The Development of a 400 Level 3C Clamped Downhole Seismic Receiver Array for 3D Imaging of Gas Reservoirs

-

The Next Generation of High Resolution 3D/4D Imaging

Paulsson Geophysical Services, Inc. (P/GSI)

Brea, CA

The Development of a 400 level 3C borehole array Project Summary

- The project is co-funded by DOE and P/GSI (50% each)
- Project started on October 1, 2001
- Estimated project duration 24 - 30 months
- First operational equipment was available Q1, 2002
- All equipment was completed Q2 2002
- Project survey planned for Q3 or Q4 2002
- Processing completed of data from Project survey by Q2 or Q3 2003
- Software development during the entire course of the project

The Development of a 400 level 3C borehole array Project Tasks

- **Order geophone cables – 320 levels ordered Nov. 20, 2001**
- **High pressure, high temperature pods being tested at present**
- **Manufacture hardware for 400 levels**
  - Centralizers completed
  - Geophone housing prototype completed 12/4/01
  - Manufacturing of 330 geophone pod housings start 12/05/01
  - Tubing ordered – scheduled to be delivered Feb. 2002
  - Other misc. components completed or ordered
  - Winches have been designed – getting quotes
  - Enclosures and trailers have been designed – getting quotes
  - Designing the acquisition system to work with our array
- **Discussing with several operators to host project survey in Q3 or Q4, 2002.**

The Development of a 400 level 3C borehole array Project Deliverables

- **A functional 400 level 3C array for boreholes available to the US gas industry for surveys.**
- **A public data set recorded in a US gas field**
  - Raw 3D VSP data recorded on the borehole seismic array
  - Processed 3D Image from the 3D VSP data
  - Interpretation of the 3D VSP image
  - Well logs from the survey well to allow correlation of the VSP image with current standard well log data.

Why Develop a Massive 3D VSP™ Technique

The Massive 3D VSP™ Technique provides:

- High frequency data (150 – 200 Hz) = High resolution
- P and S wave data = Mapping of lithology, pore fluids, stress, etc., etc.
- Excellent Repeatability for time lapse imaging
- True calibrated depth imaging along the array to support important drilling decisions.

The Massive 3D VSP™ Technique provides:

- An improved lateral and vertical resolution in the 3D image with a factor of two - eight, compared with surface seismic.
- An ability to Image in areas that previously were “non seismic”.
- An ability to map small scale faults with displacements less than 10 ft (3 m)
- A detailed velocity model through 3D tomography.
- A capability to image to 25,000 ft (7.6 km) and below.
- The highest resolution 3D imaging technology in the oil and gas industry today.

The Massive 3D VSP™ Technique Development Details:

- P/GSI developed and patented the deployment technology
- P/GSI designs and manufactures the deployment hardware
- P/GSI is developing the processing and imaging software, > 20 man years so far – now have 4 software developers
- P/GSI is processing the data, 5 processors now
- P/GSI incorporates other data for interpretation services using 3D Massive VSP™

P/GSI Receiver Array Specifications

- 80 - 400, 3C, Clamped Levels (up to 1,200 channels)
- 10 - 50 ft (3 – 15 m) Level Spacing; Tool Length up to 20,000 ft (6.1 km)
- 10,000 - 25,000 ft (3.0 – 7.6 km) Depth Capability
- Deployed on Standard Production Tubing
- Deployable in Vertical or Horizontal wells
- SM-45 HS15 Hz Geophones - No Gimbling Needed

The Massive 3D VSP™

3D VSP imaging @ 280 Hz

The History of Massive 3D VSP's™

From December, 1999 to March, 2002 P/GSI recorded the ten largest 3D VSP's in the industry. This presentation shows how the scale of projects has changed in terms of data acquisition effort and in terms of the size of volumes that are imaged.

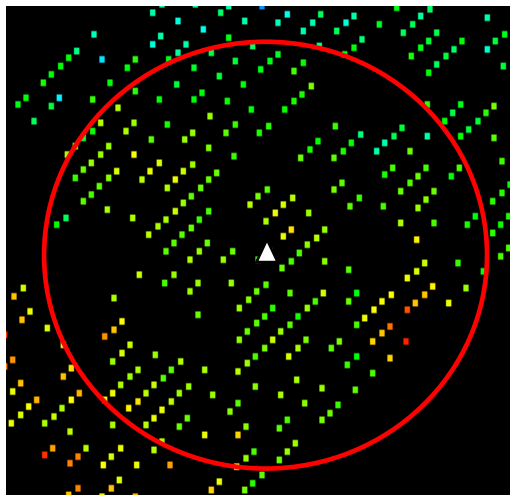
The following three shot maps are all on the same spatial scale

