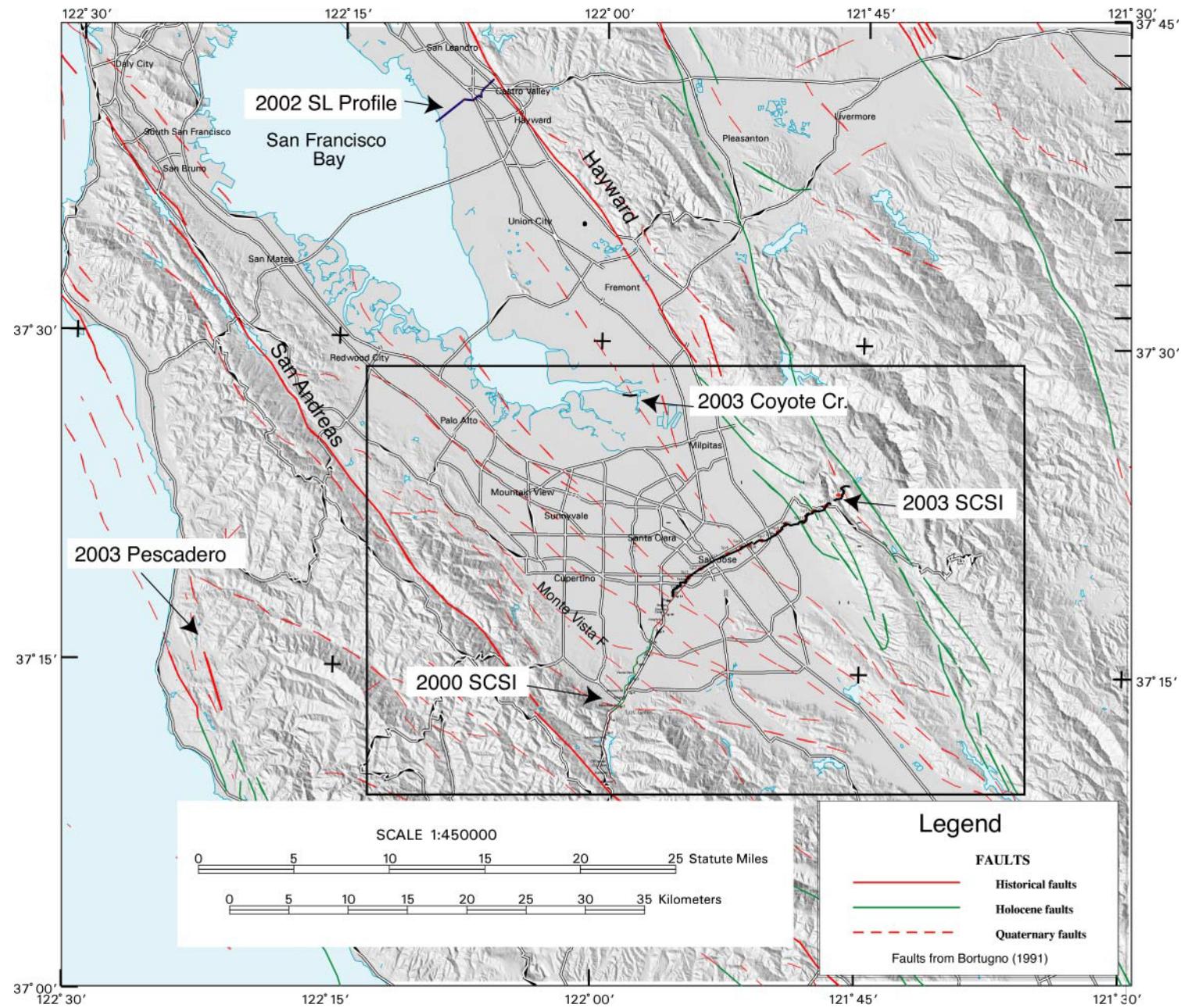
A

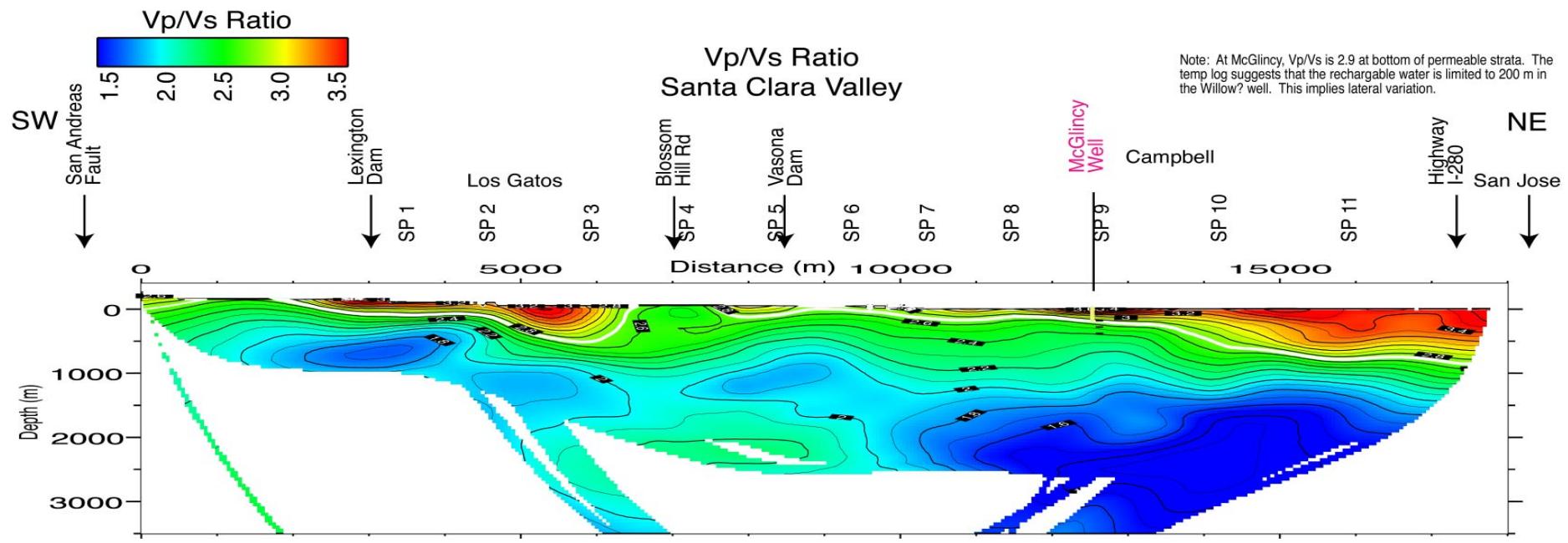
