

# SHEAR-WAVE VELOCITY-DEPTH MEASURED FROM MICROTREMOR ARRAY STUDIES for EARTHQUAKE HAZARD AND GEOTECH ENGINEERING STUDIES

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Presented at the Workshop on Coyote Creek Shear Velocity Comparison

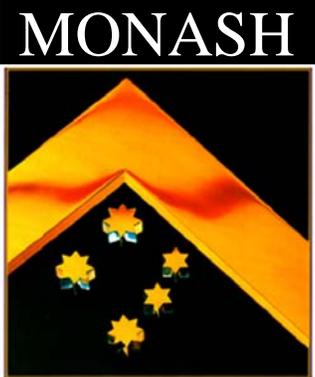
USGS Menlo Park, May 3, 2004



# SOURCES OF MICROTREMORS

Wave propagation principally as surface waves

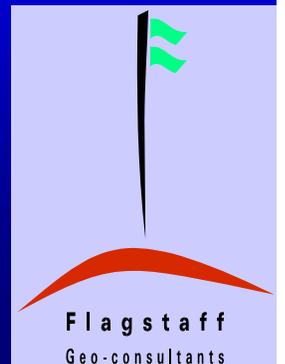
- 0.05-0.5 Hz : Meteorological -  
(eg wave action)
- 1-30 Hz : Cultural -  
vehicles, trains, machinery



# INFORMATION CONTENT OF MICROSEISMS

- spectral maxima indicate resonances which may be used for earthquake-risk site classification
- phase velocity gives thickness and shear-strength of sediments

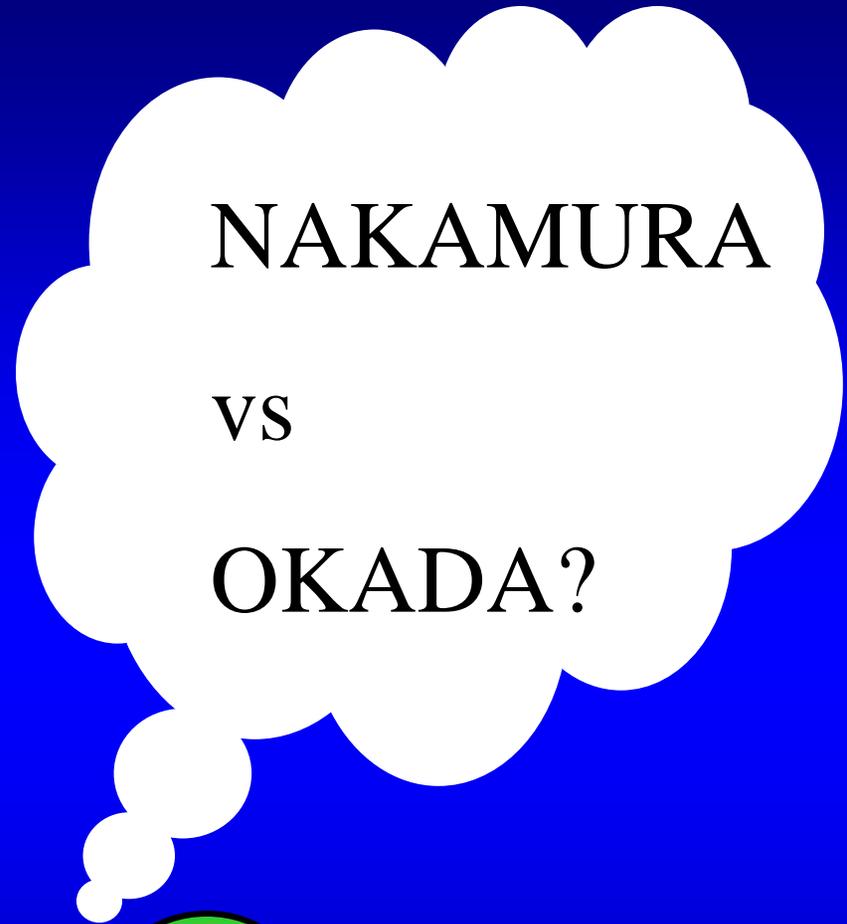
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# INFORMATION CONTENT OF MICROSEISMS

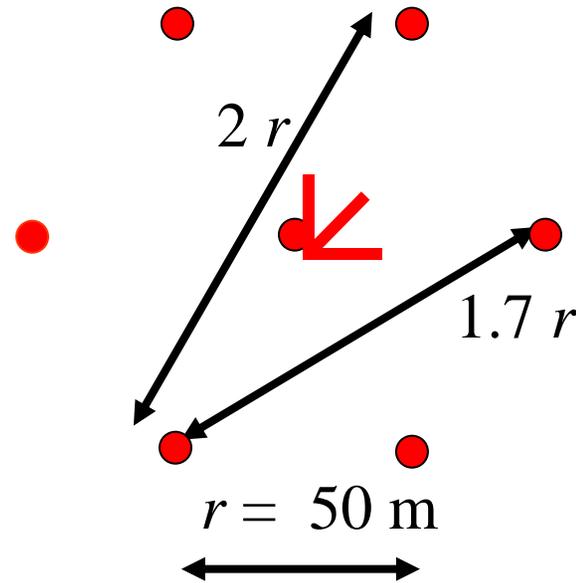
- spectral maxima indicate resonances which may be earthquake risks
- phase velocity gives thickness and shear-strength of sediments

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# INSTRUMENT FOR ARRAY SURVEY

A hexagonal array frequently used in microtremor studies in Australia



6 Vertical seismometers

1 central 3-axis seismometer

9-channel Kelunji recorder

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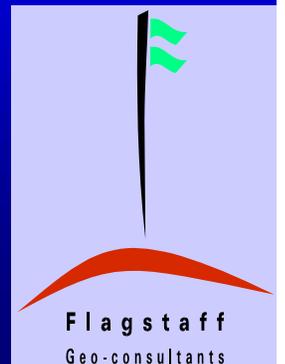
# INFORMATION CONTENT OF MICROSEISMS

- spectral maxima indicate resonances which may contribute to earthquake risk
- phase velocity gives thickness and shear-strength of sediments

NAKAMURA  
AND  
OKADA!



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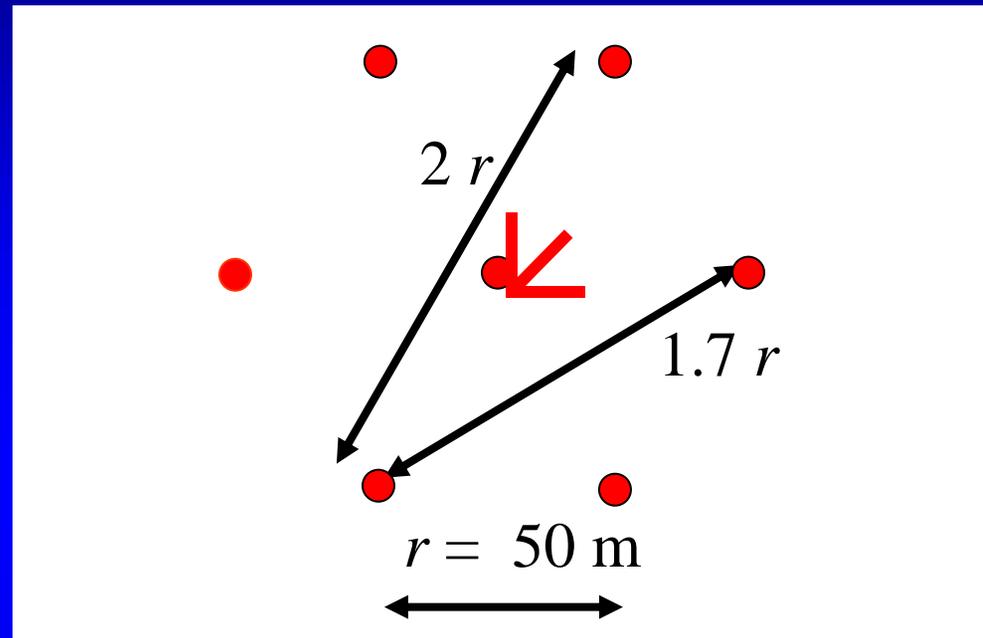
# MEASUREMENT OF PHASE VELOCITY WITH AN ARRAY

- Beam-forming - good for sources with defined direction (eg Liu et al 2000)
- Spatial auto-correlation or Spatially Averaged Coherency (SPAC) - good for omni-directional sources

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# PROCESSING OF ARRAY DATA



## Spatially Averaged Coherency (SPAC)

- Compute inter-station coherencies
- spatially average around the circle

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# Spatial auto-correlation (SPAC)

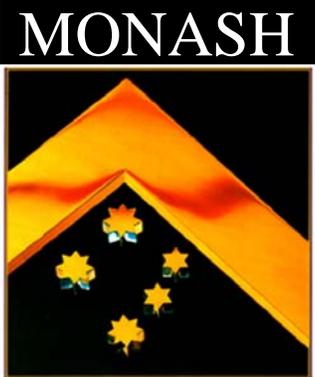
- good for omni-directional sources

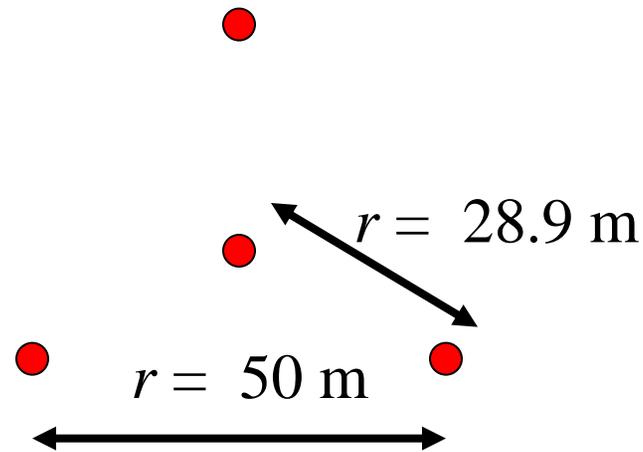
For a plane wave passing pairs of stations, *averaged in azimuth*  $\theta$ , gives

$$\bar{\rho}(f) = \int e^{i k \cdot r} d\theta = J_0(k \cdot r),$$

where  $k = 2\pi f / C$ .

(Aki, 1957, 1965)





The simplest array of 4 stations, for SPAC processing. Range of  $r$  may be 5 to 100 m.

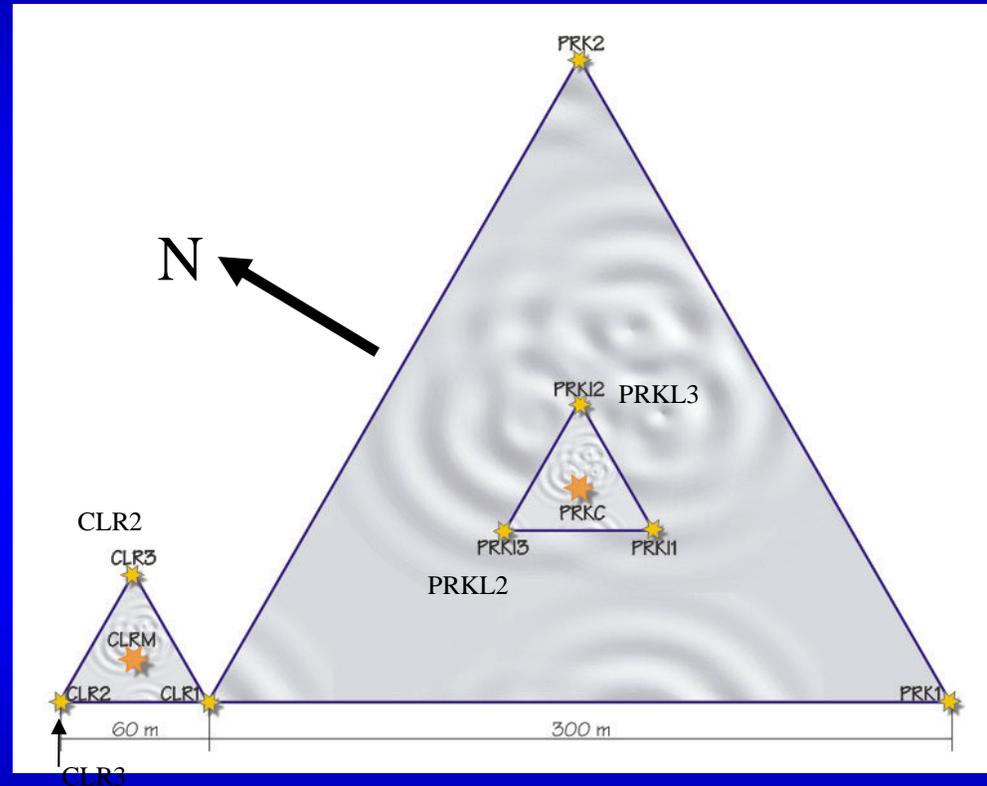
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# COYOTE ARRAY GEOMETRY

(after Hortencia Flores)

Array of seven seismometers used in microtremor observations at the Coyote Creek (William Park) site, Santa Clara Valley CA.