P/GSI Single well 3D VSP Surveys

Year 1999

1 Well, 239 shots, 57,360 traces

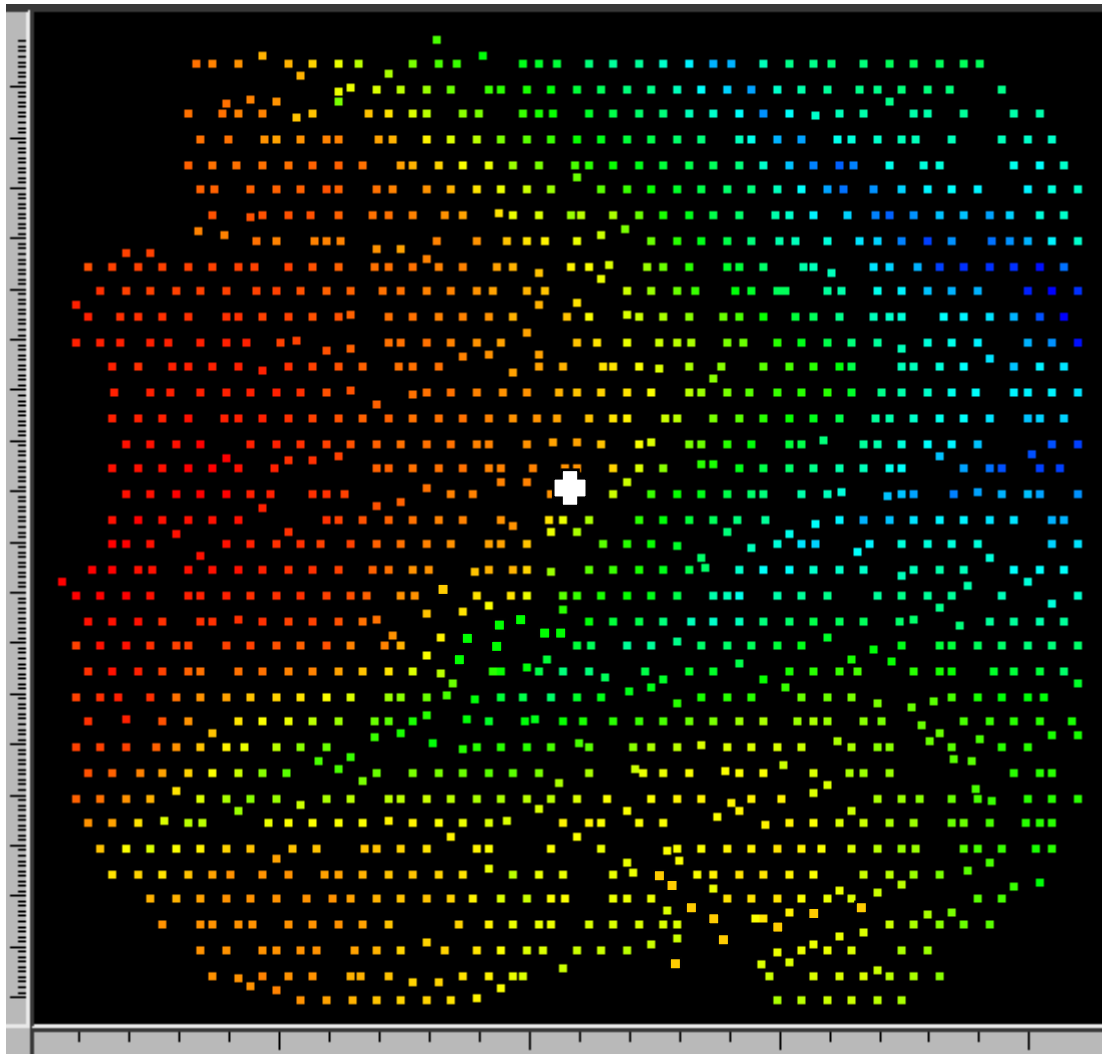
9,800 ft, 3.1 km



Year 2001

1 Well, 1,400 shots, 336,000 traces

21,000 ft, 6.4 km

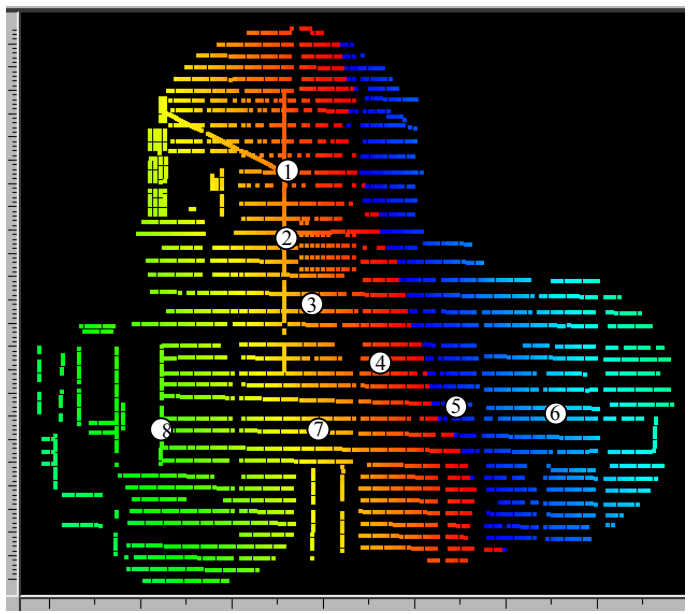


Example of a Multi Well 3D VSP Survey

Year 2000

8 Wells, 5,200 shots, 1,040,000 traces

14,000 ft, 4.3 km



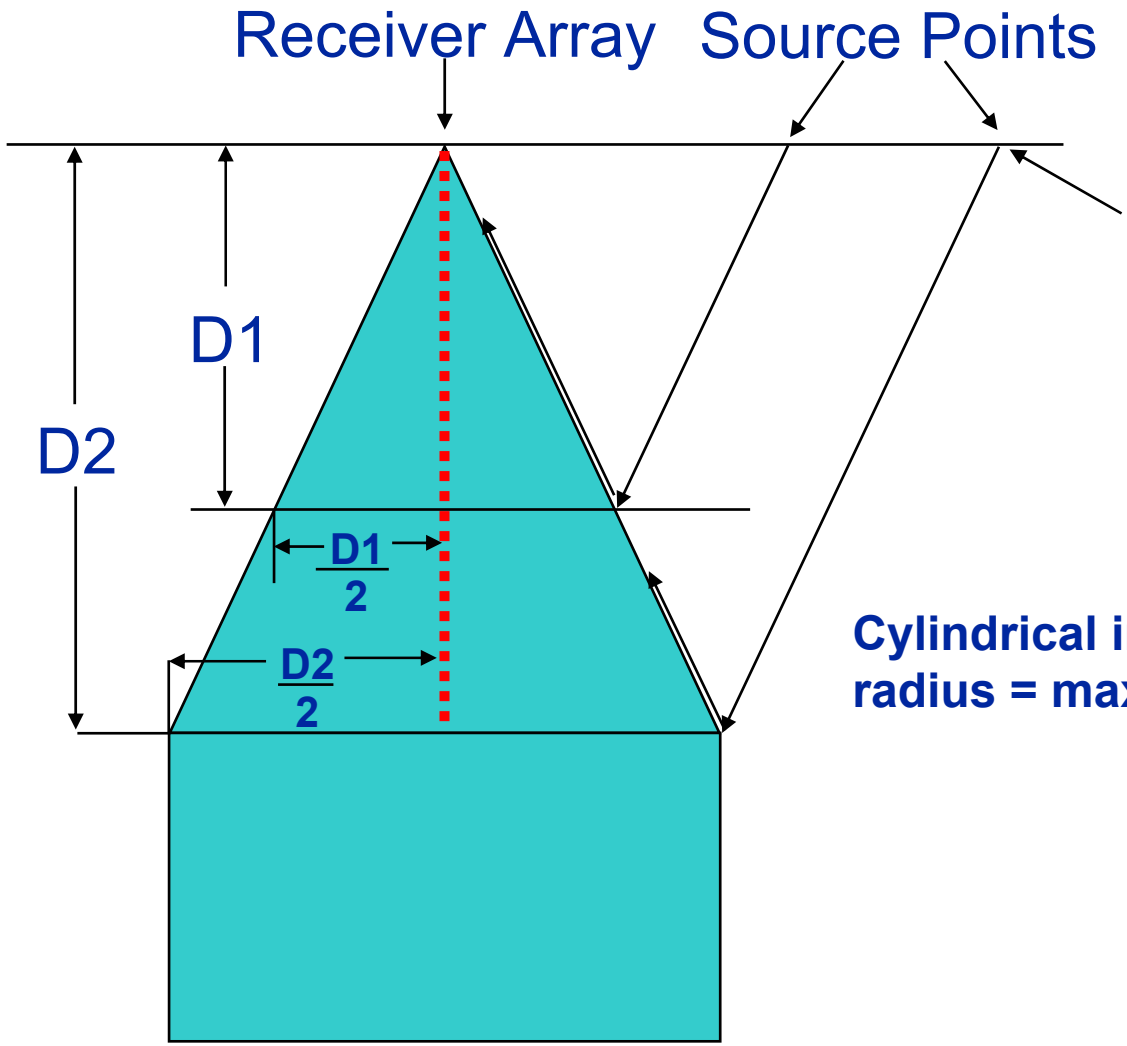
Multi Well Massive 3D VSP™ Surveys Recently concluded

- A Multi-well on-shore Massive 3D VSP survey recorded simultaneously in four deviated wells (Alaska)
- A Multi-well marine survey in five deviated wells (California)

Multi Well Massive 3D VSP Surveys currently under consideration

- A 20 Well survey covering about 80 square miles (Wyoming)