## SF Peninsula Profile

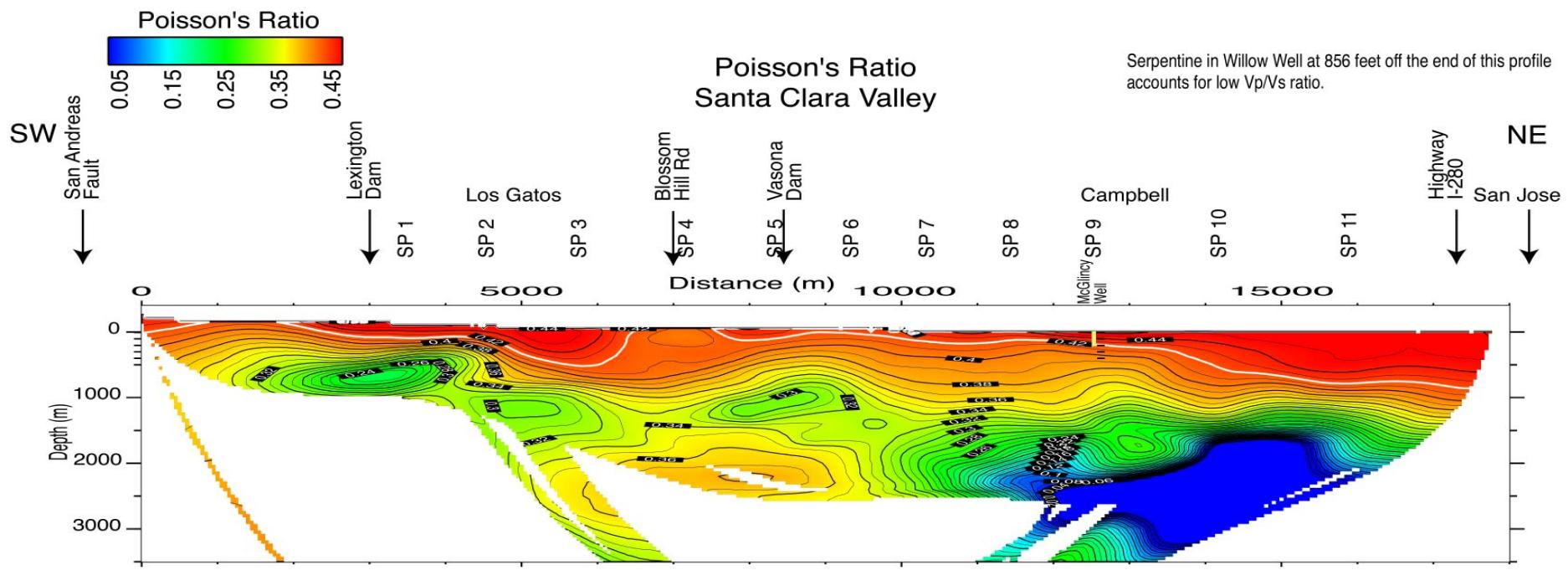
A'