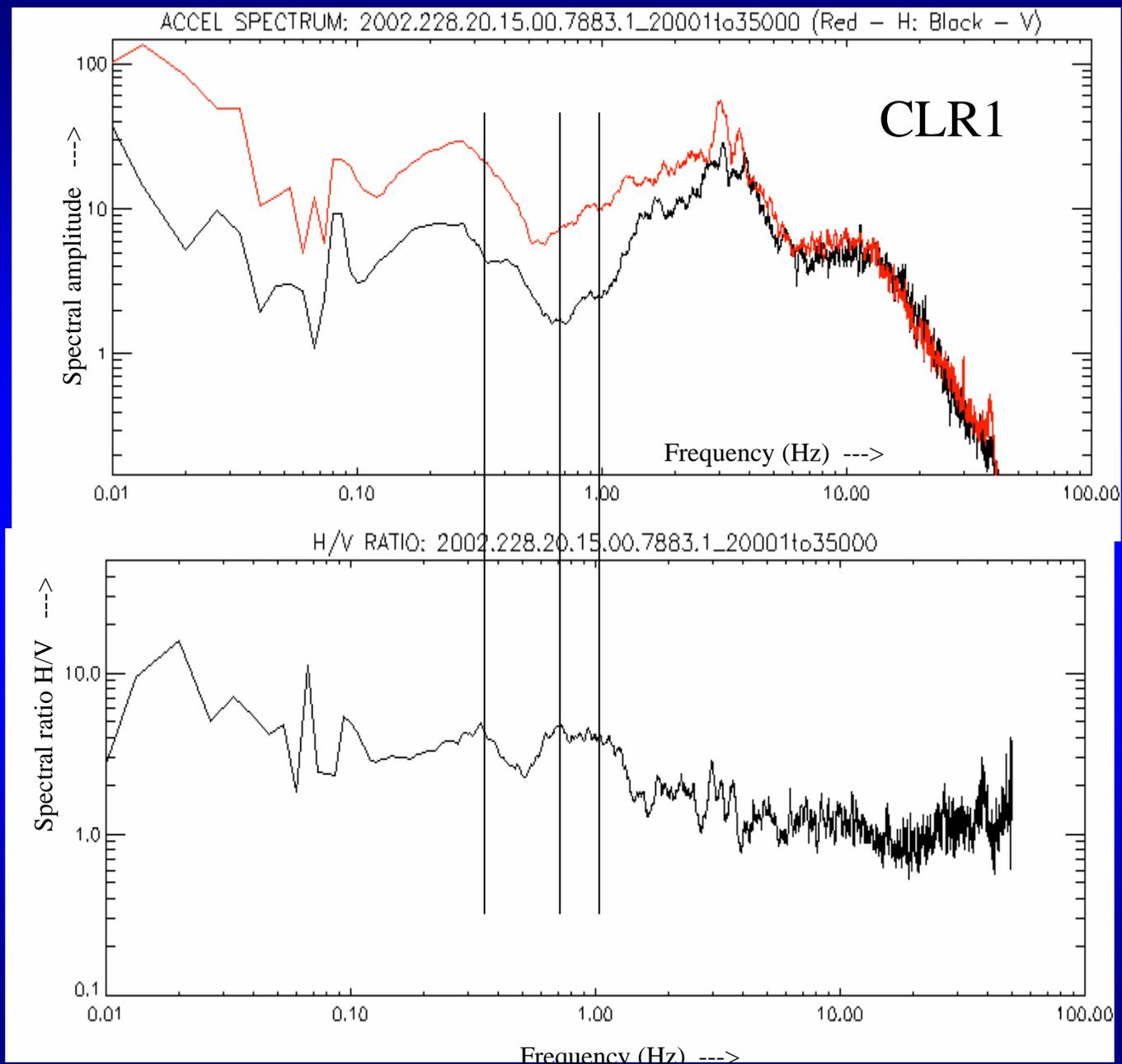


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# COYOTE SPECTRA

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# COYOTE SPECTRA

-From

-NNW

-To SSE

-Changes from NNW to

-SSE are slight, so geology

-appears to be 1D

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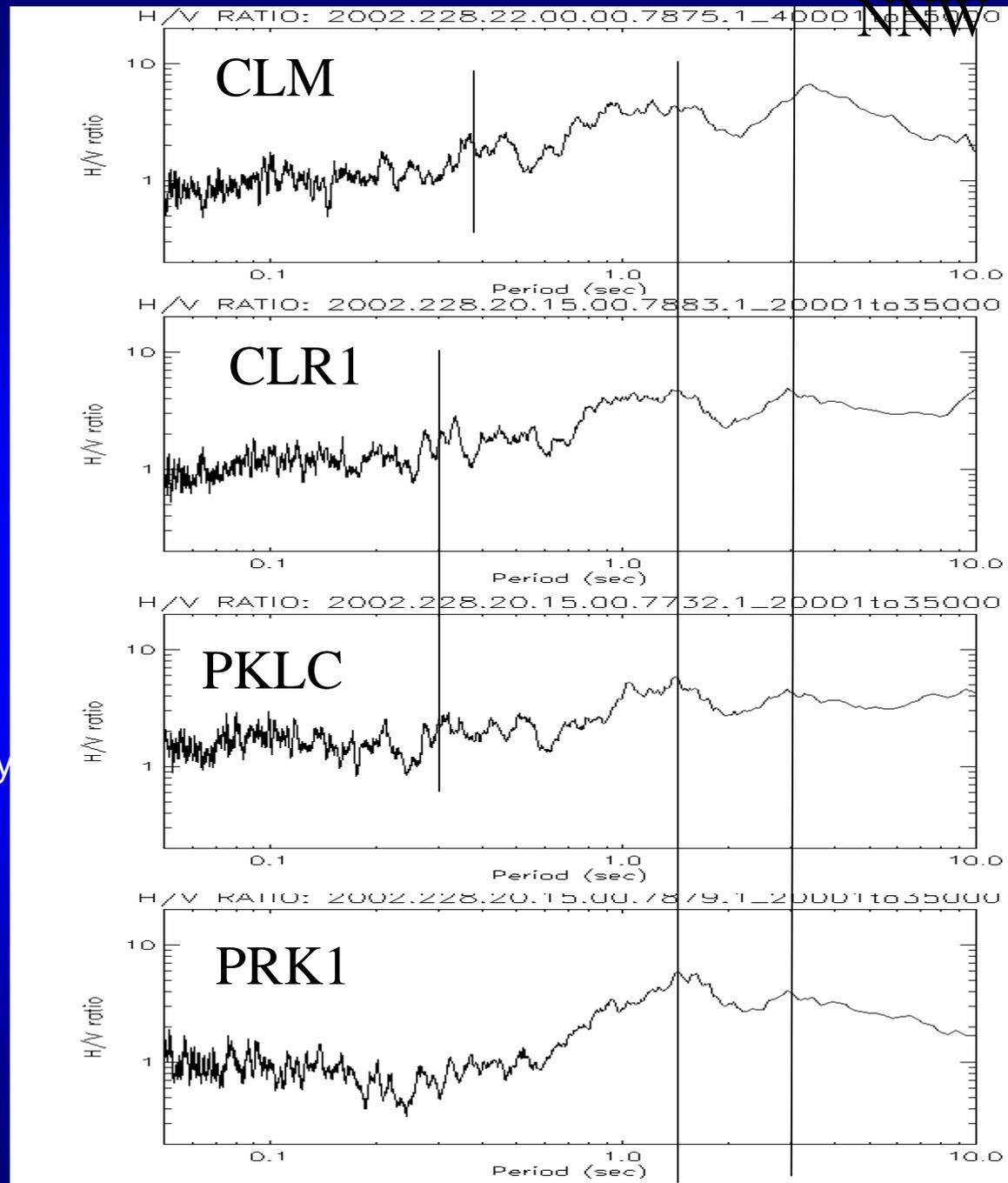
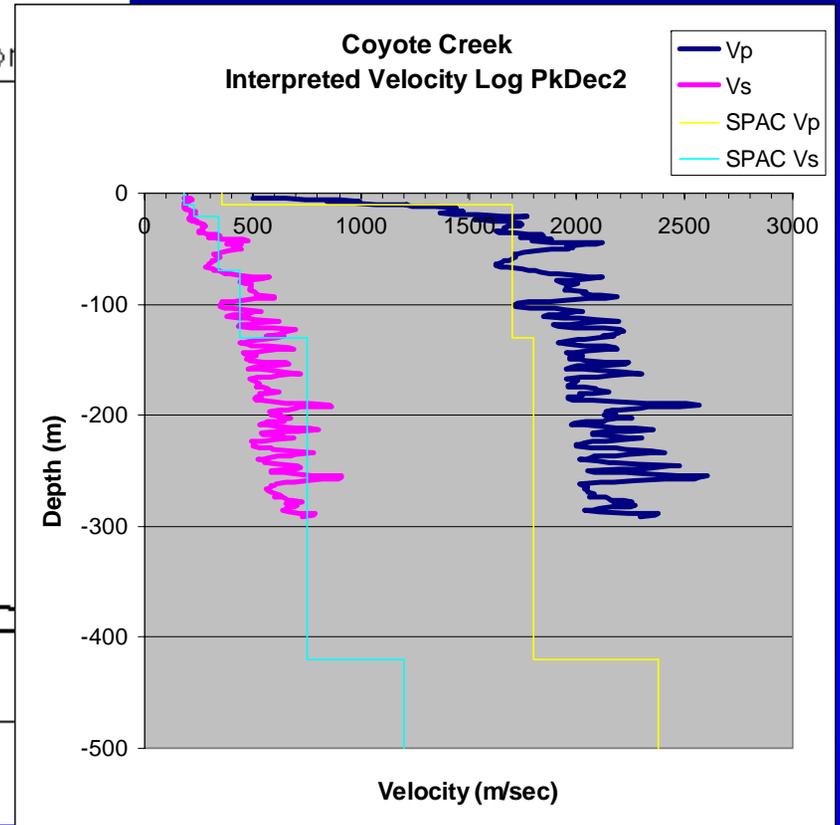
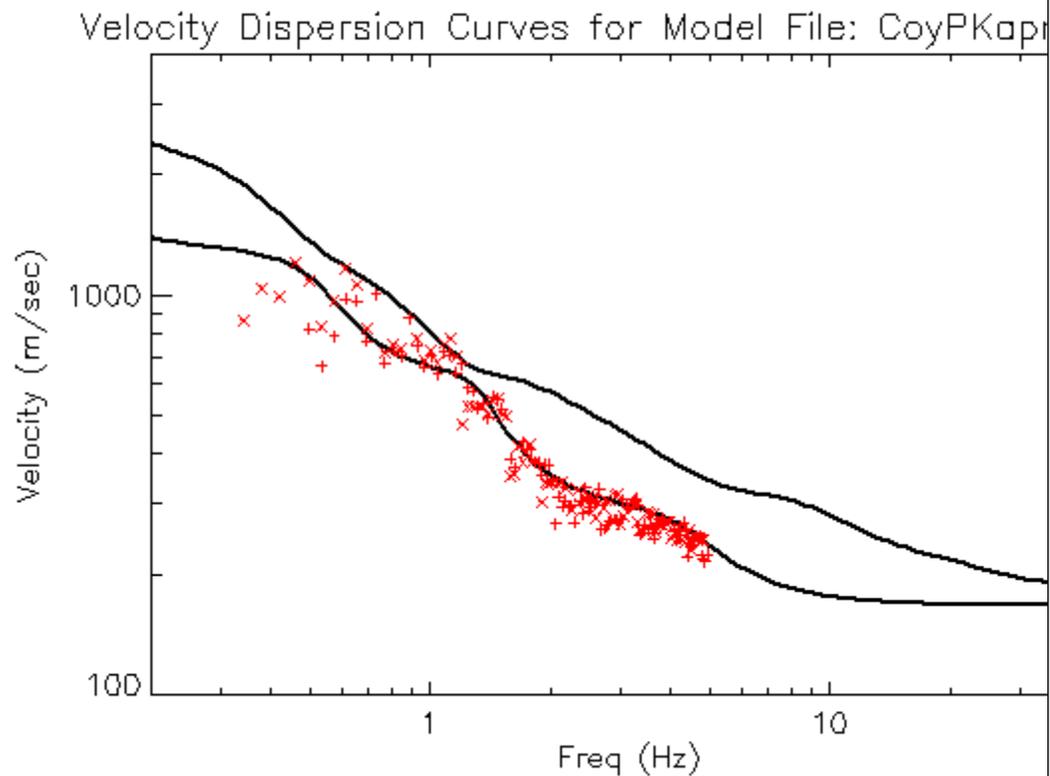


Fig. 4. Comparison of H/V spectra across the arrays from NNW to SSE.

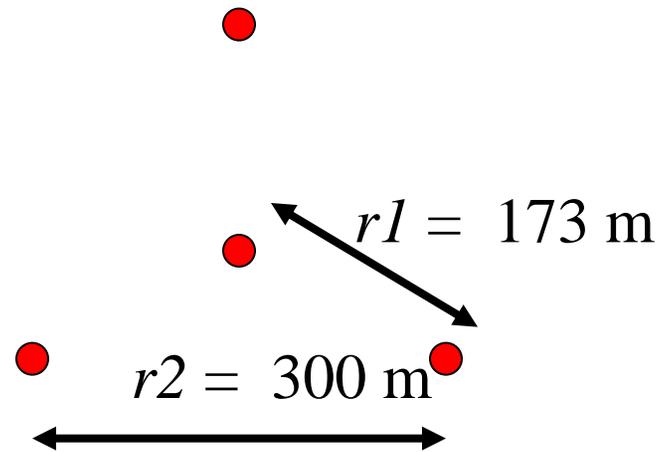
# COYOTE INTERP: BEST “BLIND” RESULT



Interpretation of velocities from SPAC data for the large array (300 m side-length). At right is the interpreted layered-earth model produced “blind”, ie without knowledge of geology or velocity logs in the borehole.