Massive 3D VSP™ Survey – Image Volume



Maximum source offset = D2

Cylindrical image below array: radius = max source offset/2 = D/2

A Massive 3D VSP™ recorded in the Arctic March 2002

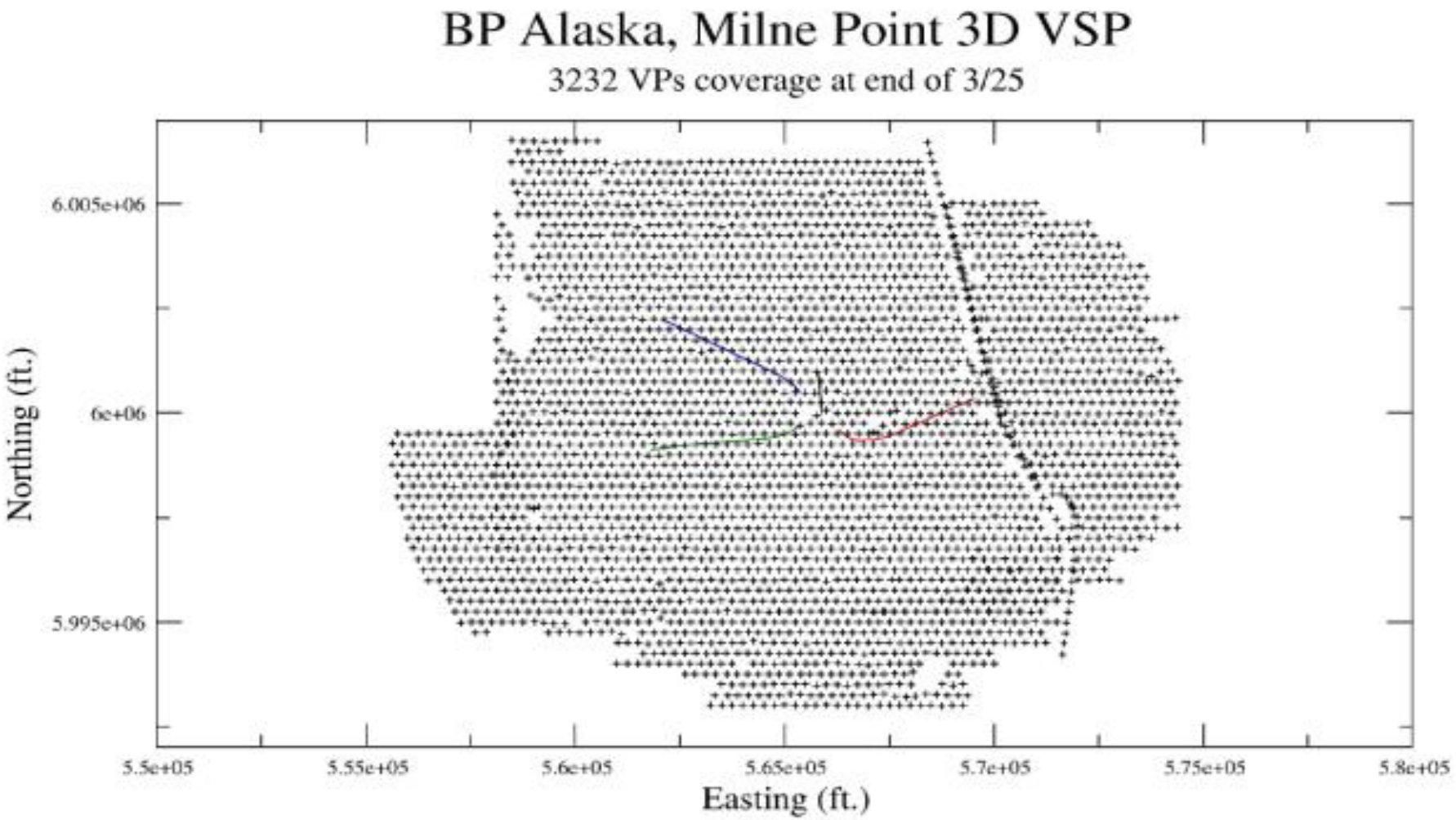
A Massive 3D VSP™ in the Arctic:

- Four wells and 960 channels recorded simultaneously
- 3,232 source points
- 3.0 million traces
- Surface vibrator used as a source
- Sweep: 5 – 200 Hz