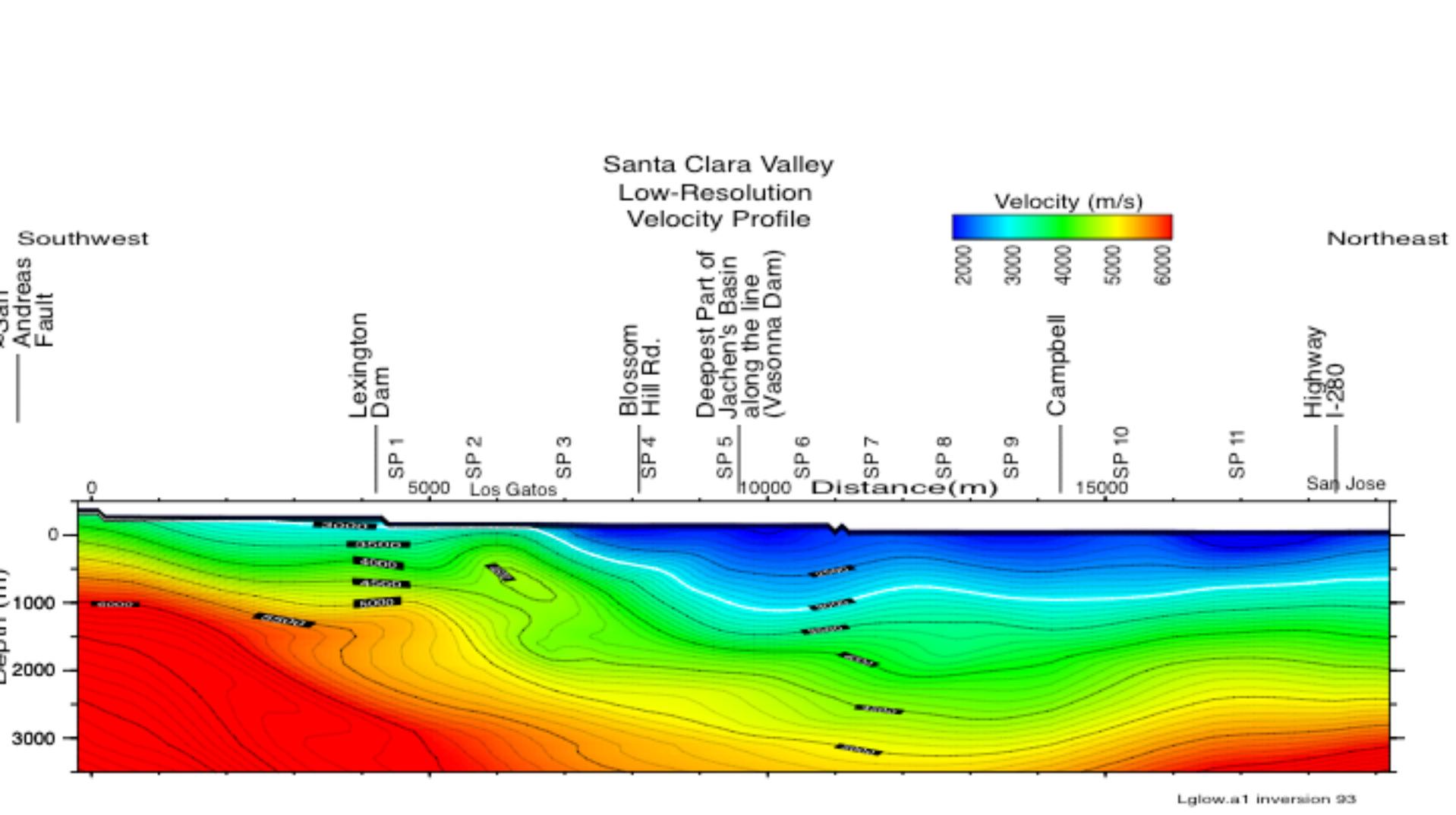
West Side of SAF



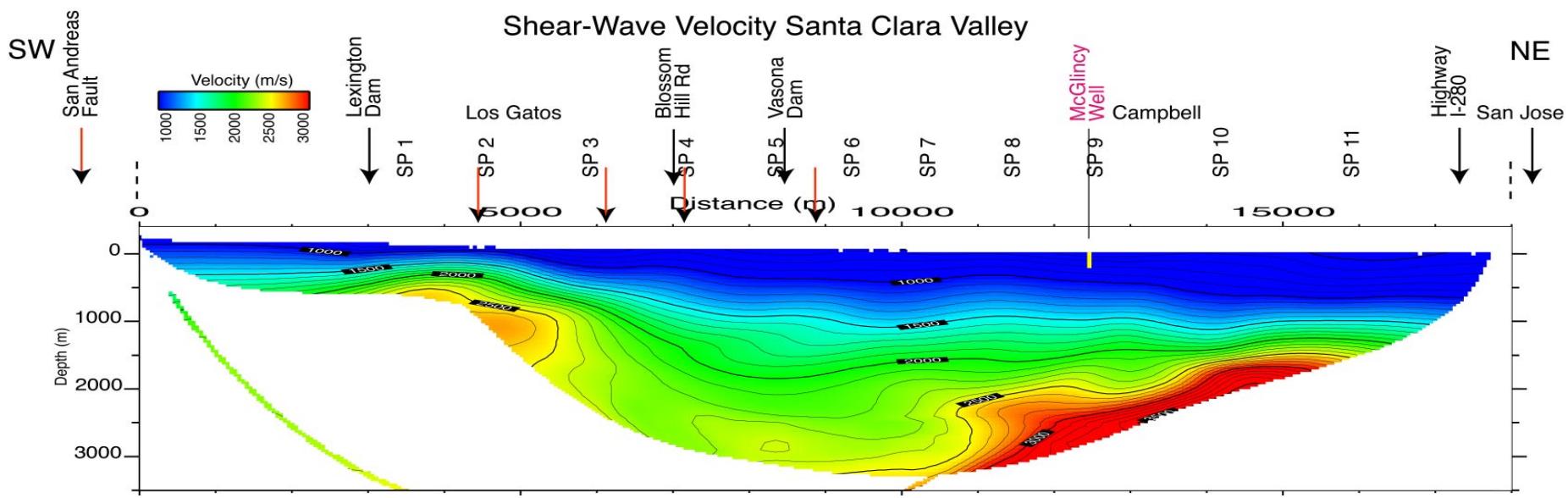


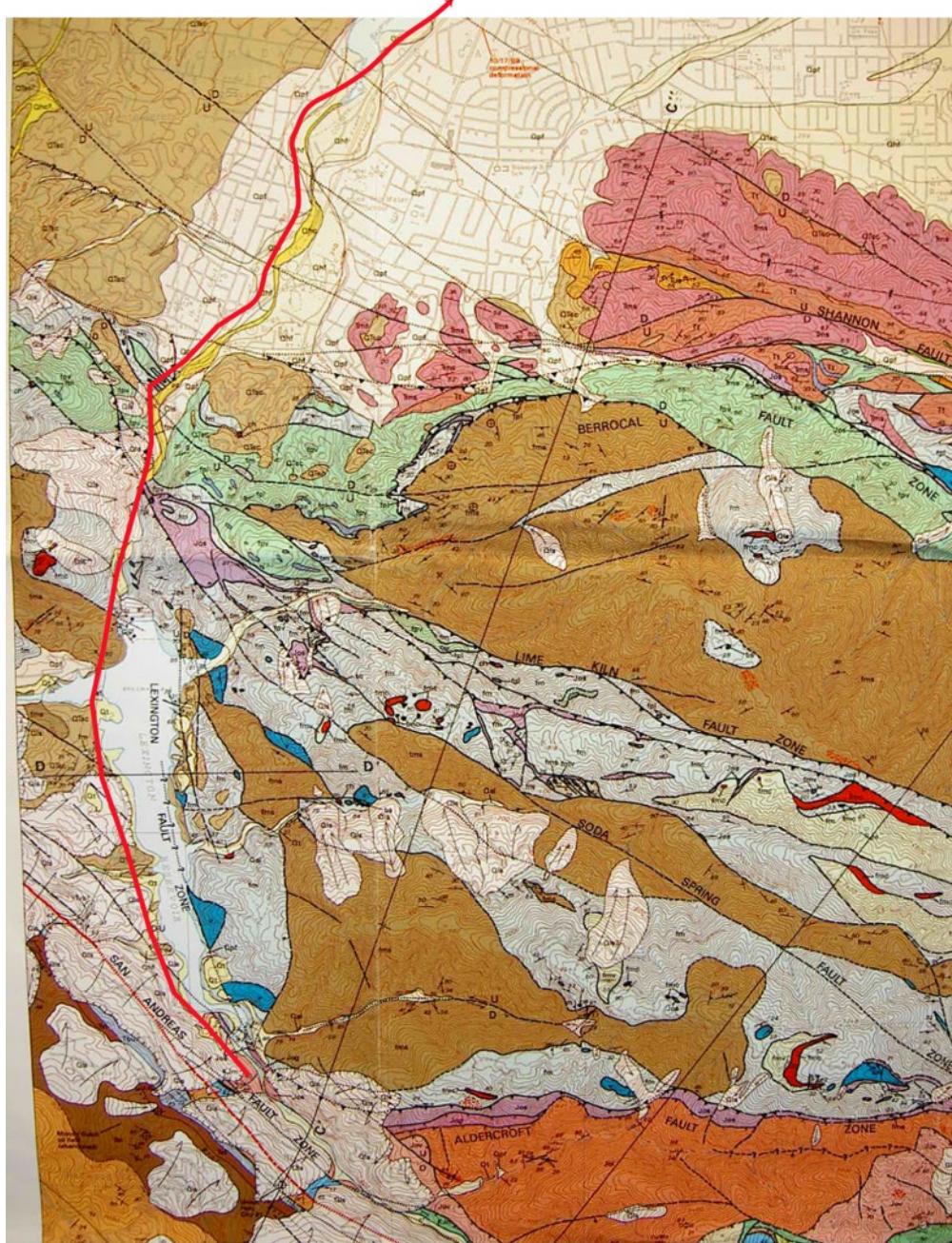