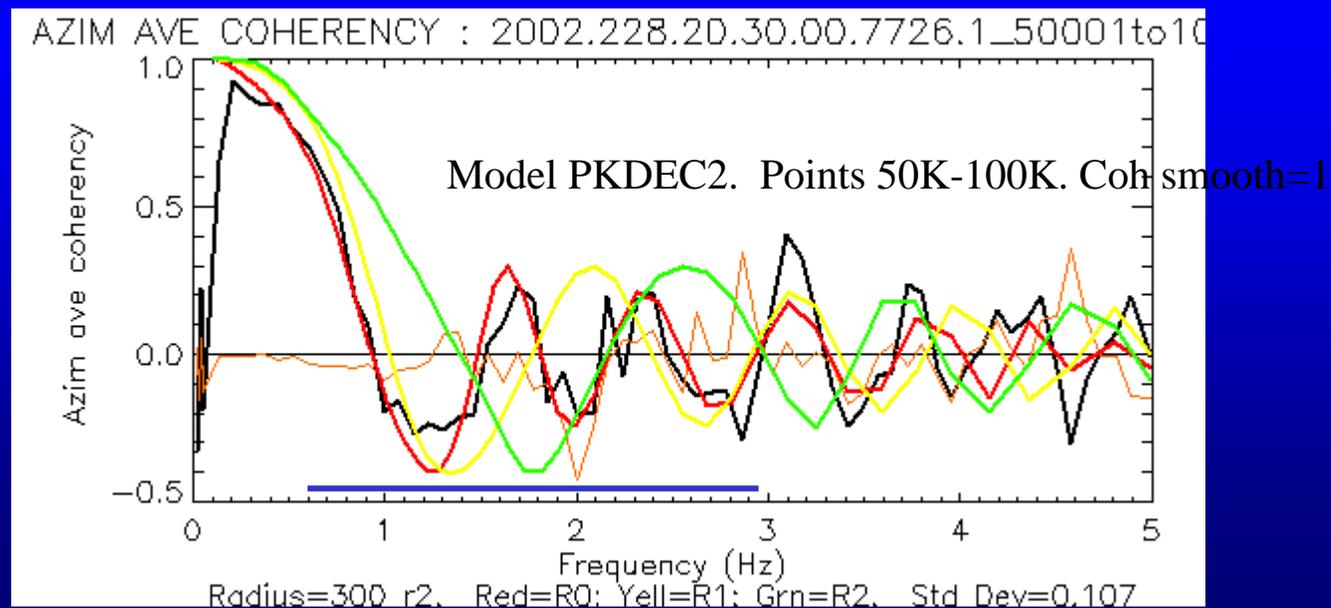
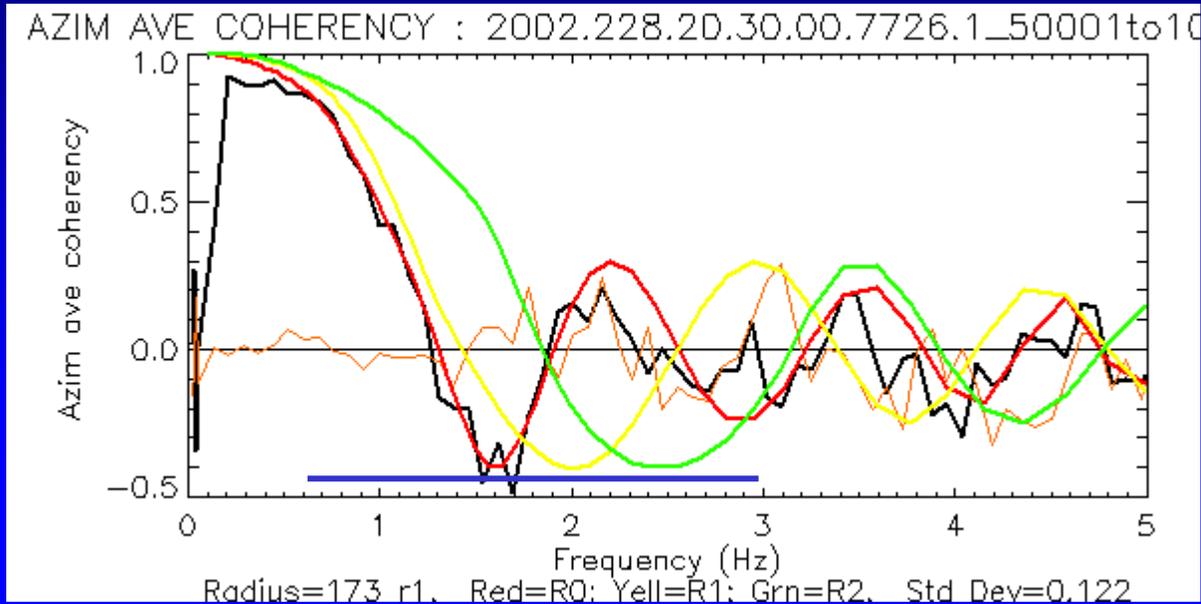
Superimposed on the layered earth model is the S and P-wave velocity logs, supplied after completion of the “blind” interpretation.

# COYOTE INTERP: BEST "BLIND" RESULT



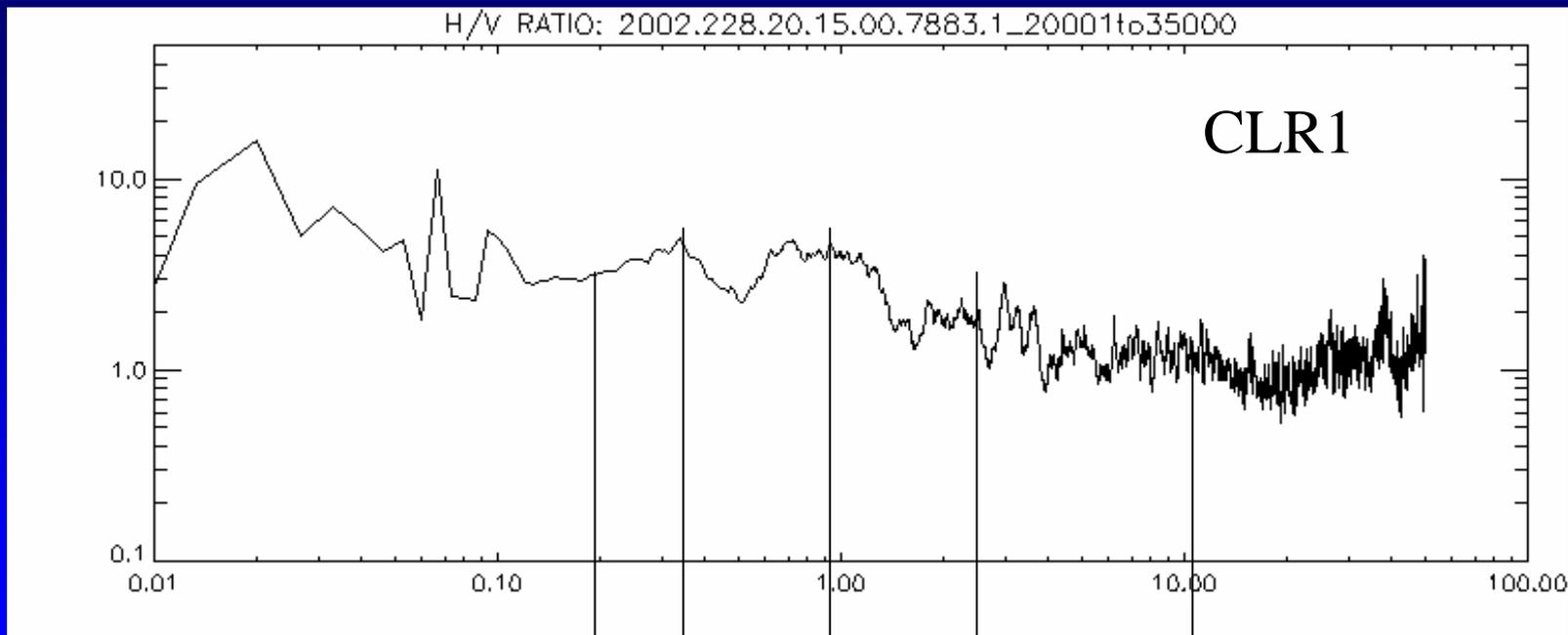
# COYOTE INTERP: BEST "BLIND" RESULT

The process of interpretation. Curve fitting of observed SPAC coherency spectra with modelled SPAC spectra is performed in coherency space (not in velocity space as is done in most other papers on the SPAC method).



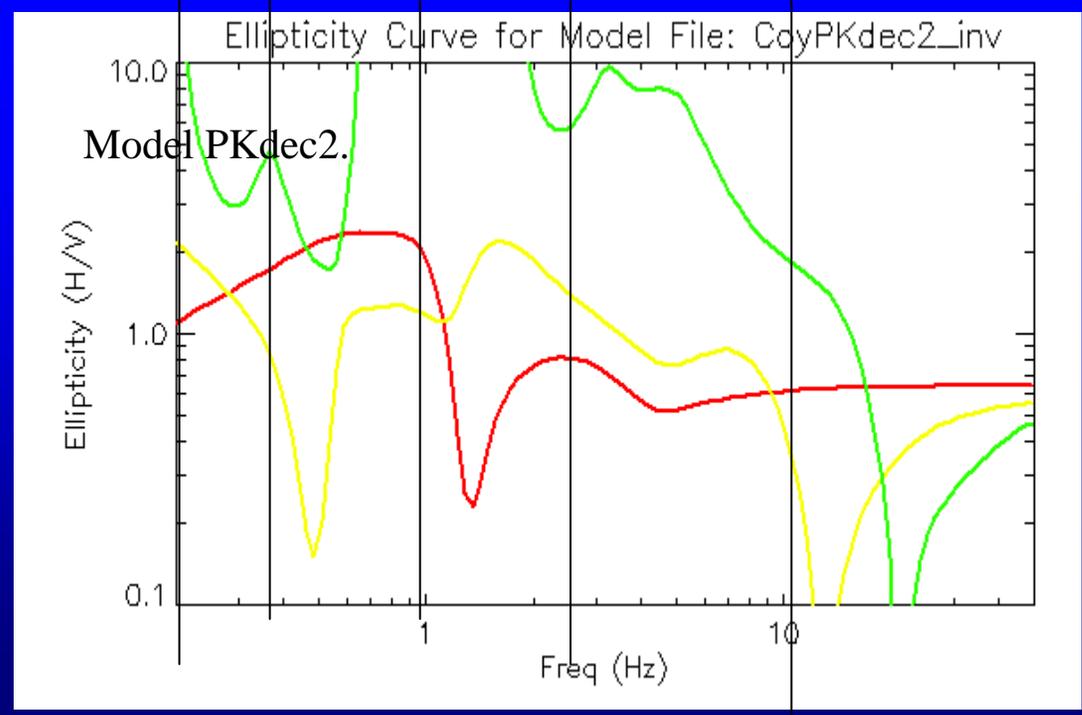
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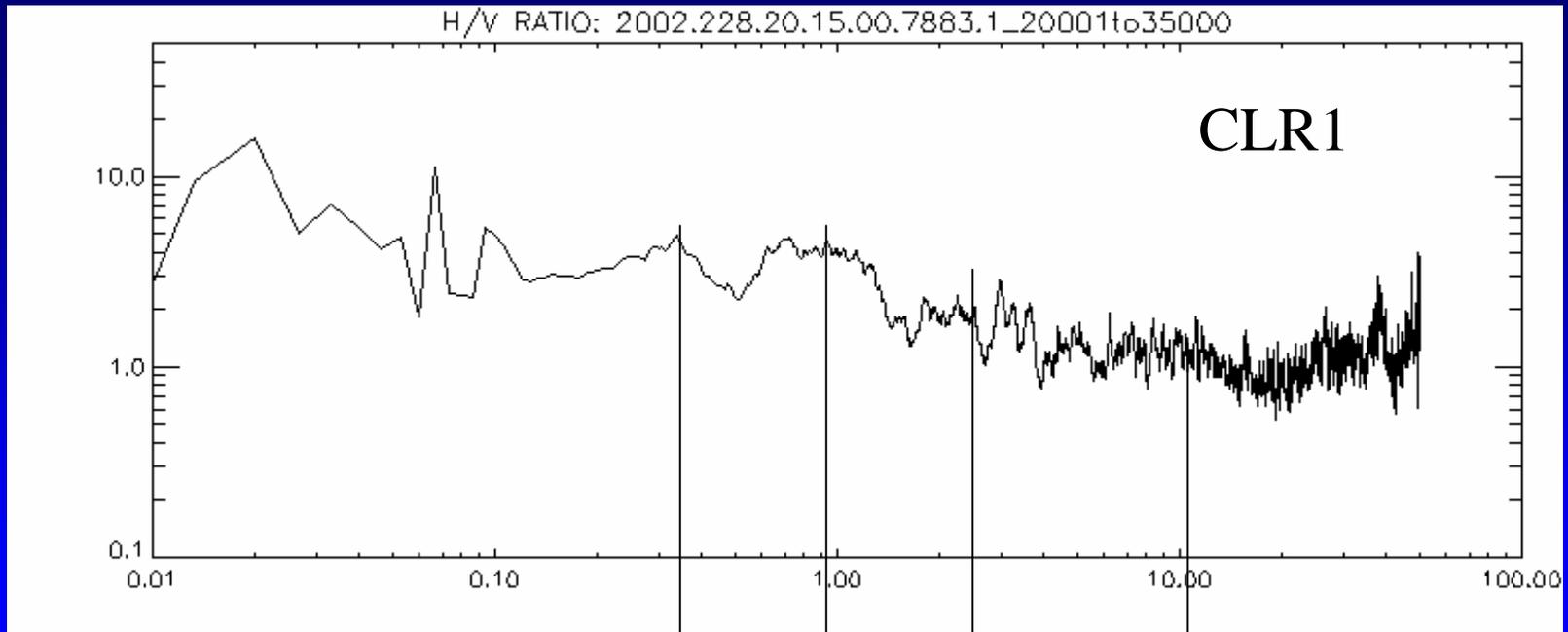
## COYOTE SPECTRA

- H/V for model PKdec2 (the “blind” model) and observed spectra fails to match



## COYOTE SPECTRA

- The failure of the “blind” model to match the H/V spectra poses questions requiring a re-interpretation of both the SPAC and H/V spectral data. The following slides show a modified layered-earth model which allows both SPAC and H/V to match model and field observations. This second phase of modelling was performed after geological and P-S logs for the Coyote water bore were made available.