A Massive 3D VSP™ in the Arctic

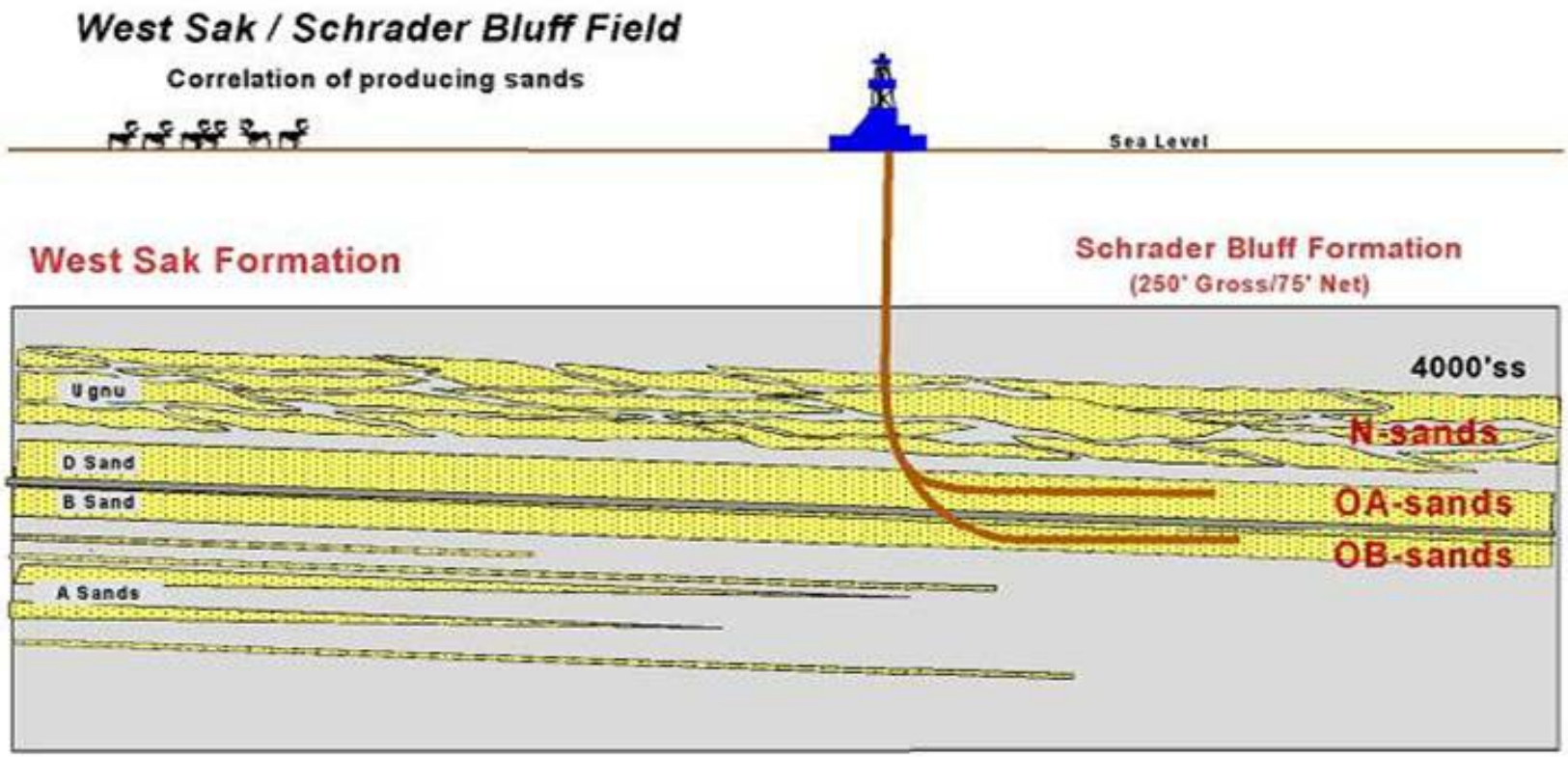
A Massive 3D VSP™ in the Arctic

A Massive 3D VSP™ in the Arctic



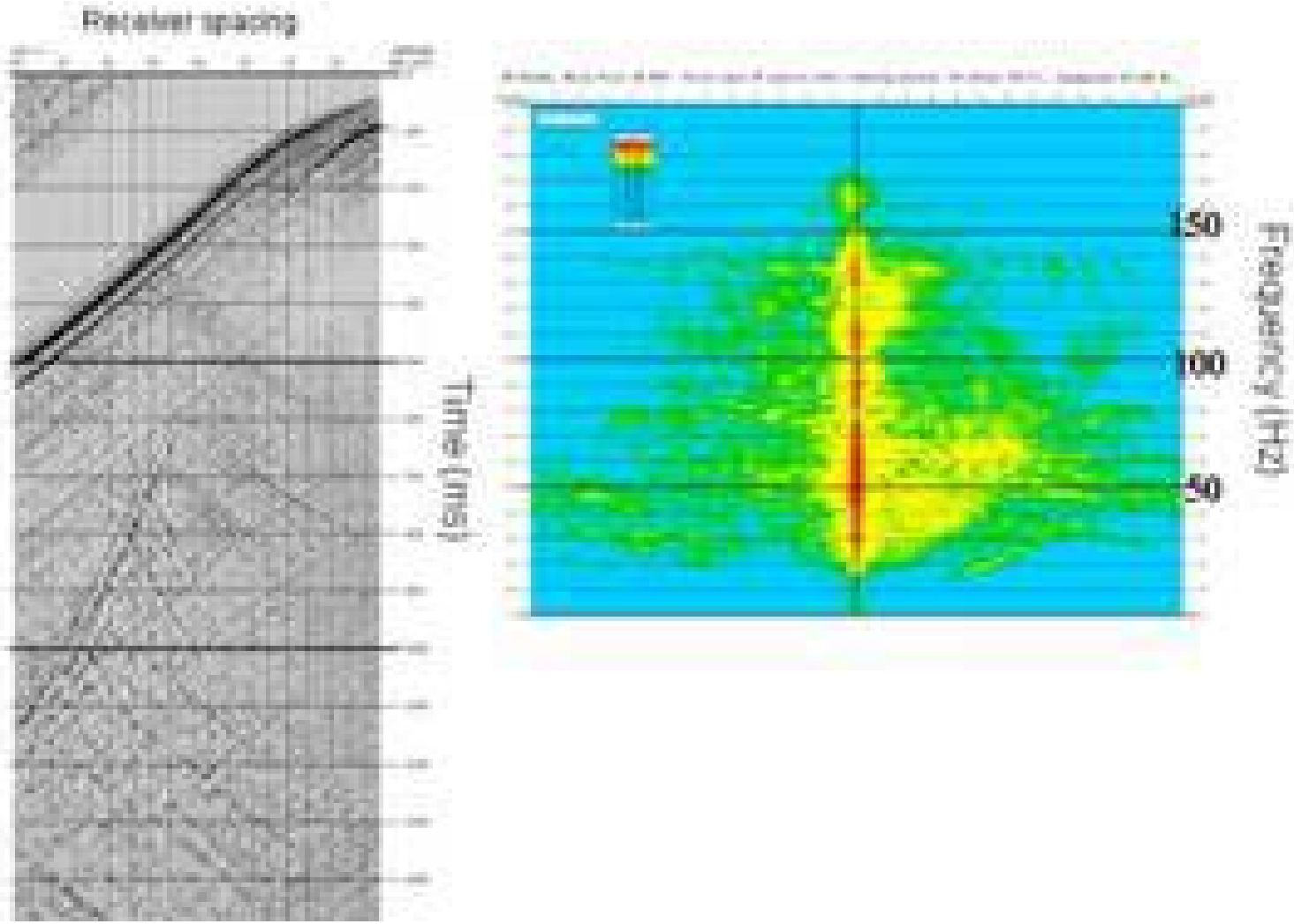
From Sullivan et al., 2002, Extended Abstract, SEG, 2002, Salt Lake City

A Massive 3D VSP™ in the Arctic



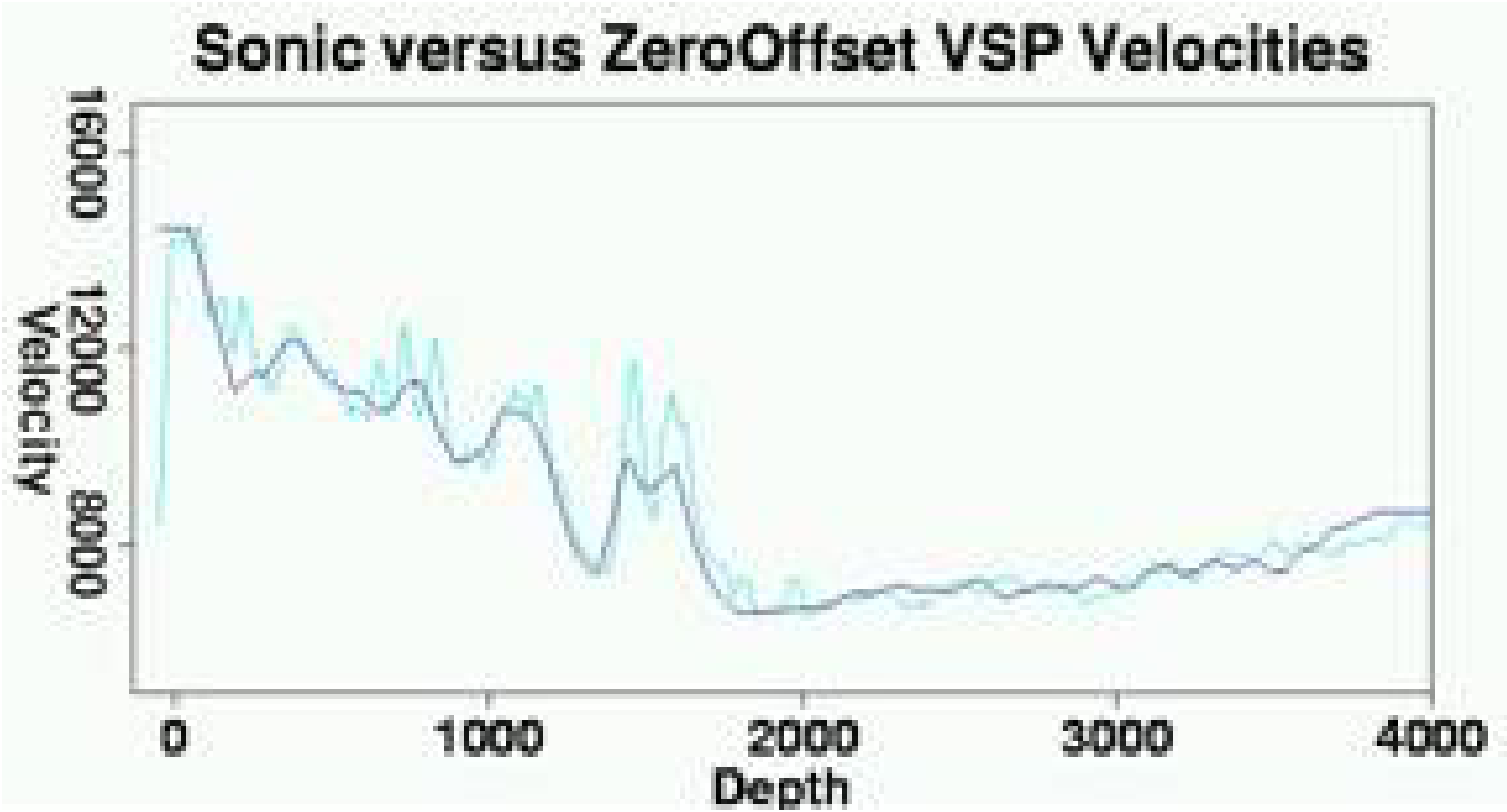
From Sullivan et al., 2002, Extended Abstract, SEG, 2002, Salt Lake City