# Vs Model Western Santa Clara Valley

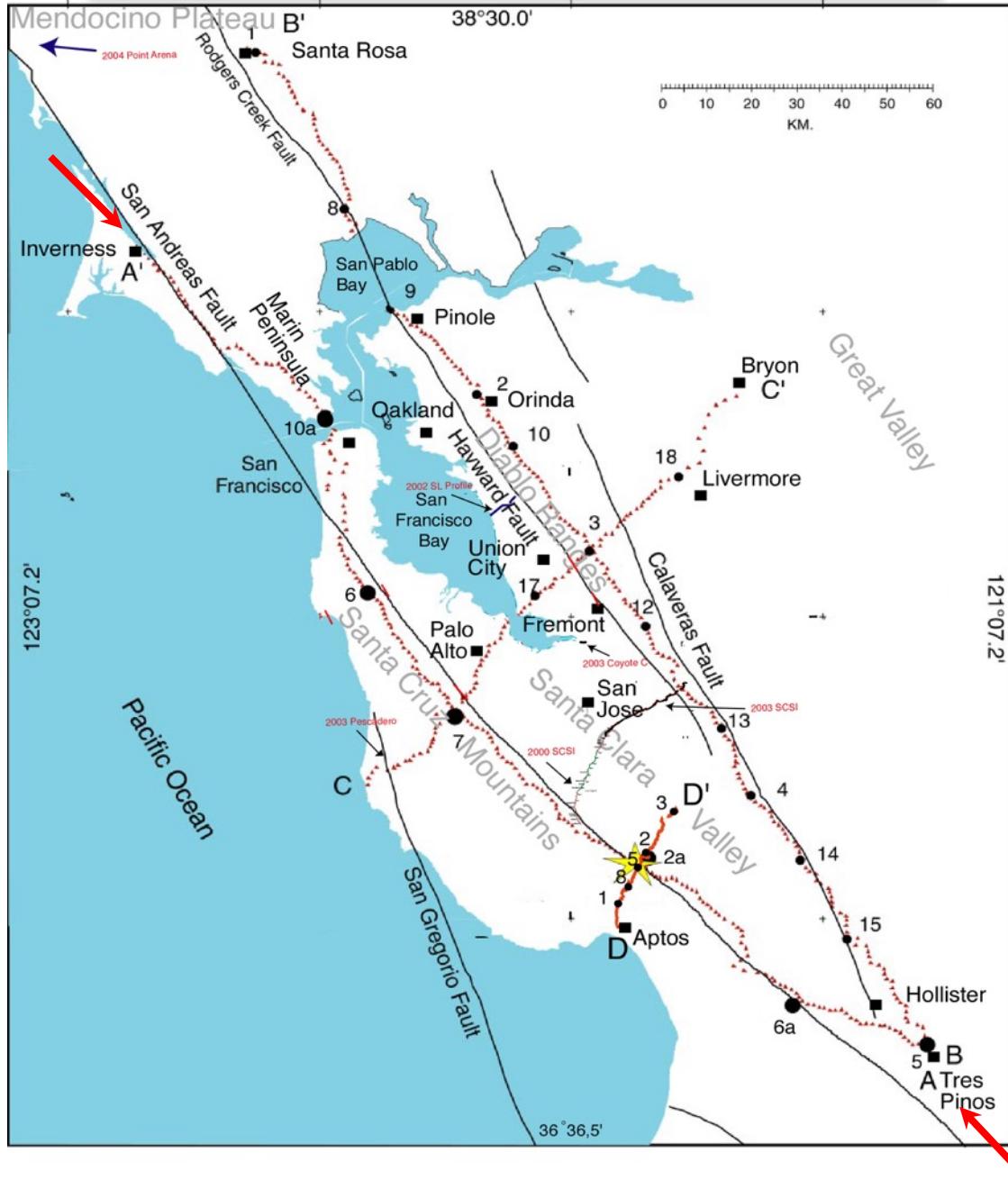




From McLaughlin et al. (2001)