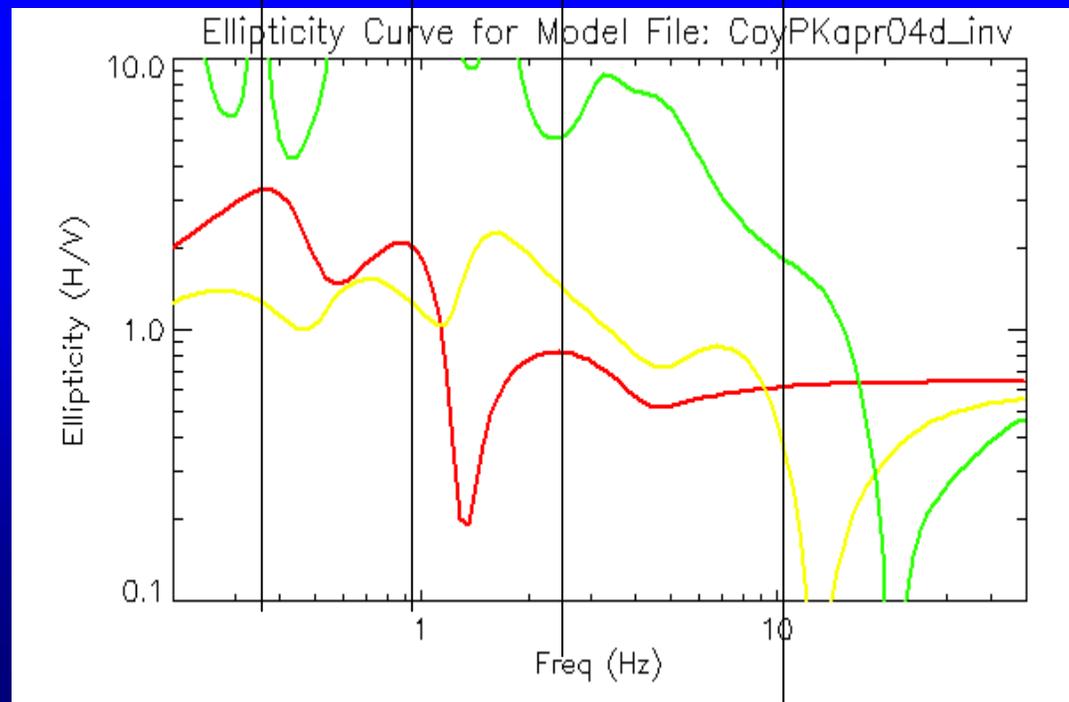
# COYOTE SPECTRA

- H/V “new” model  
Pkapr03e

Matches spectra

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AND  
SPAC



# COYOTE SPAC INTERPRETATION

## PARAMETER SENSITIVITY STUDY

-Each layer velocity is varied by  $\pm 5\%$  or  $10\%$ , and the change in the resulting fit of coherency spectra is computed as an rms error, computed over a specified frequency band (shown as the blue bar on following plots). The rms error is shown as "StdErr=" at bottom right of each plot.

-It is found that a change of order  $10\%$  in the rms error corresponds to a significant mis-fit in the coherency curve match. This allows estimation of error bounds on the velocity Vs parameters for the layers.

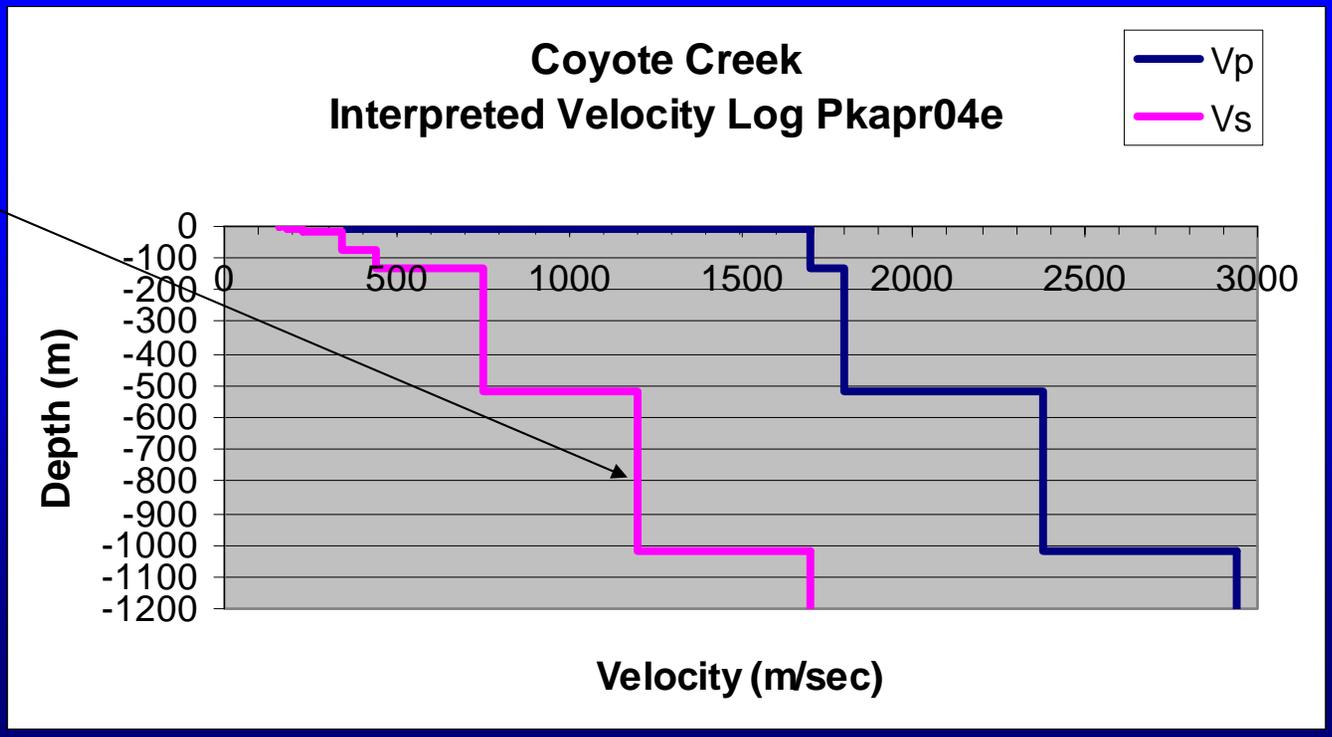
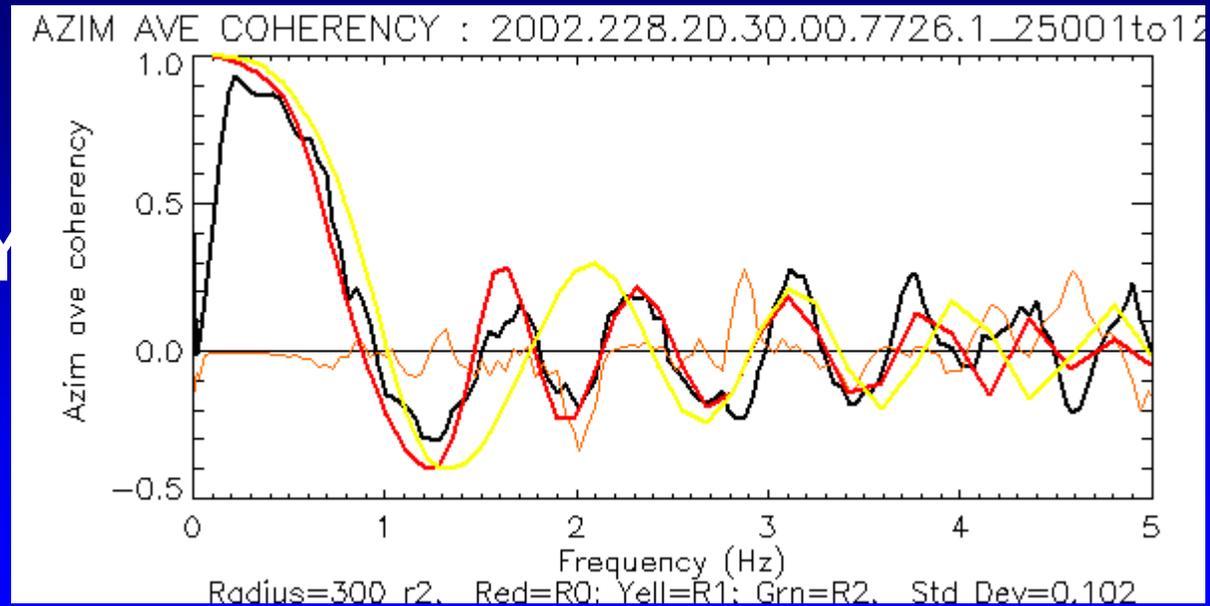
-In other cases a change in a parameter gives rise to a noticeable shift in one or more peaks or troughs in the SPAC spectrum; a shift giving a visibly poor match is also an indicator used for estimation of error bounds on the Vs parameters for the layers.

# COYOTE SENSITIVITY STUDY

Layer 7

Resolved  
ONLY from  
H/V spectra

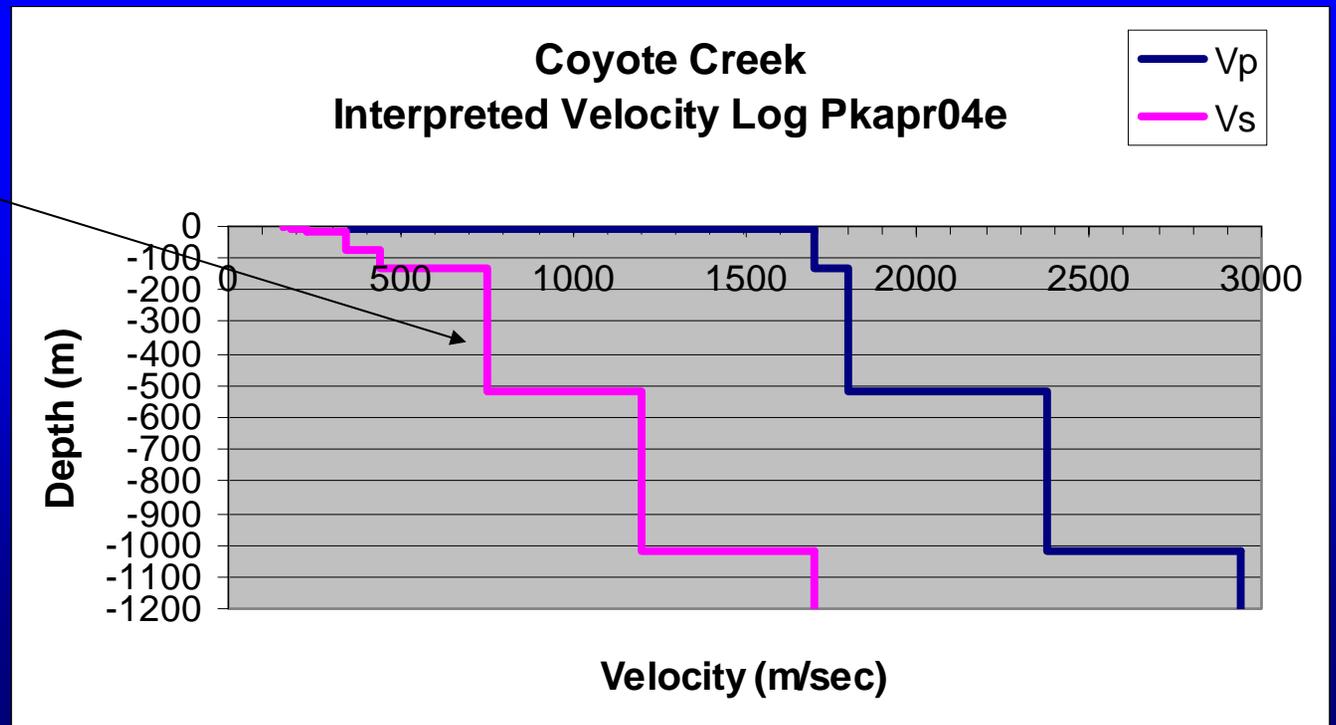
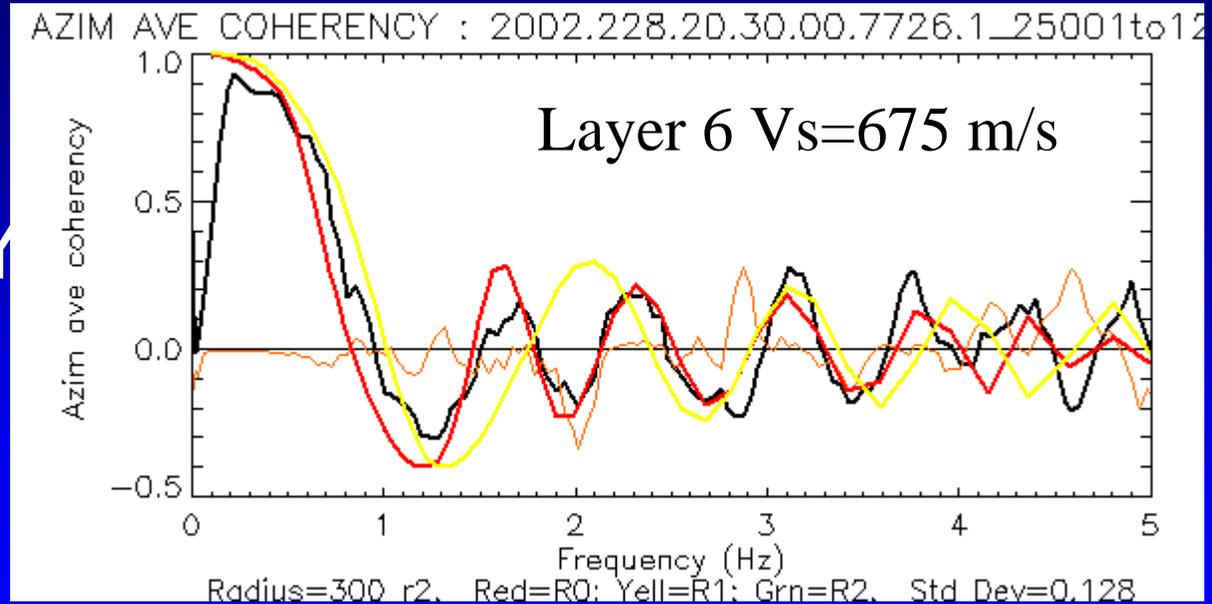
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# COYOTE SENSITIVITY STUDY