A Massive 3D VSP™ in the Arctic



From Sullivan et al., 2002, Extended Abstract, SEG, 2002, Salt Lake City

A Massive 3D VSP™ in the Arctic



From Sullivan et al., 2002, Extended Abstract, SEG, 2002, Salt Lake City

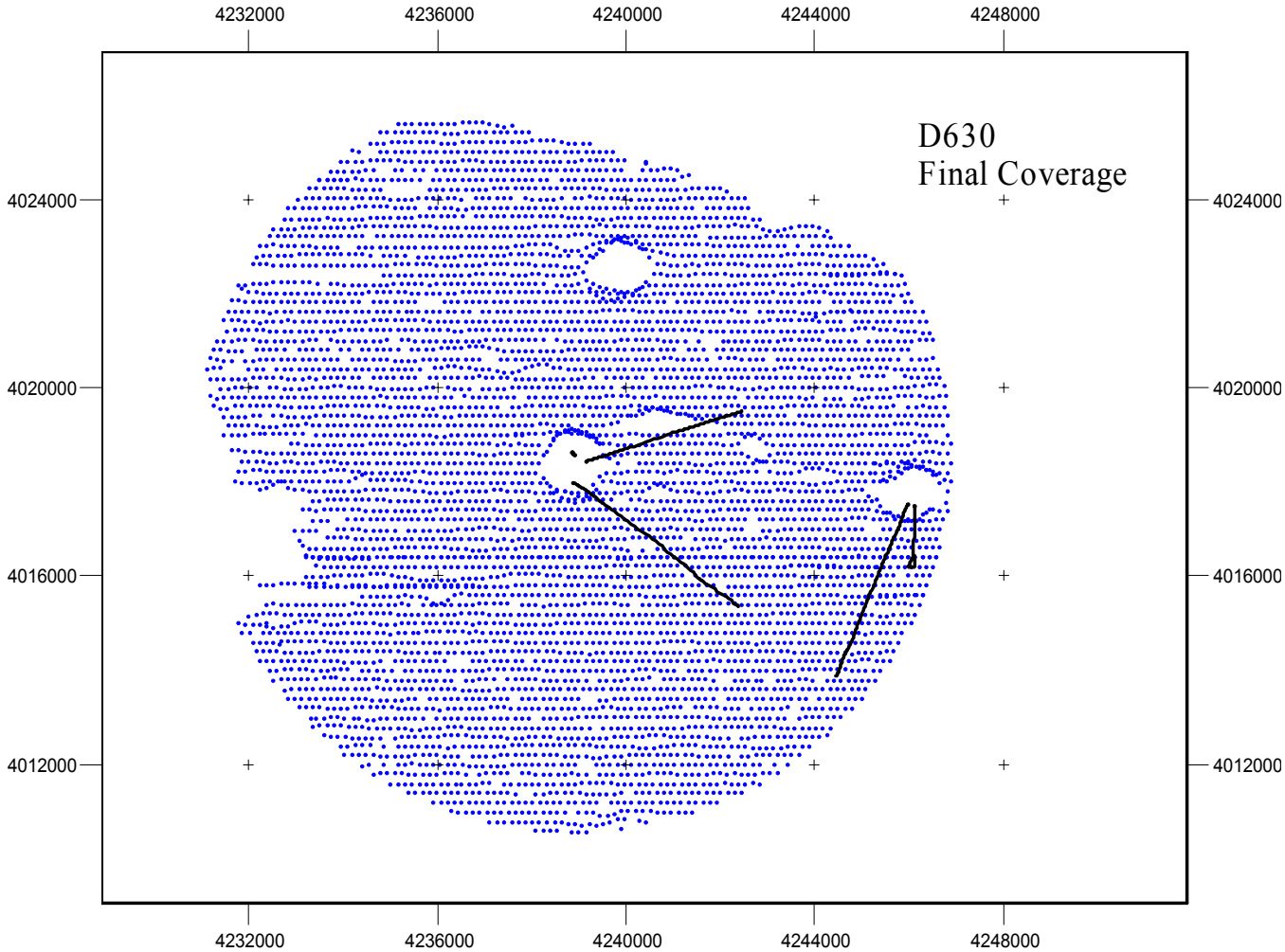
A Massive 3D VSP™ recorded Offshore February 2002