# Deep Seismic Profiles

SF & Marin  
Peninsulas



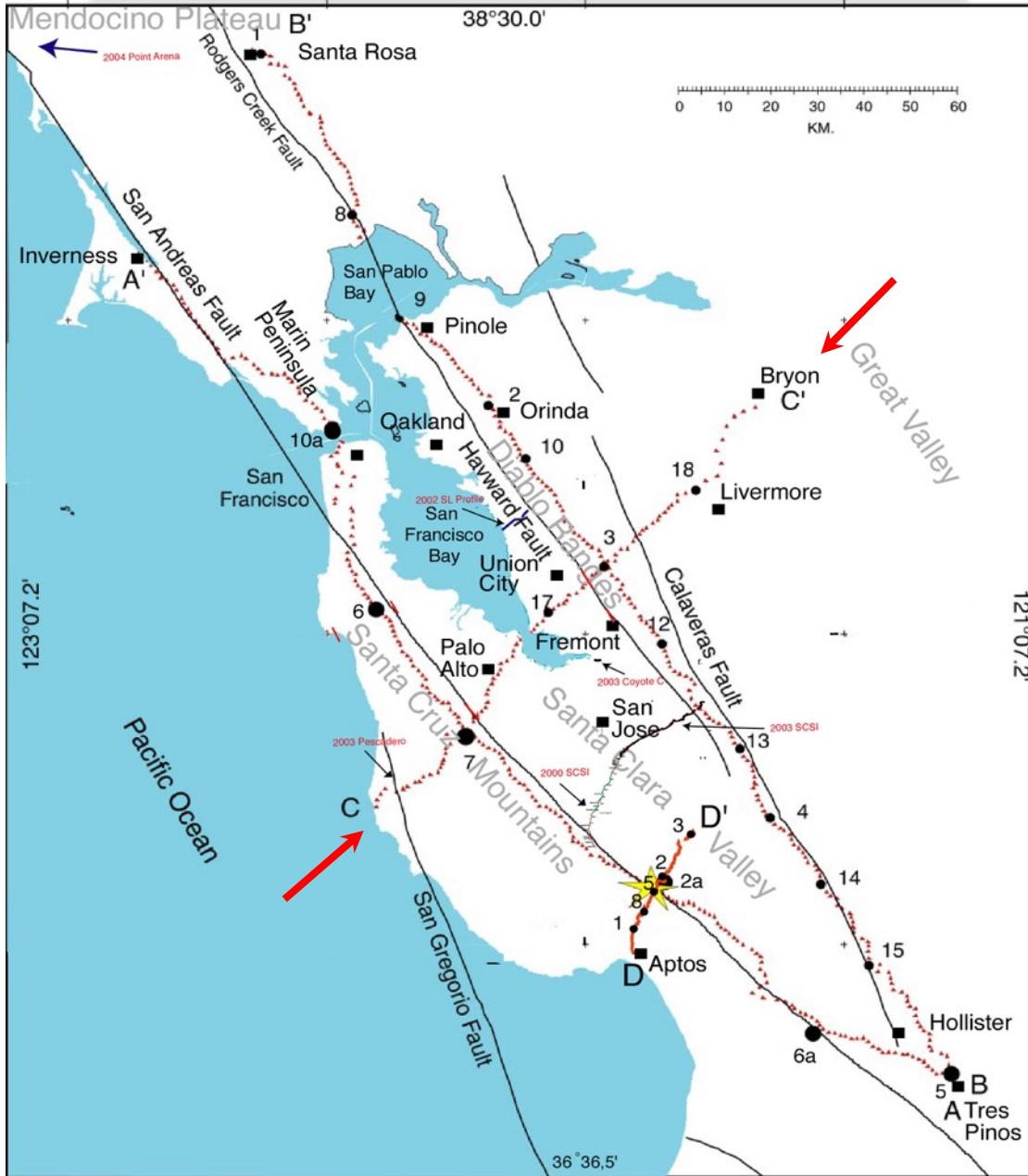
# Deep Seismic Profiles

# East and South Bay Profiles



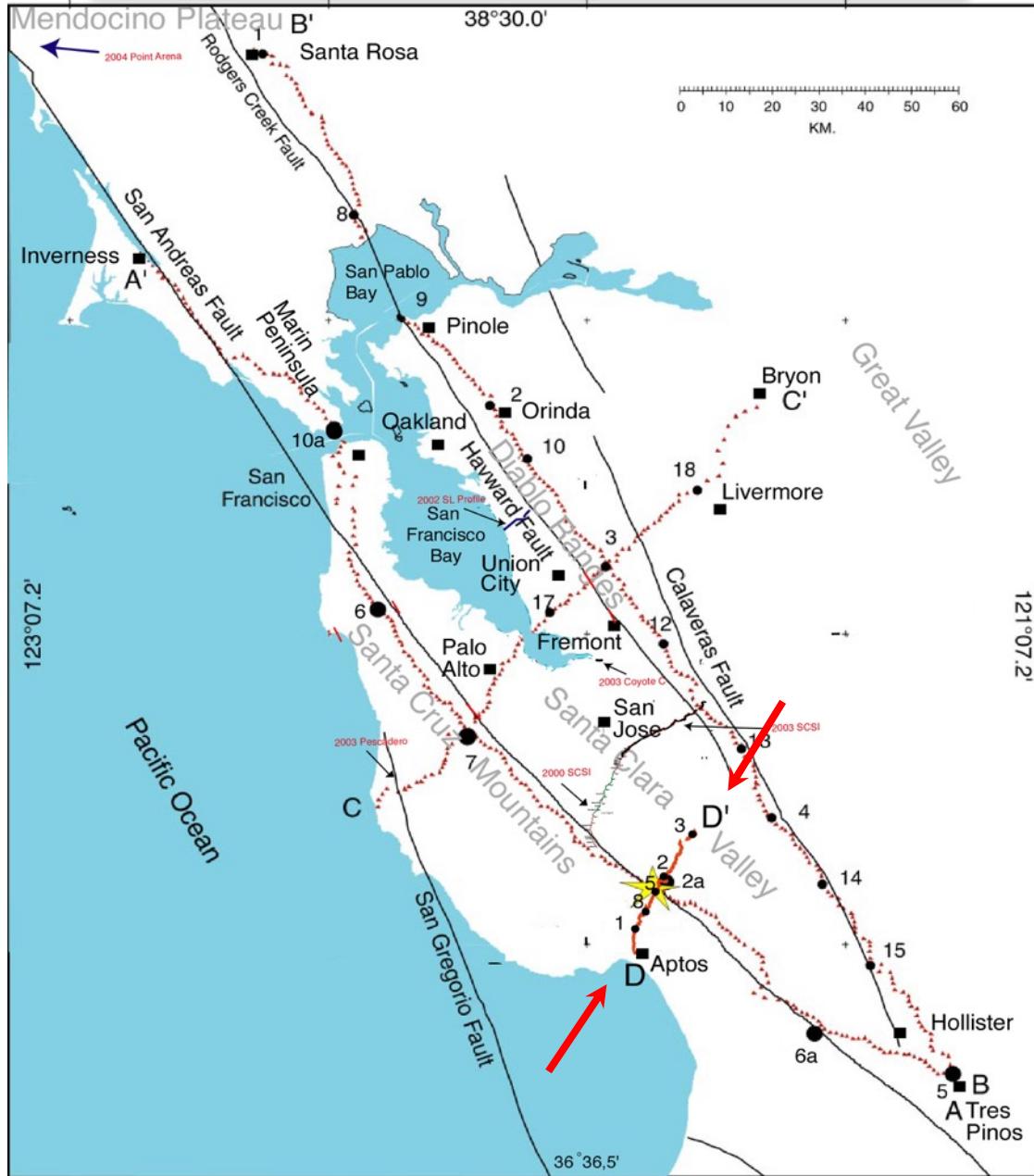