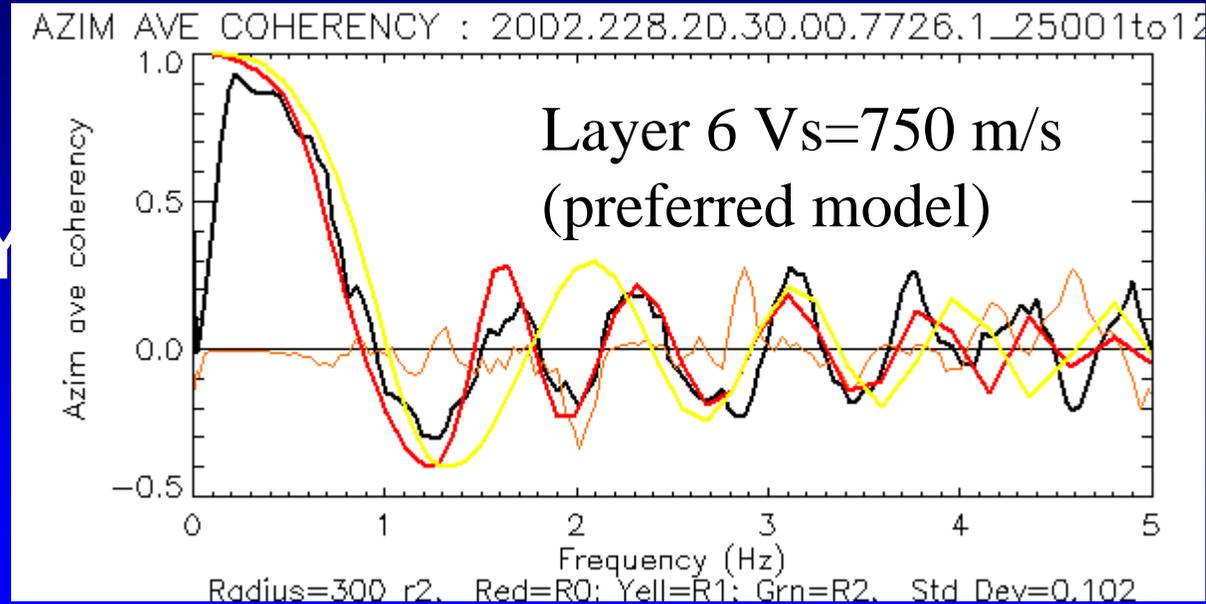
Layer 6  
Resolved  
between 675  
and 900 m/s

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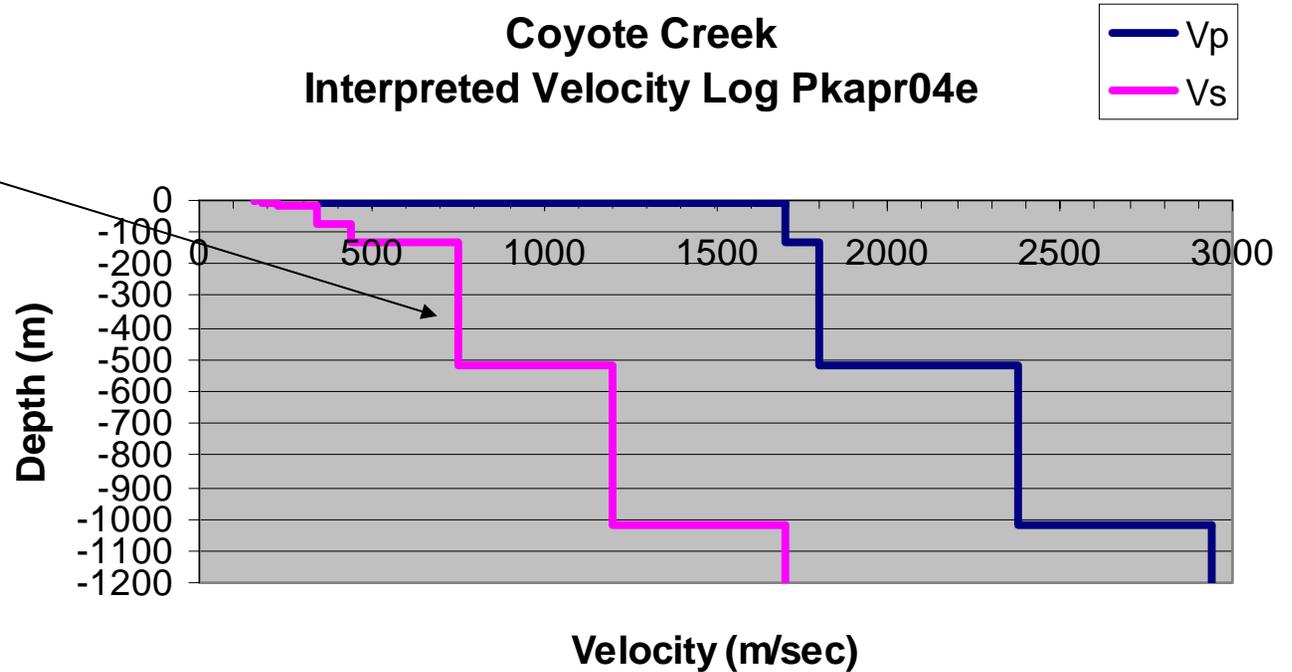


# COYOTE SENSITIVITY STUDY

Resolved  
between 675  
and 900 m/s



Coyote Creek  
Interpreted Velocity Log Pkapr04e

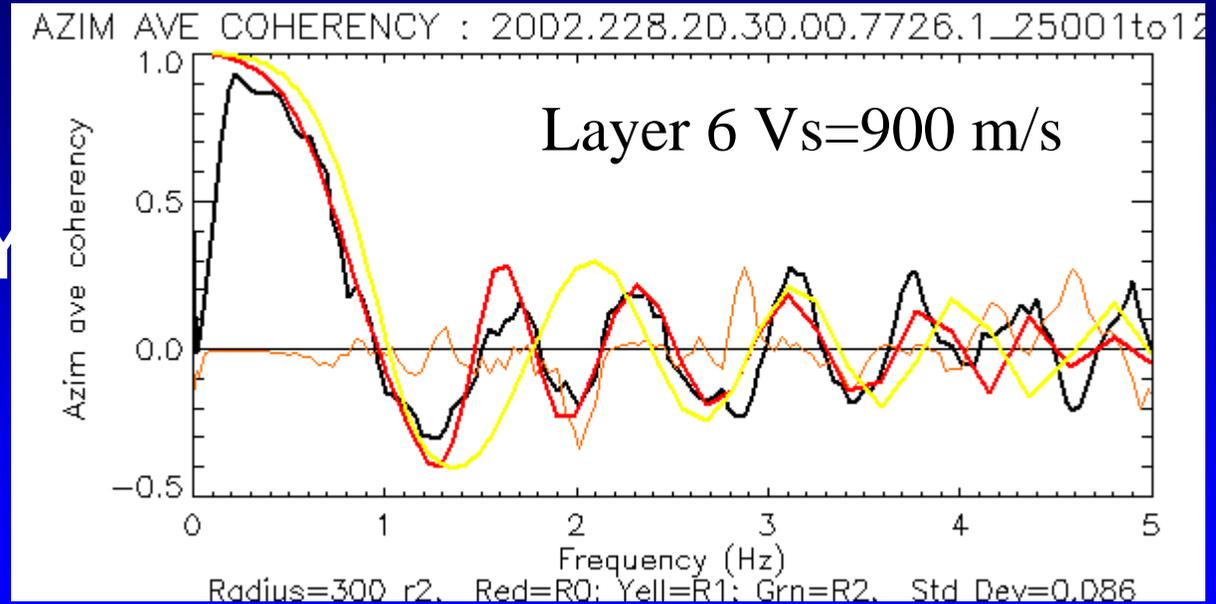


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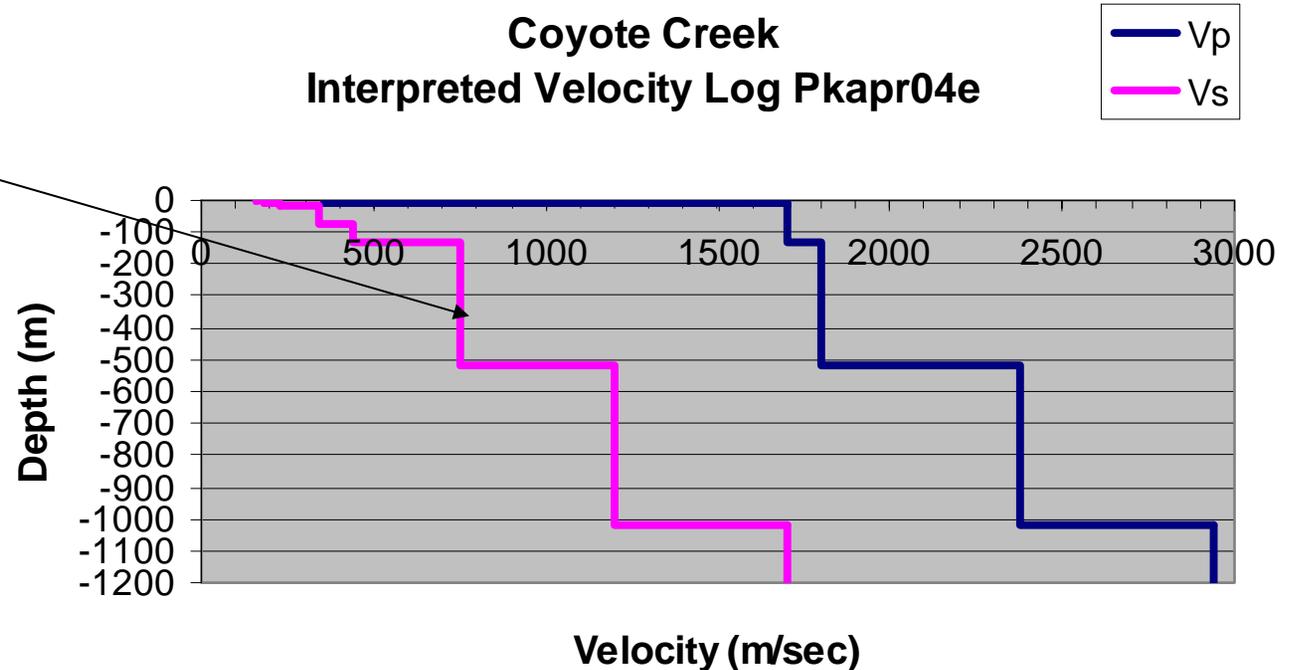


# COYOTE SENSITIVITY STUDY

Resolved  
between 675  
and 900 m/s



Coyote Creek  
Interpreted Velocity Log Pkapr04e



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# COYOTE SPAC INTERPRETATION

## PARAMETER SENSITIVITY STUDY

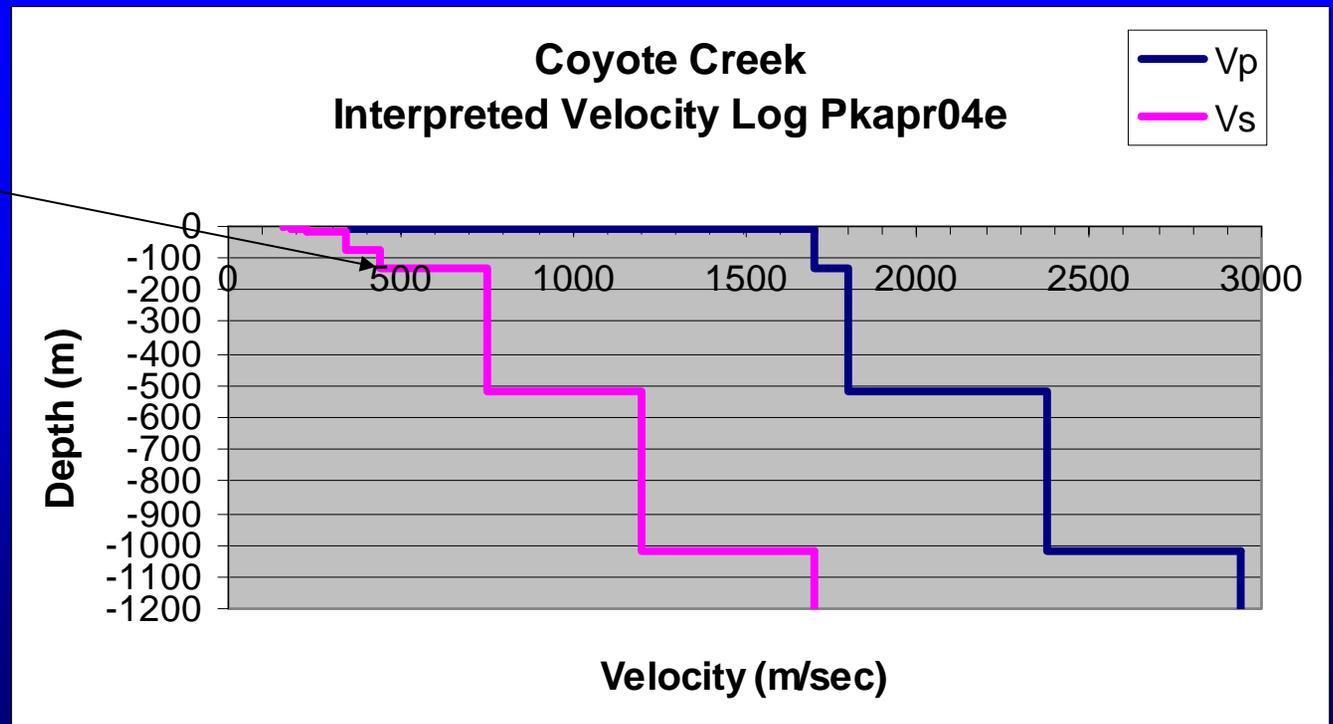
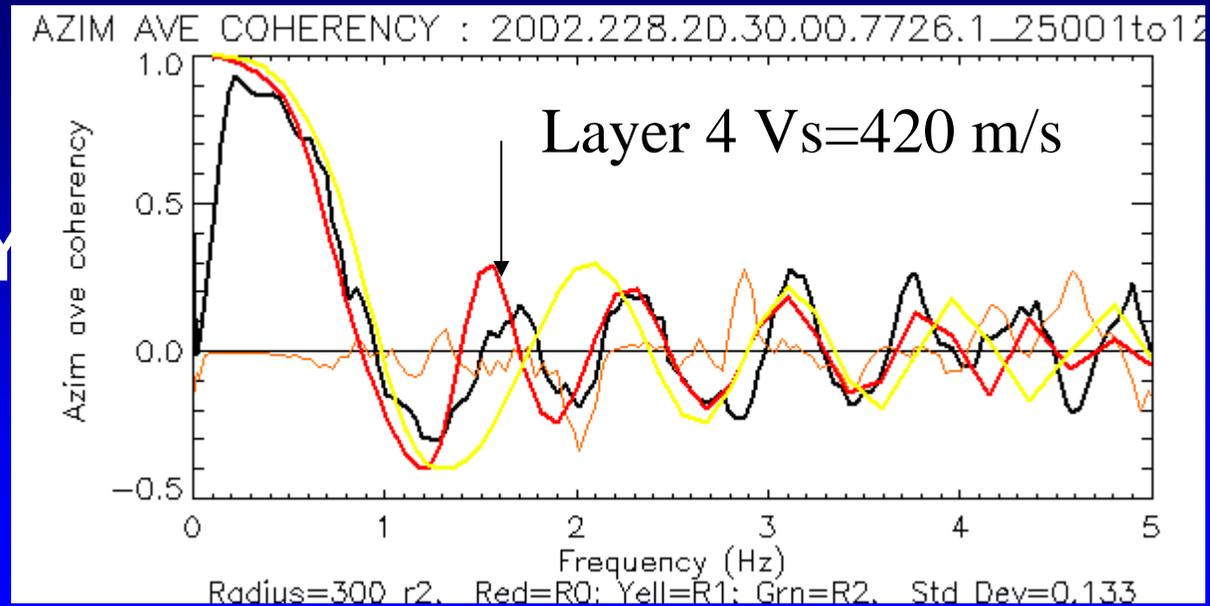
-