A Massive Offshore 3D VSP™

A Massive Offshore 3D VSP™

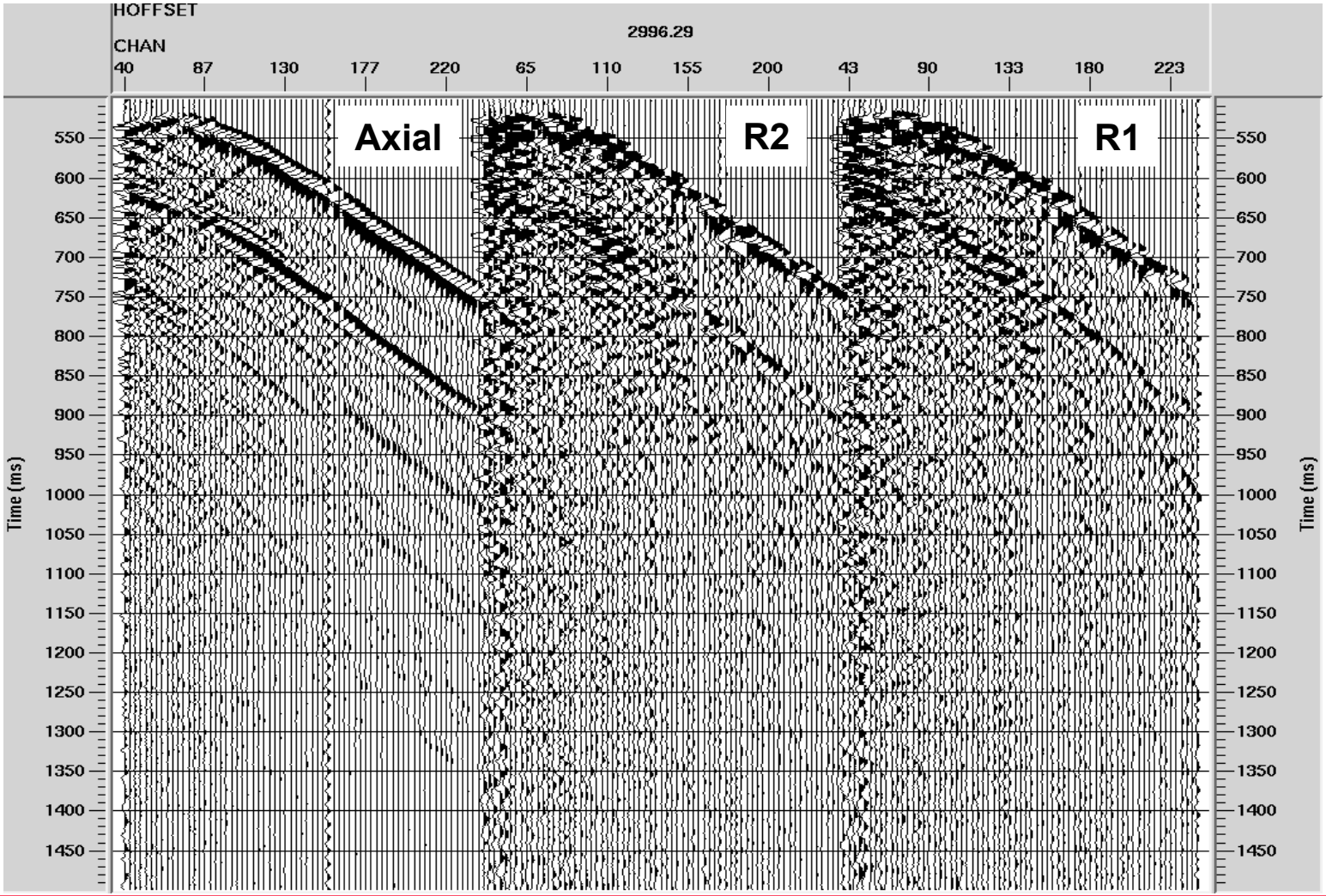
A Massive Offshore 3D VSP™

Final Shot coverage into Wells



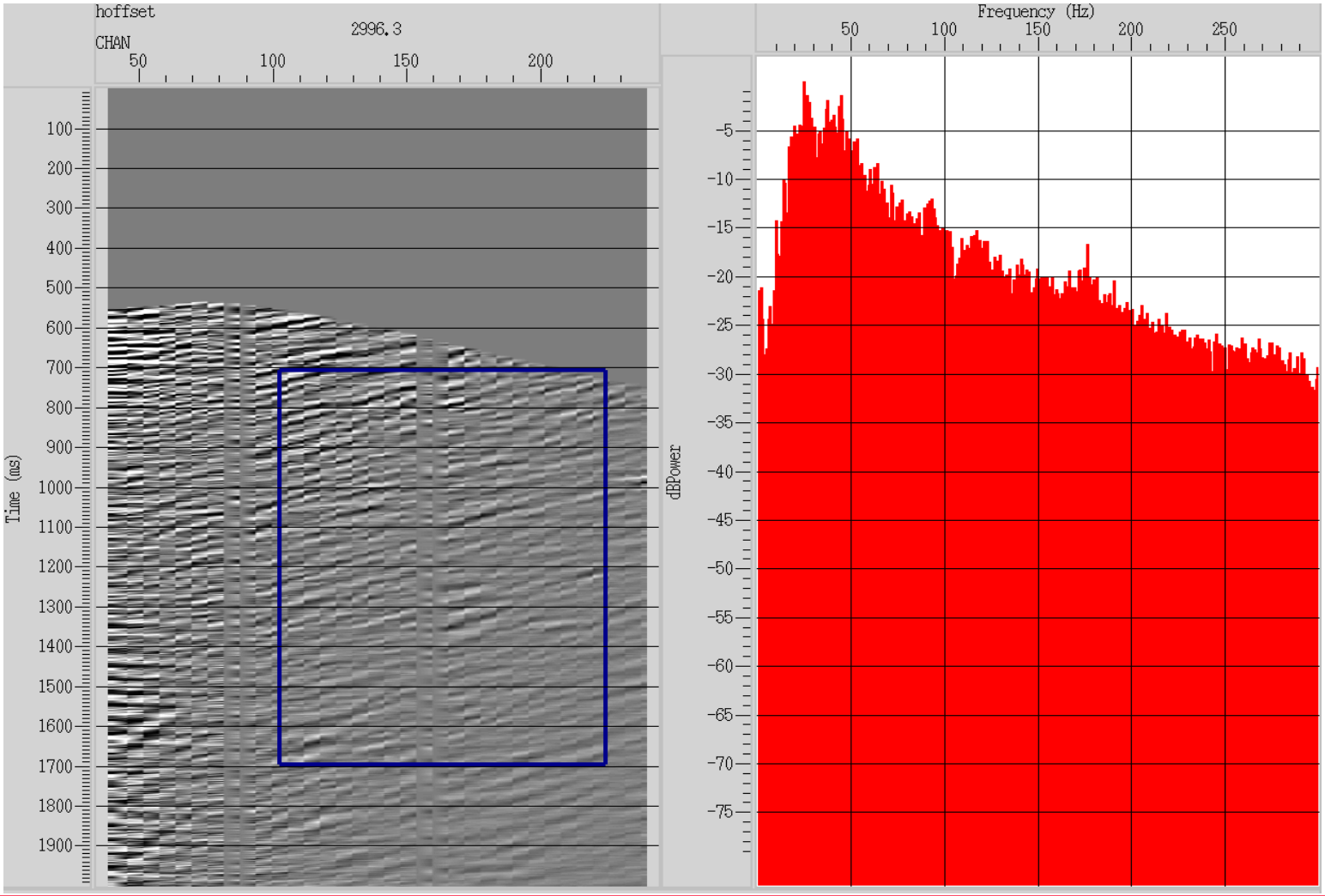
A Massive Offshore 3D VSP™

Vertical Well Raw 3C at 2,996 ft Offset



A Massive Offshore 3D VSP™

Vertical Well1C Separation at Offset of 2,996 ft Spectra



A 9C 3D Massive VSP™ recorded for DOE/LBL in NM July 2002

A 9C 3D VSP™ in NM for DOE/LBL:

- Objective: To study the use of back scattered energy to characterize fractured reservoirs
- 160 receiver positions, dz=25 ft
- 50 * 3C source points
- Two different 3C Surface vibrators used as sources
- Sweeps, P: 10–140 Hz, S: 10-70 Hz