# Deep Seismic Profiles

## Cross-Bay Profile



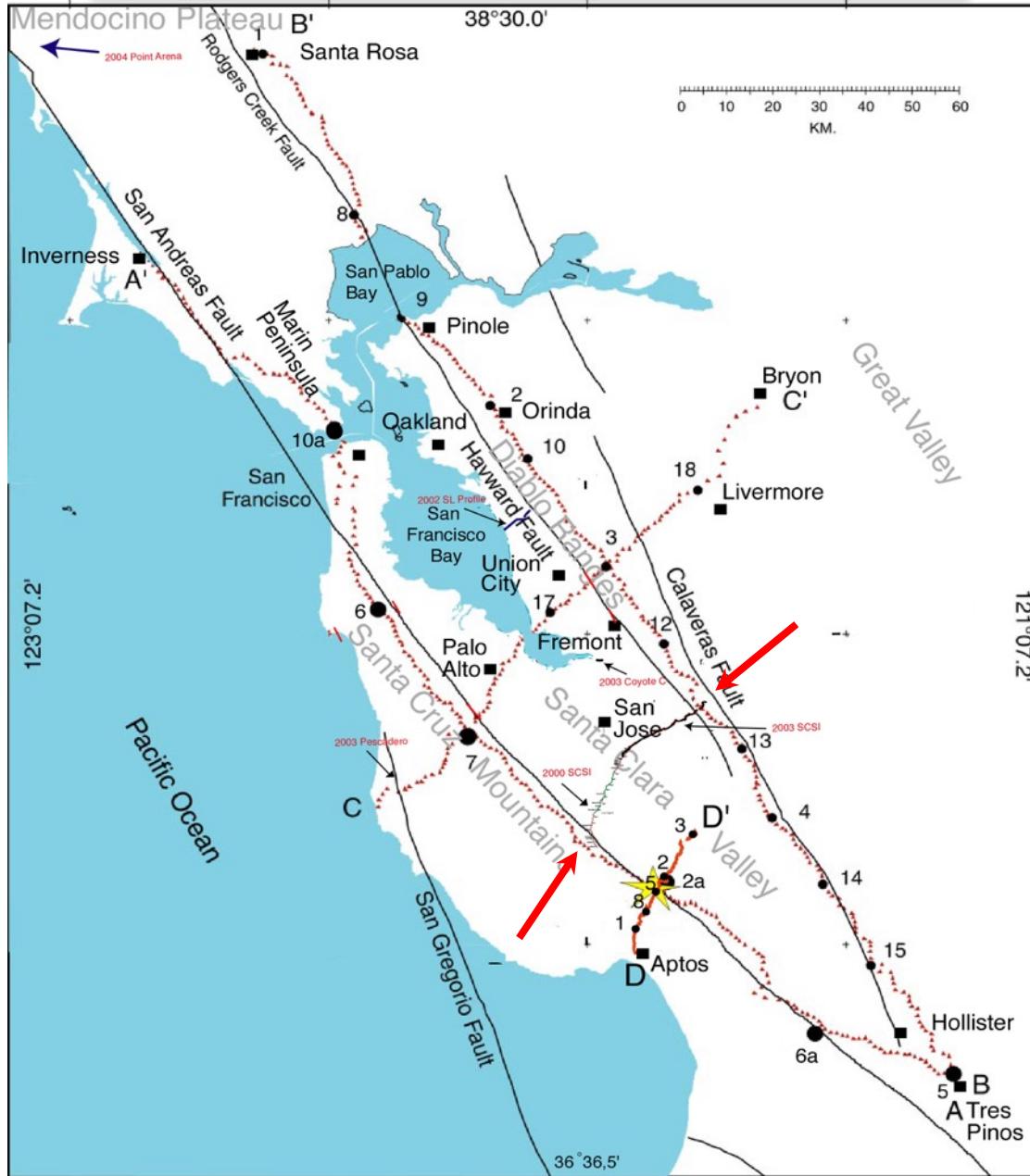
# Deep Seismic Profiles

## Loma Prieta Profile



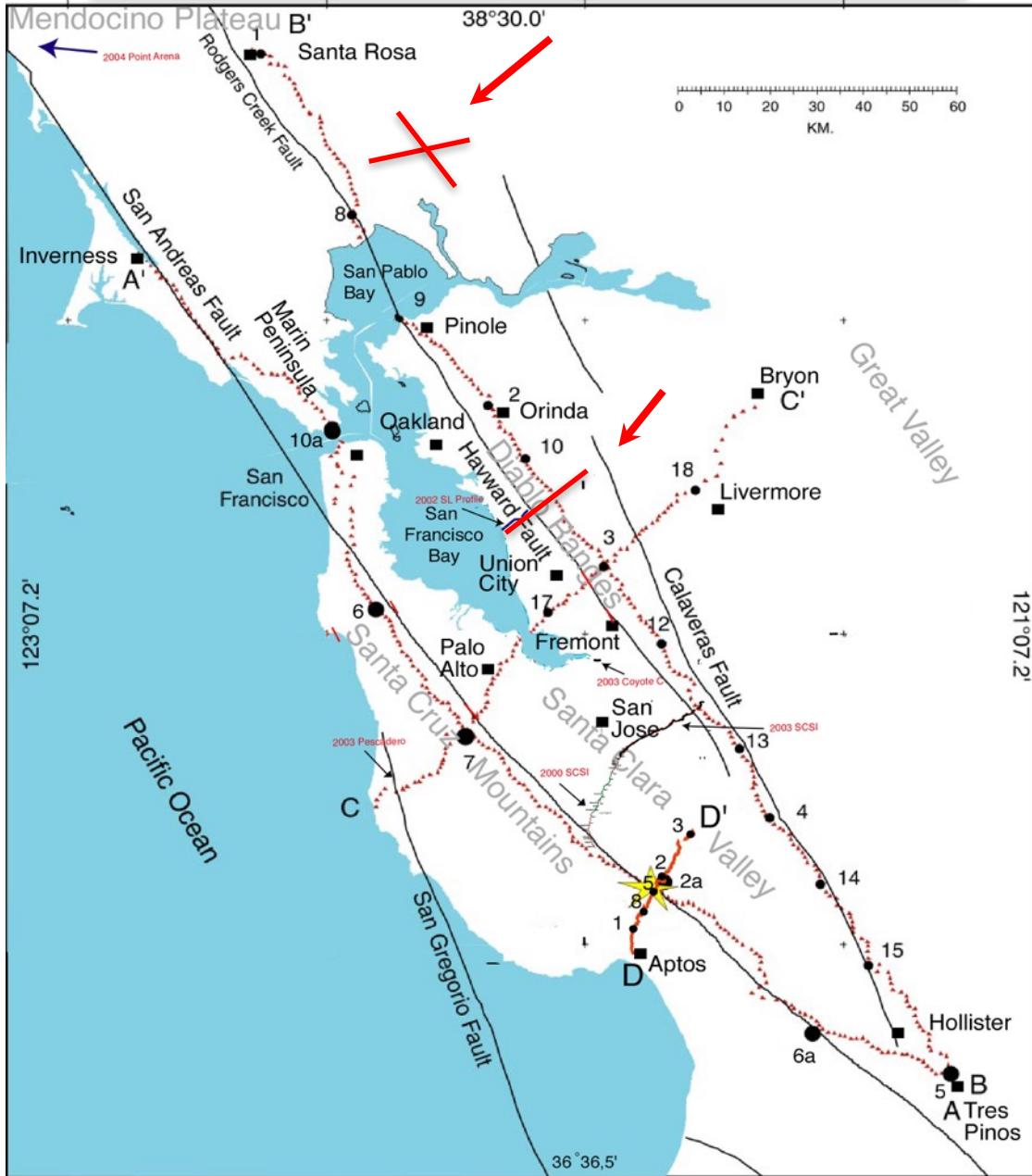
# Deep Seismic Profiles

# Santa Clara Valley Profiles

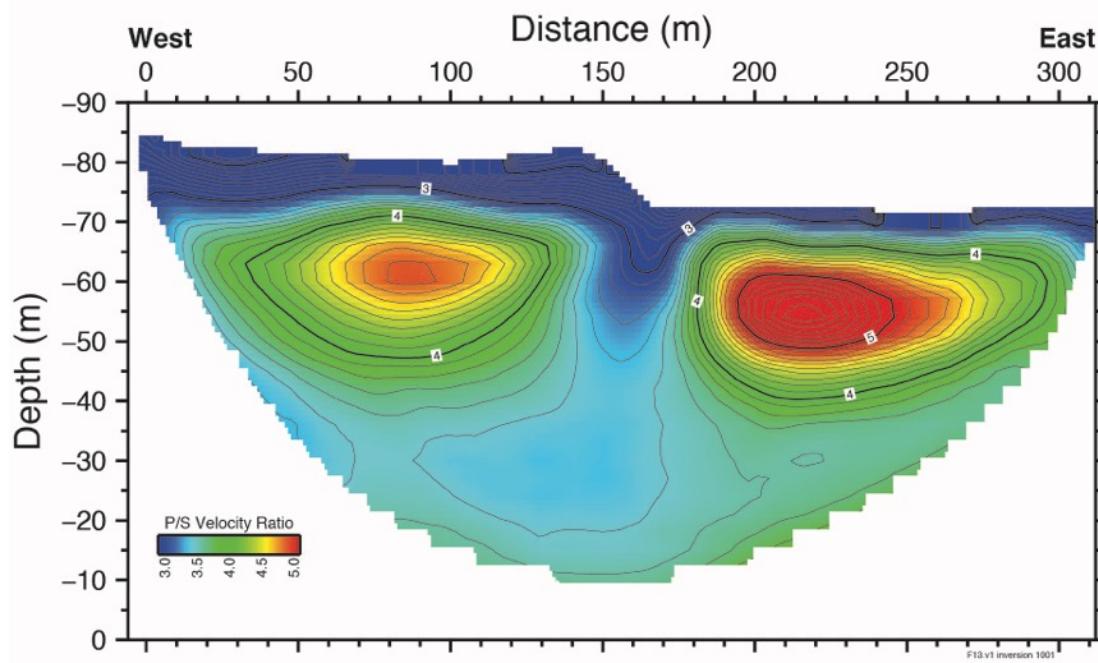