-The following 3 slides show the value of layer 4  $V_s$  is exceedingly well resolved by the SPAC data, and must lie in the range 420 to 460 m/s.

# COYOTE SENSITIVITY STUDY

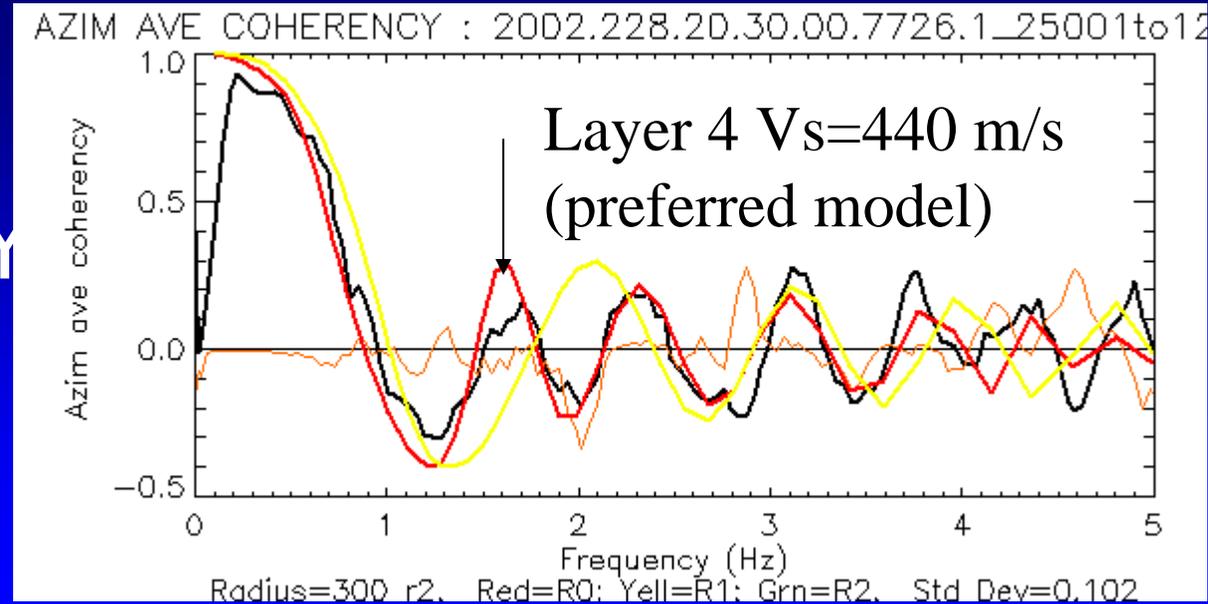
Layer 4  
Resolved  
between 420  
and 460 m/s

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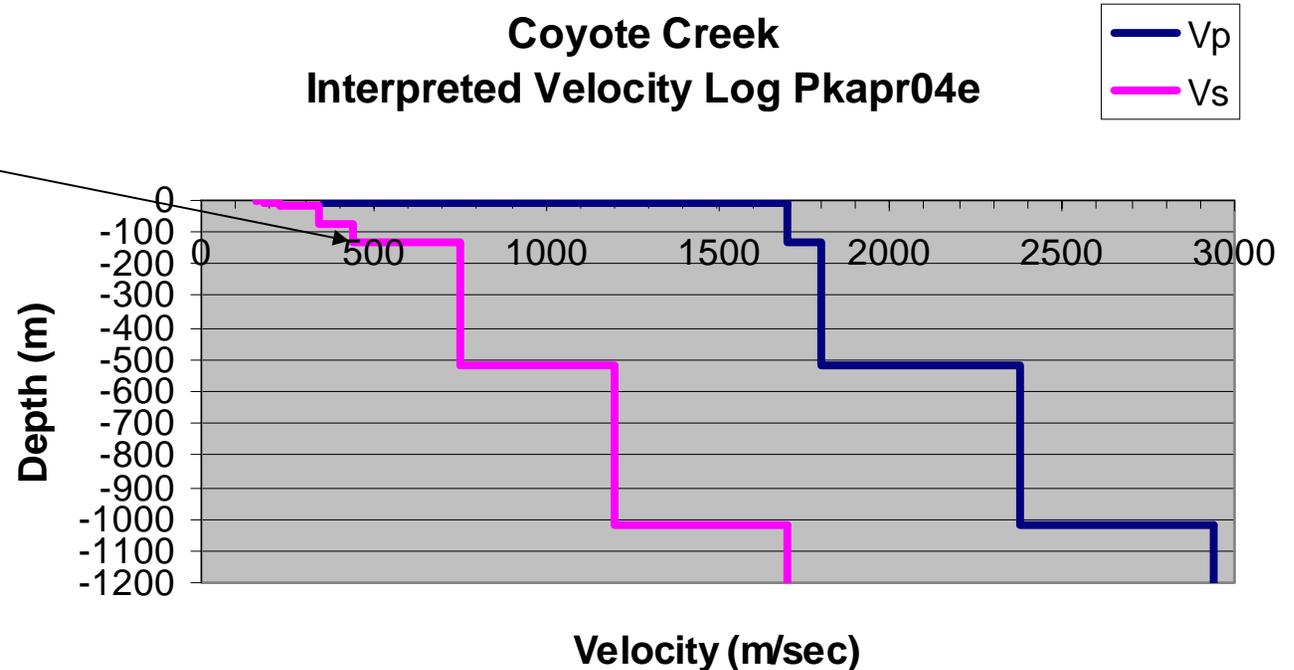


# COYOTE SENSITIVITY STUDY

Layer 4  
Resolved  
between 420  
and 460 m/s



Coyote Creek  
Interpreted Velocity Log Pkapr04e

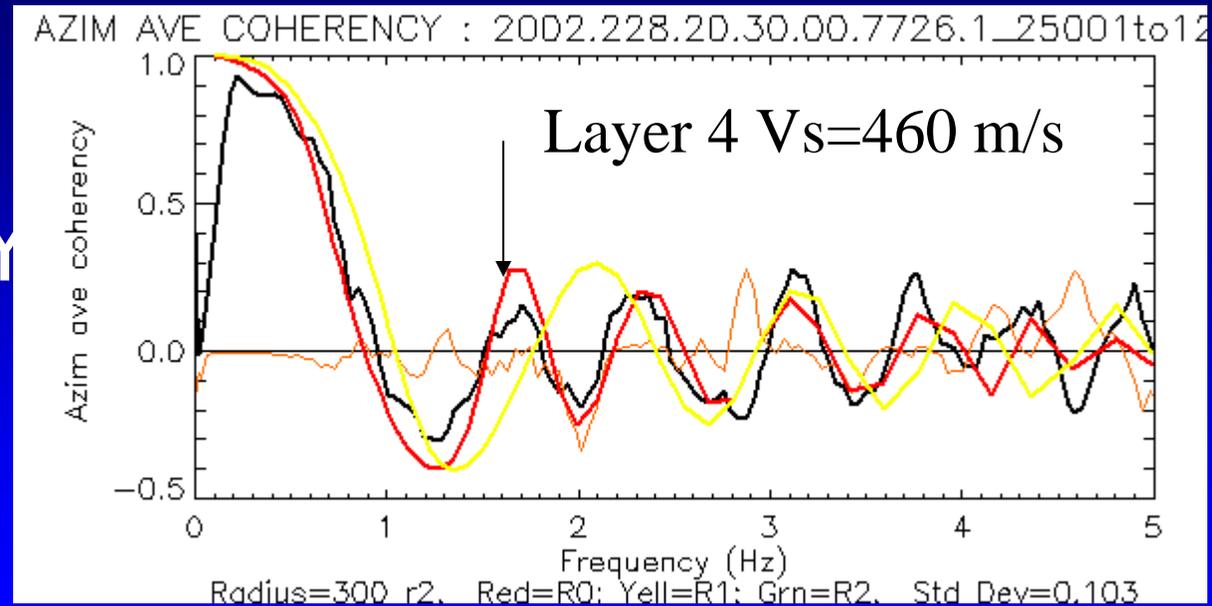


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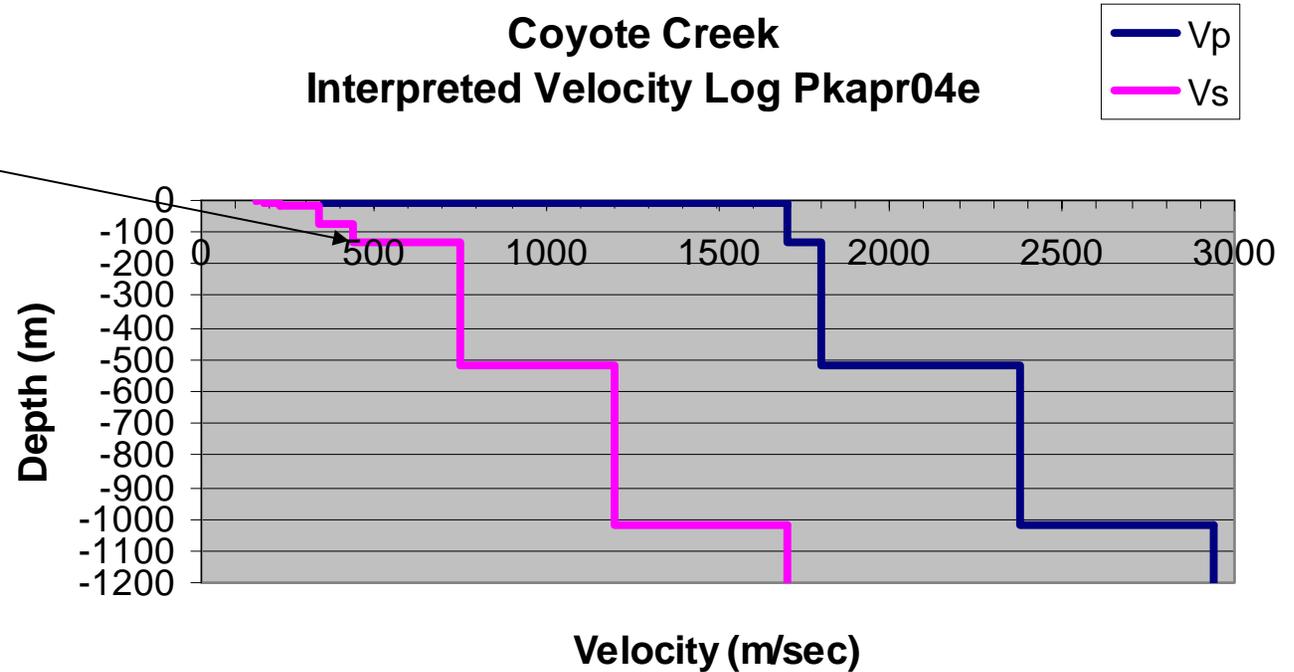


# COYOTE SENSITIVITY STUDY

Layer 4  
Resolved  
between 420  
and 460 m/s



Coyote Creek  
Interpreted Velocity Log Pkapr04e



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## COYOTE SPAC INTERPRETATION