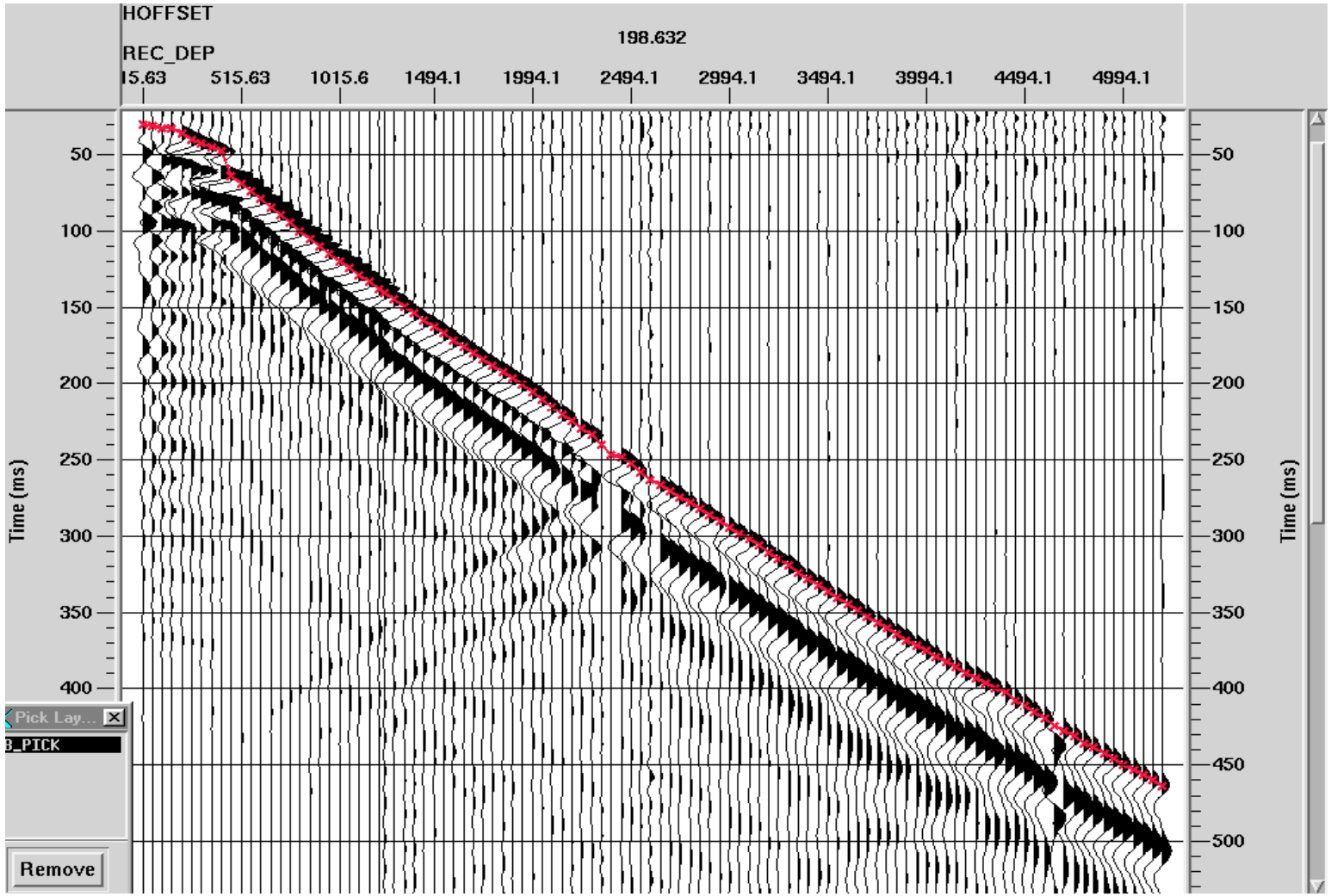
Acquisition of a 9C Massive 3D VSP™

Acquisition of a 9C Massive 3D VSP™

Acquisition of a 9C Massive 3D VSP™

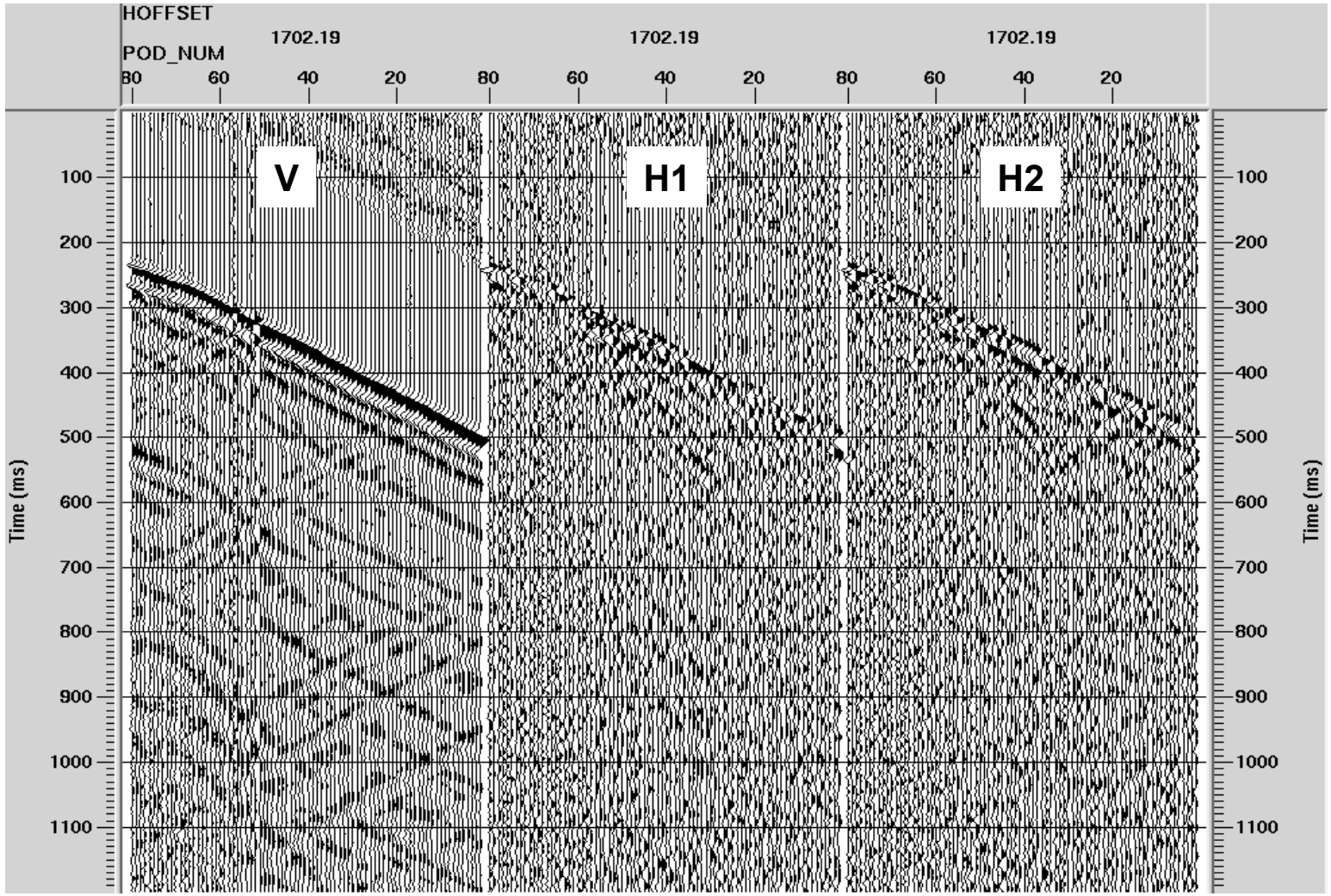
LBL – Newburry LS-2C 3D VSP

Zero Offset VSP from Surface to 5100 ft. depth



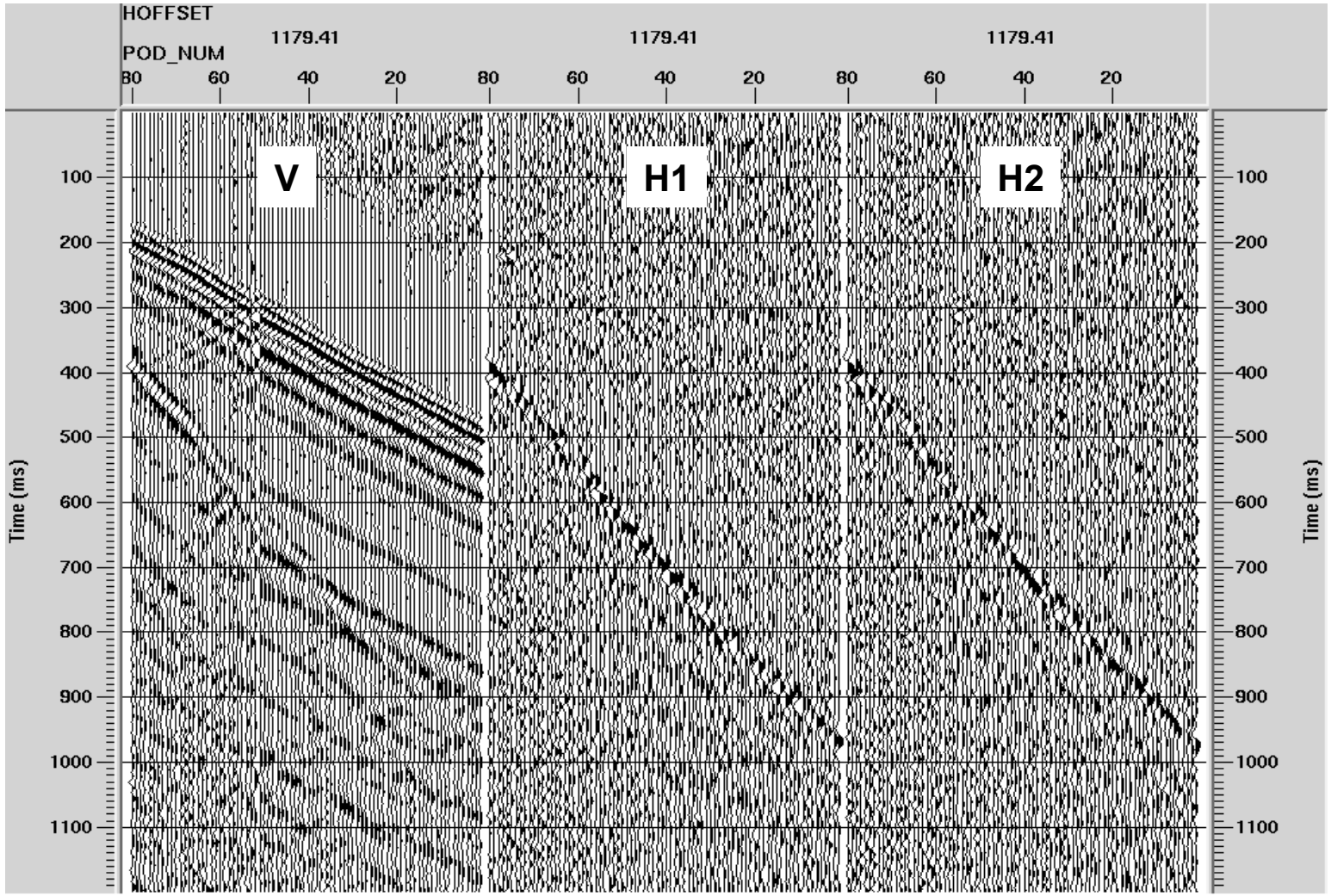