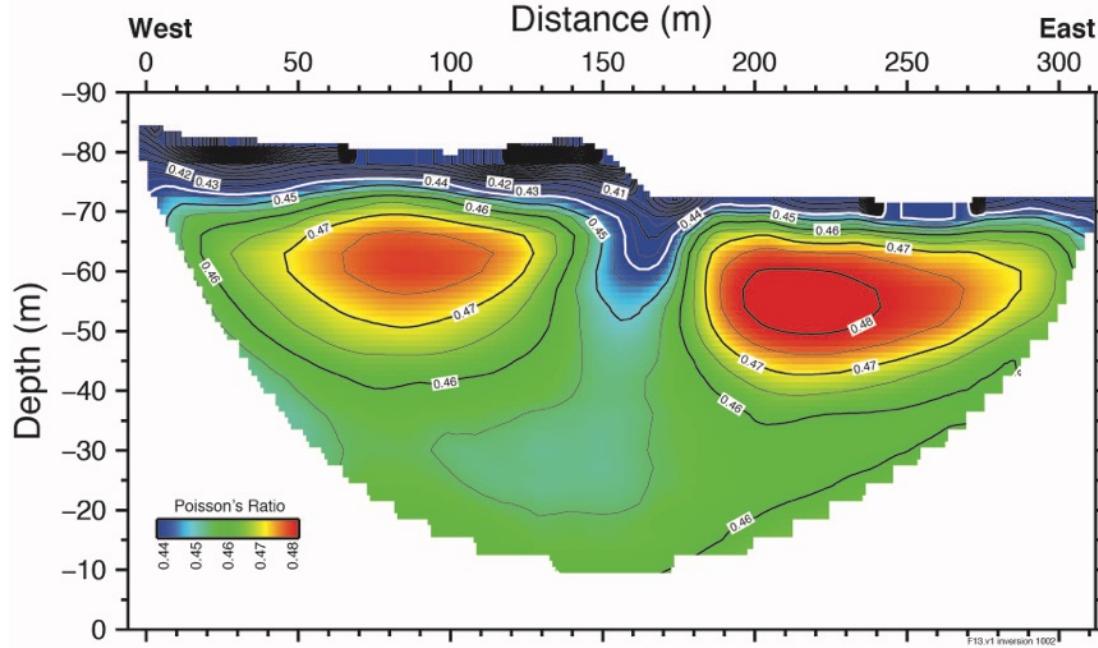


# Deep Seismic Profiles

Napa and East Bay Profiles



And Dozens of  
Shallow-Depth  
Seismic Profiles



# Improving the Existing Bay Area 3-D Velocity Model

## Potential problems with using dominantly gravity- and rules-based models- examples

- All models can be non-unique, but seismic models based dominantly on gravity can be highly non-unique
- Example from Los Gatos