### PARAMETER SENSITIVITY STUDY

-

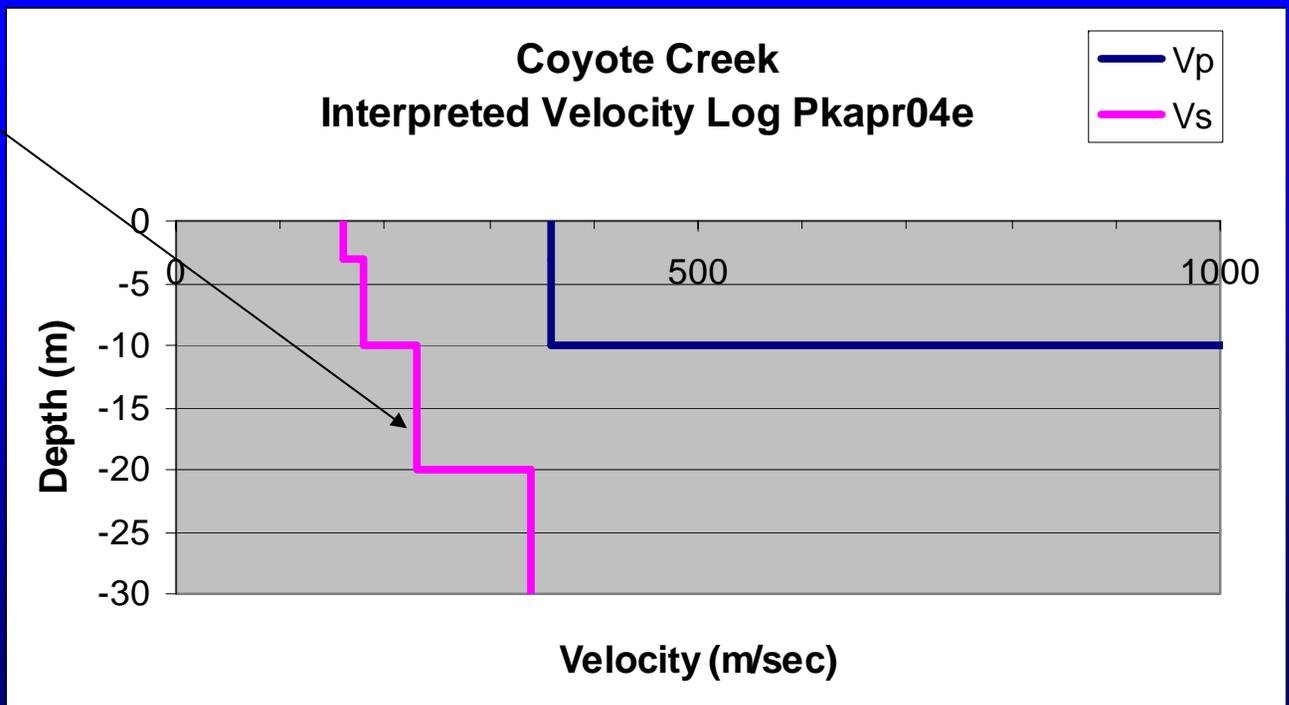
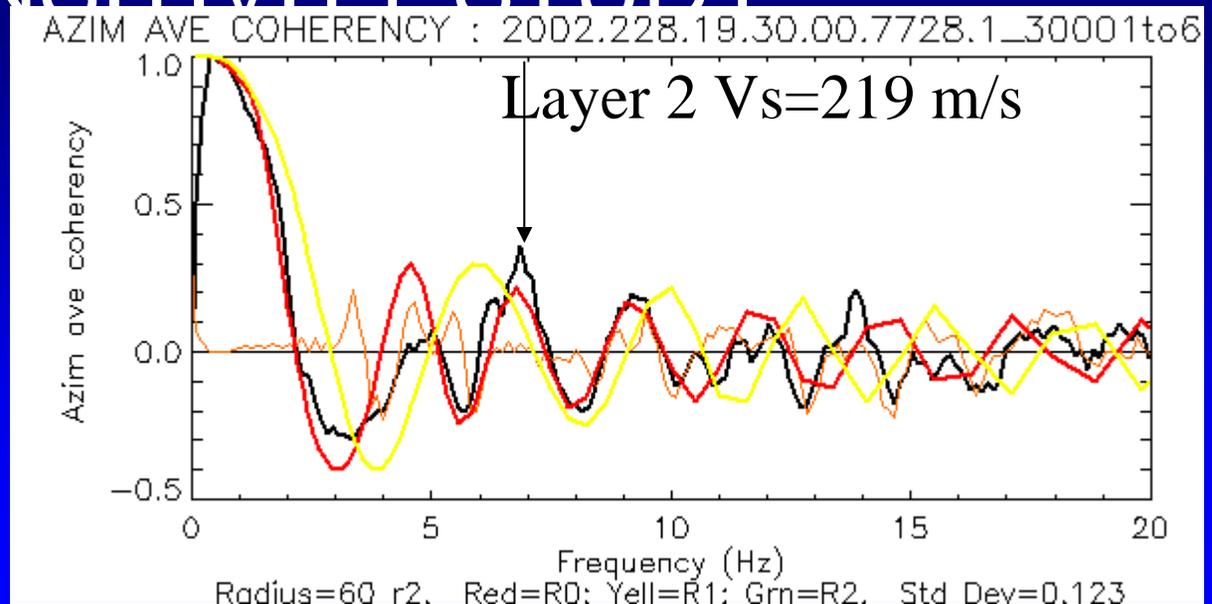
-The following 3 slides show the value of layer 2  $V_s$  is well resolved by the SPAC data for the small triangular array, and must lie in the range 219 to 241 m/s.

# COYOTE SENSITIVITY STUDY

Small 60 m array:

Layer 2

Resolved between 219 and 241 m/s



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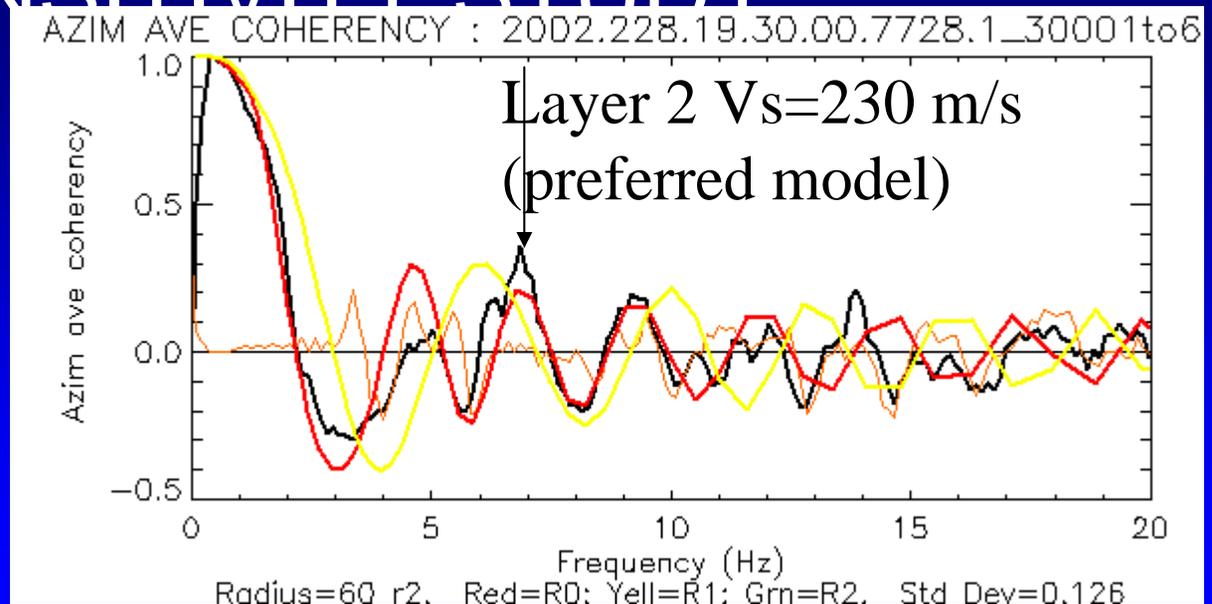


# COYOTE SENSITIVITY STUDY

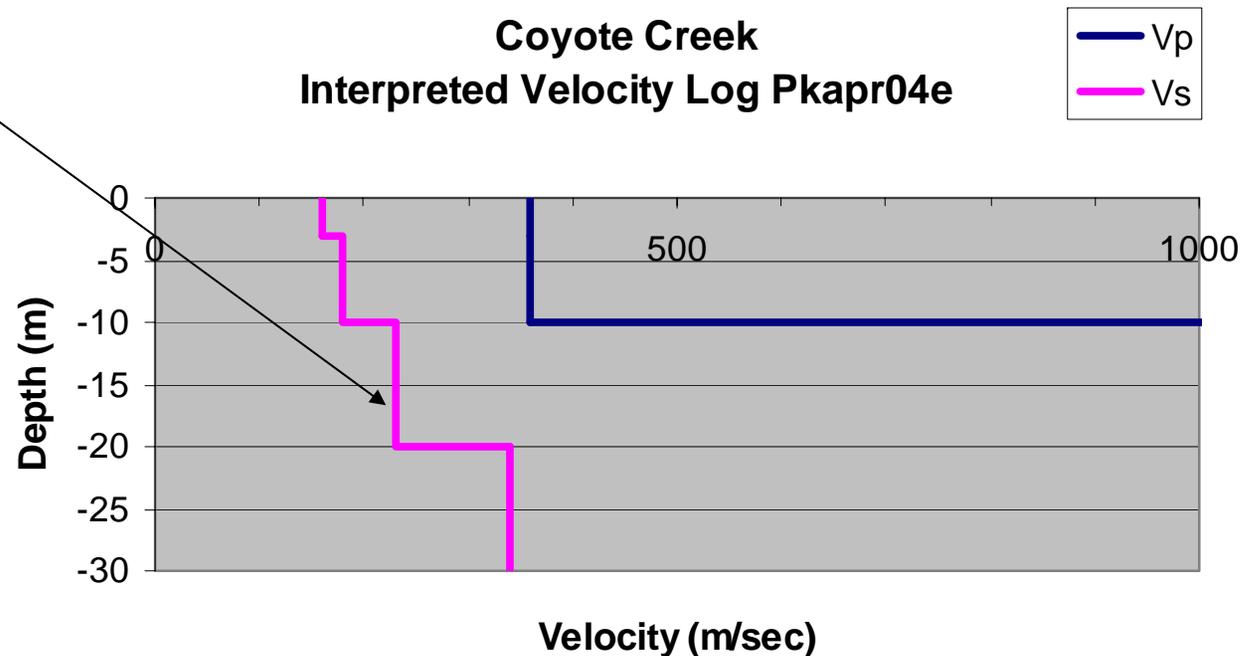
Small 60 m array:

Layer 2

Resolved between 219 and 241 m/s



Coyote Creek  
Interpreted Velocity Log Pkapr04e



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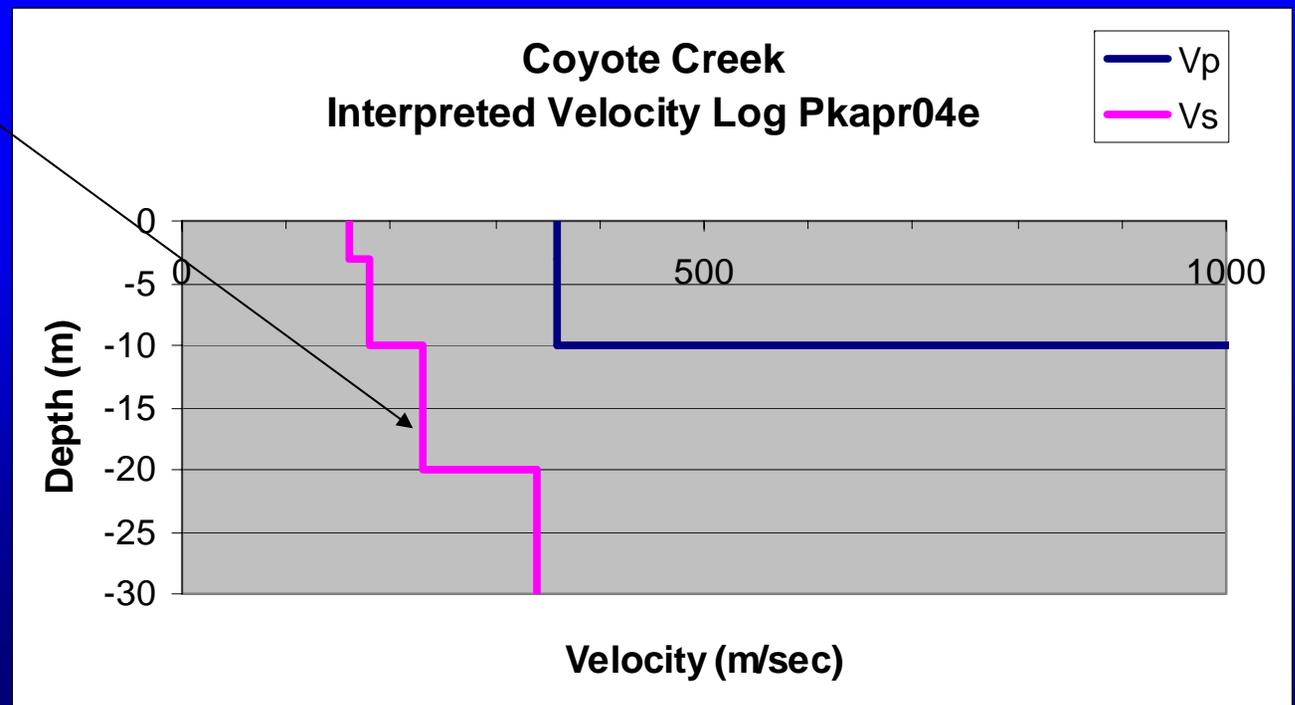
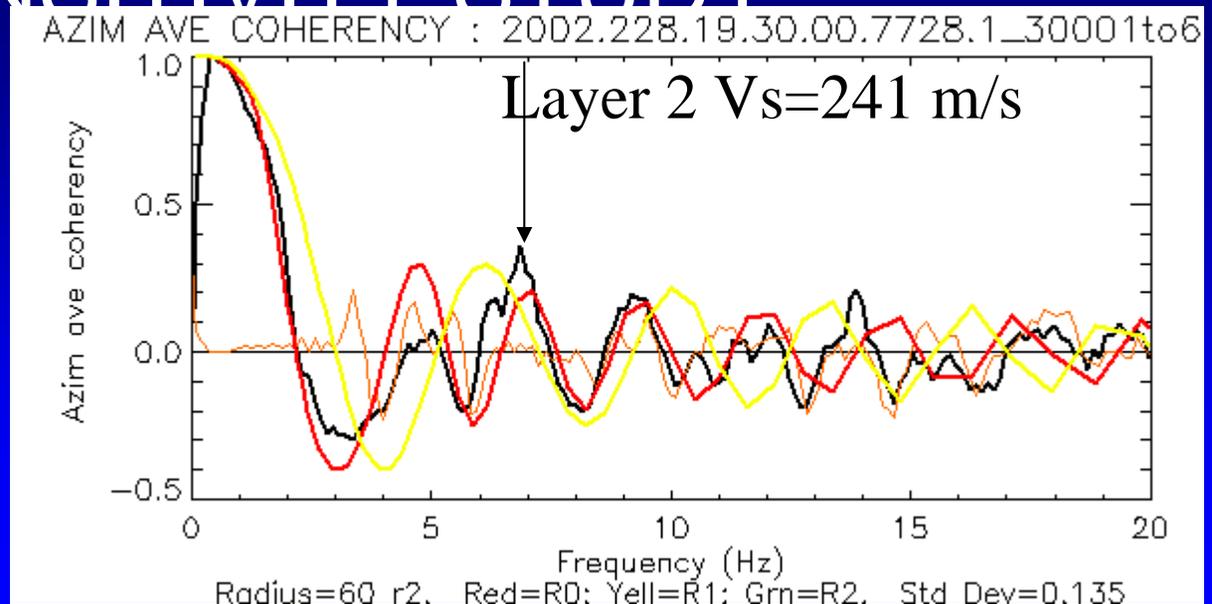


# COYOTE SENSITIVITY STUDY

Small 60 m array:

Layer 2

Resolved between 219 and 241 m/s



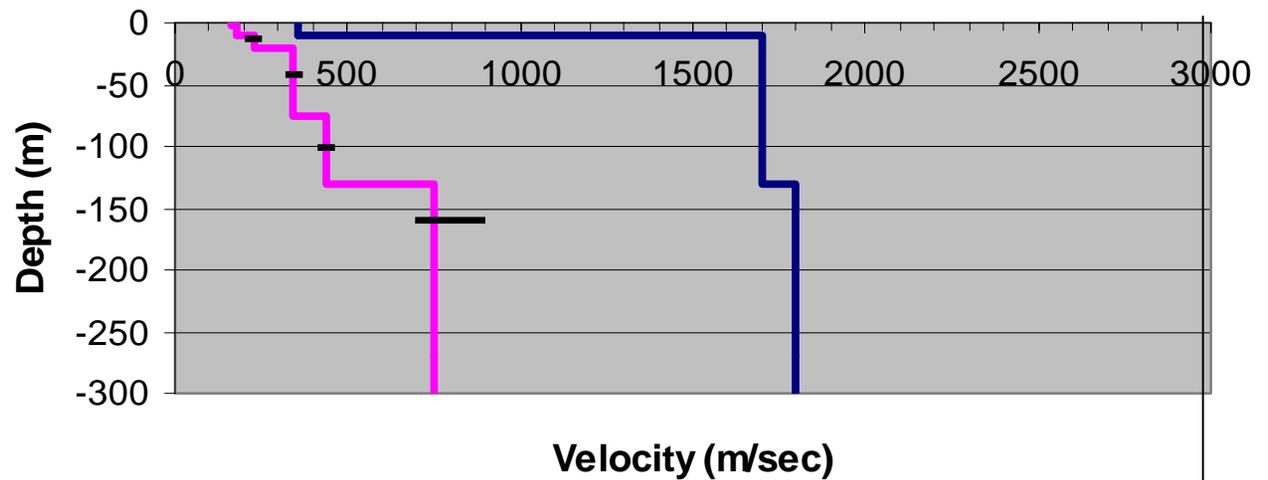
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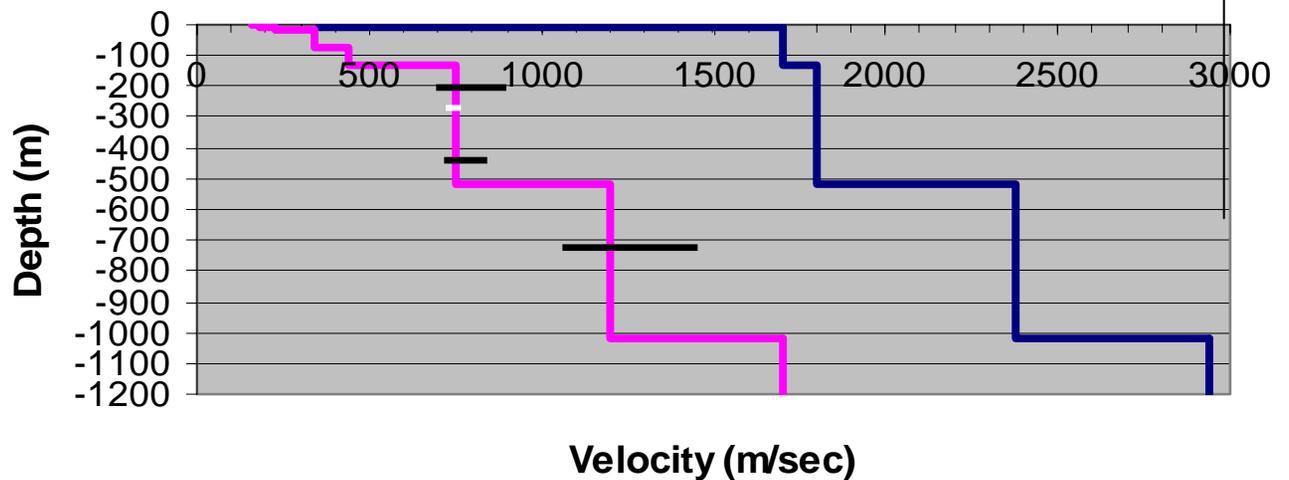
# COYOTE SENSITIVITY SUMMARY

(Black bars show sensitivity ranges for  $V_s$ , derived from perturbations of each  $V_s$  in turn).

Coyote Creek  
Interpreted Velocity Log Pkapr04e



Coyote Creek  
Interpreted Velocity Log Pkapr04e

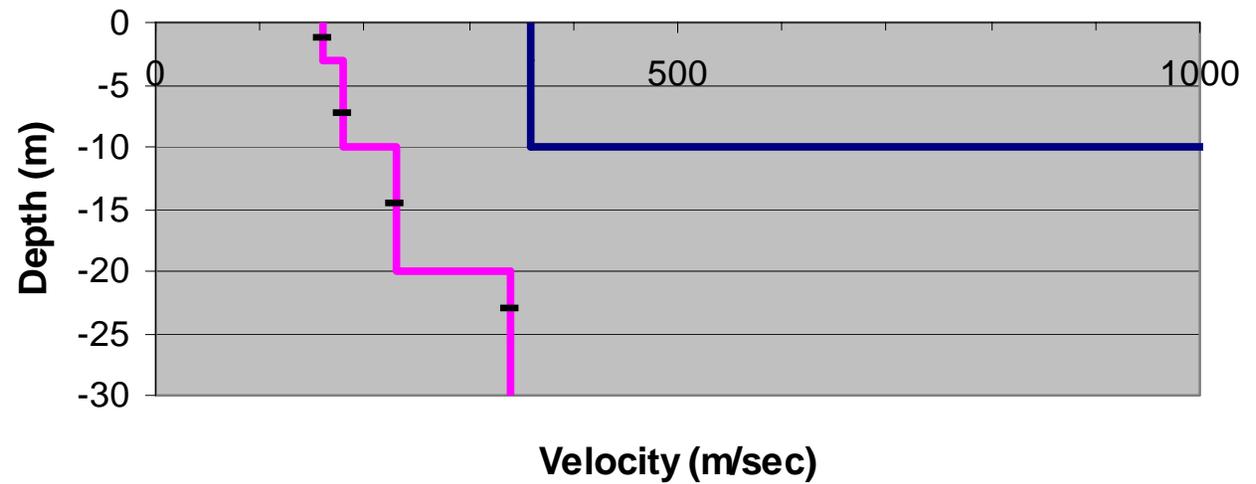


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# COYOTE SENSITIVITY SUMMARY FOR Vs30

Coyote Creek  
Interpreted Velocity Log Pkapr04e



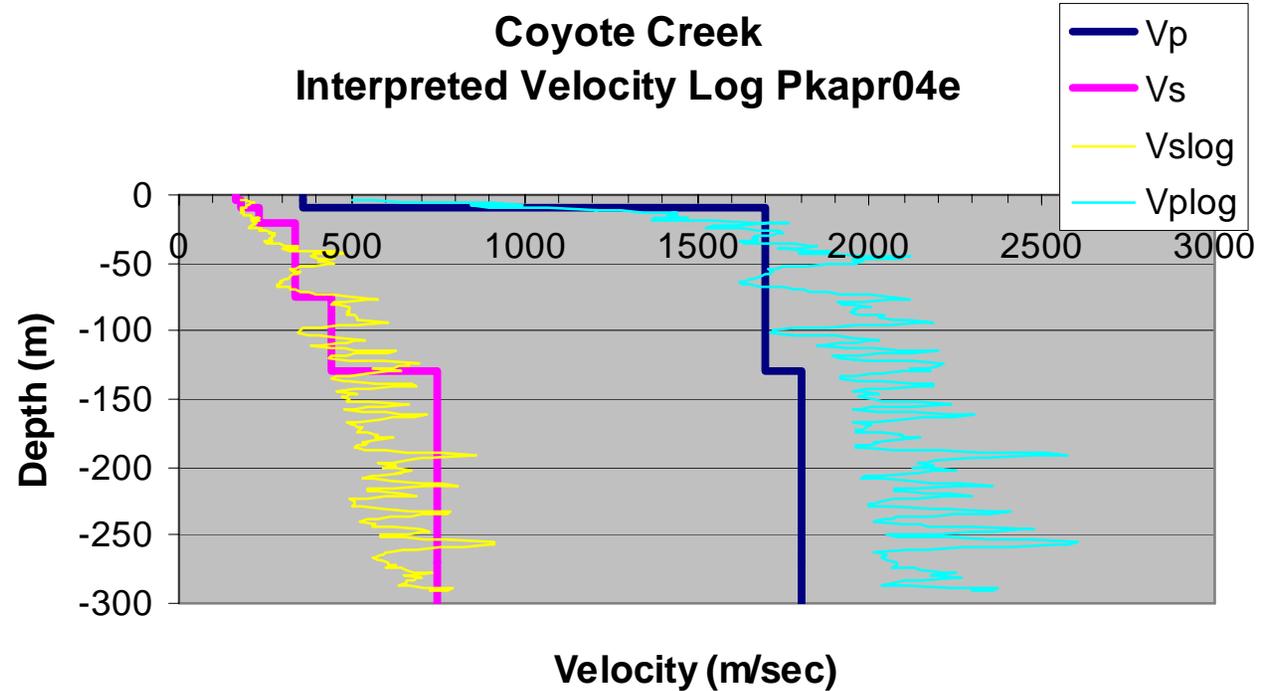
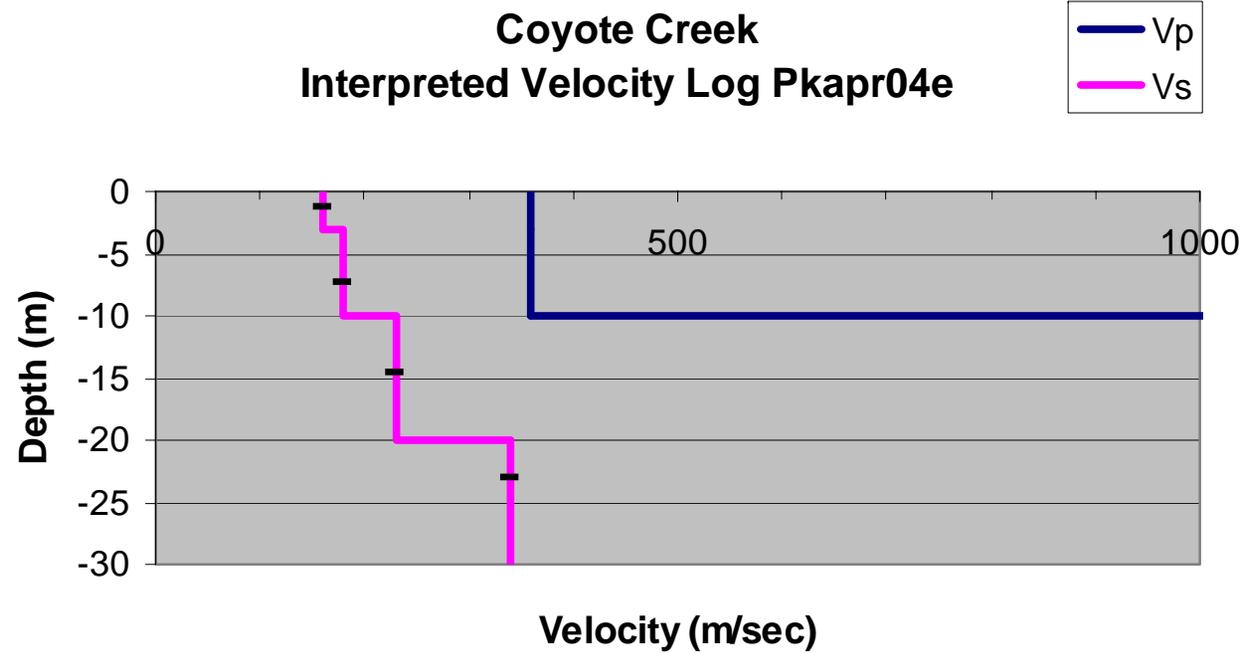
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# COYOTE SENSITIVITY SUMMARY

Including  
comparison  
with P-S logs  
in the Coyote  
water bore

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# ACKNOWLEDGMENTS

Hortencia Flores – array design

Russell Sell – data acquisition

David Boore – Data Gate Keeper  
Extraordinaire

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# REFERENCES

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