LBL – Newburry LS-2C 3D VSP

Sample P-wave Shot – 1,700 ft Offset from Well



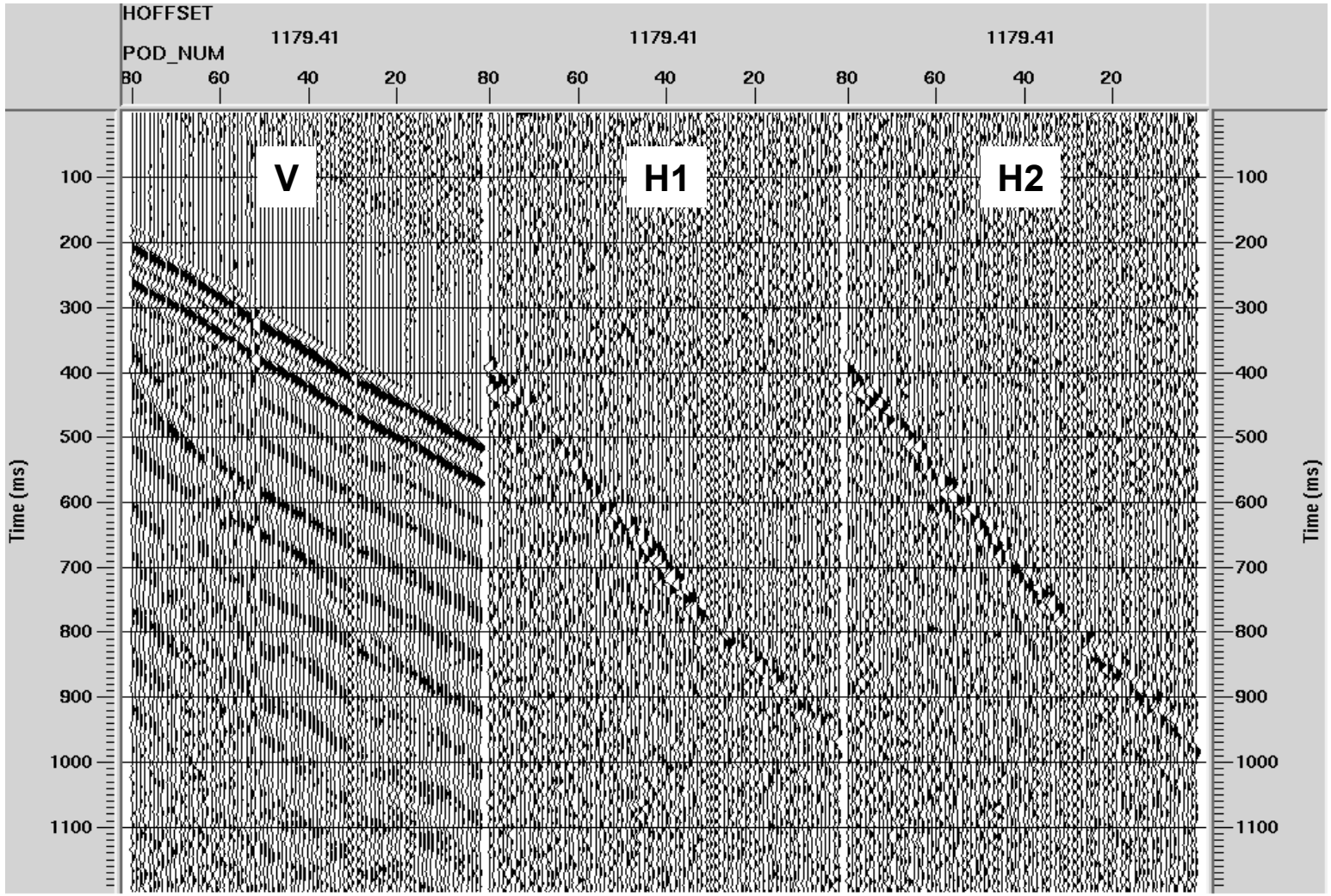
LBL – Newburry LS-2C 3D VSP

Sample SL Wave Shot 1180 ft. offset from Well

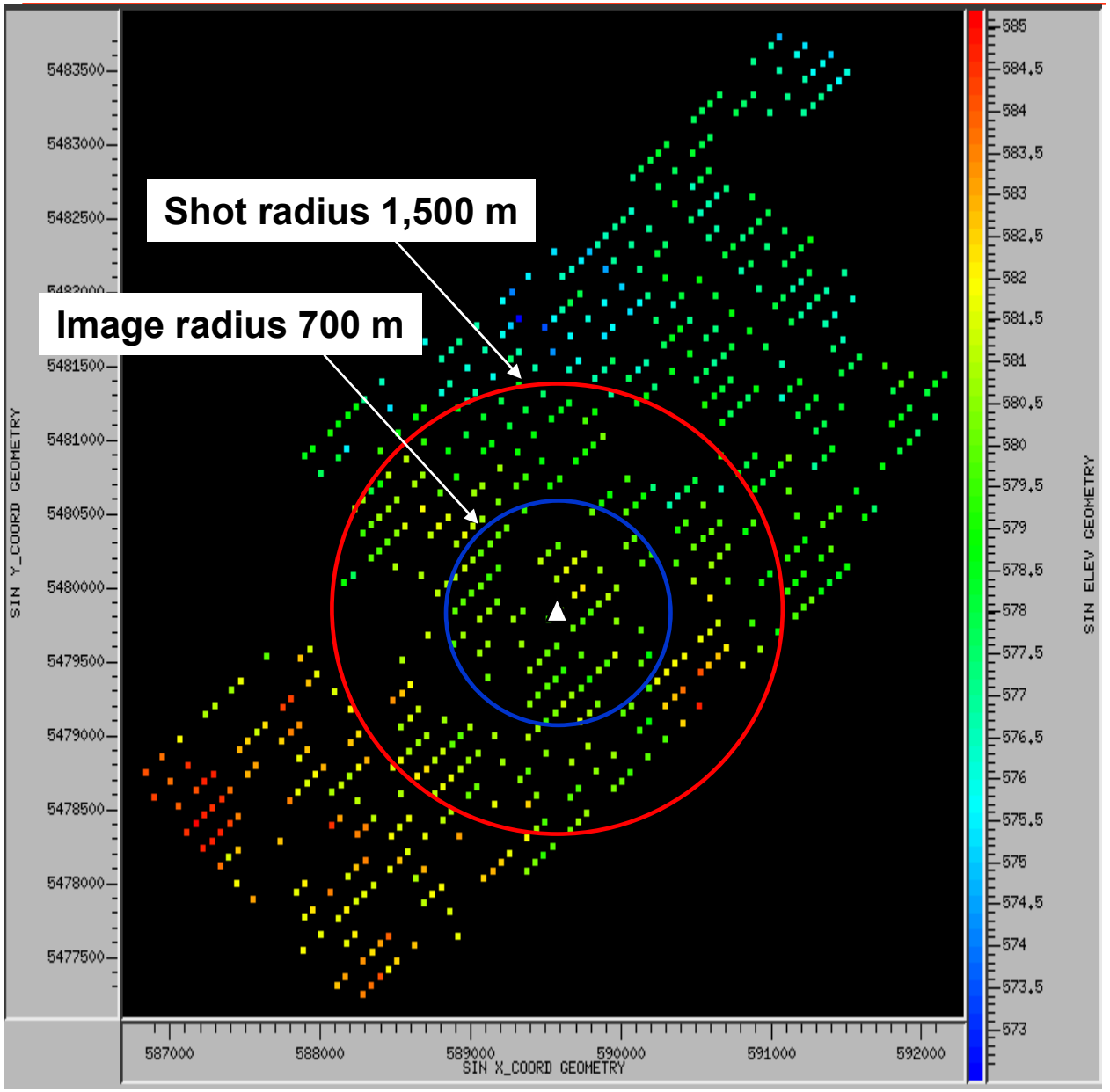


LBL – Newburry LS-2C 3D VSP

Sample SH Wave Shot 1180 ft. offset from Well



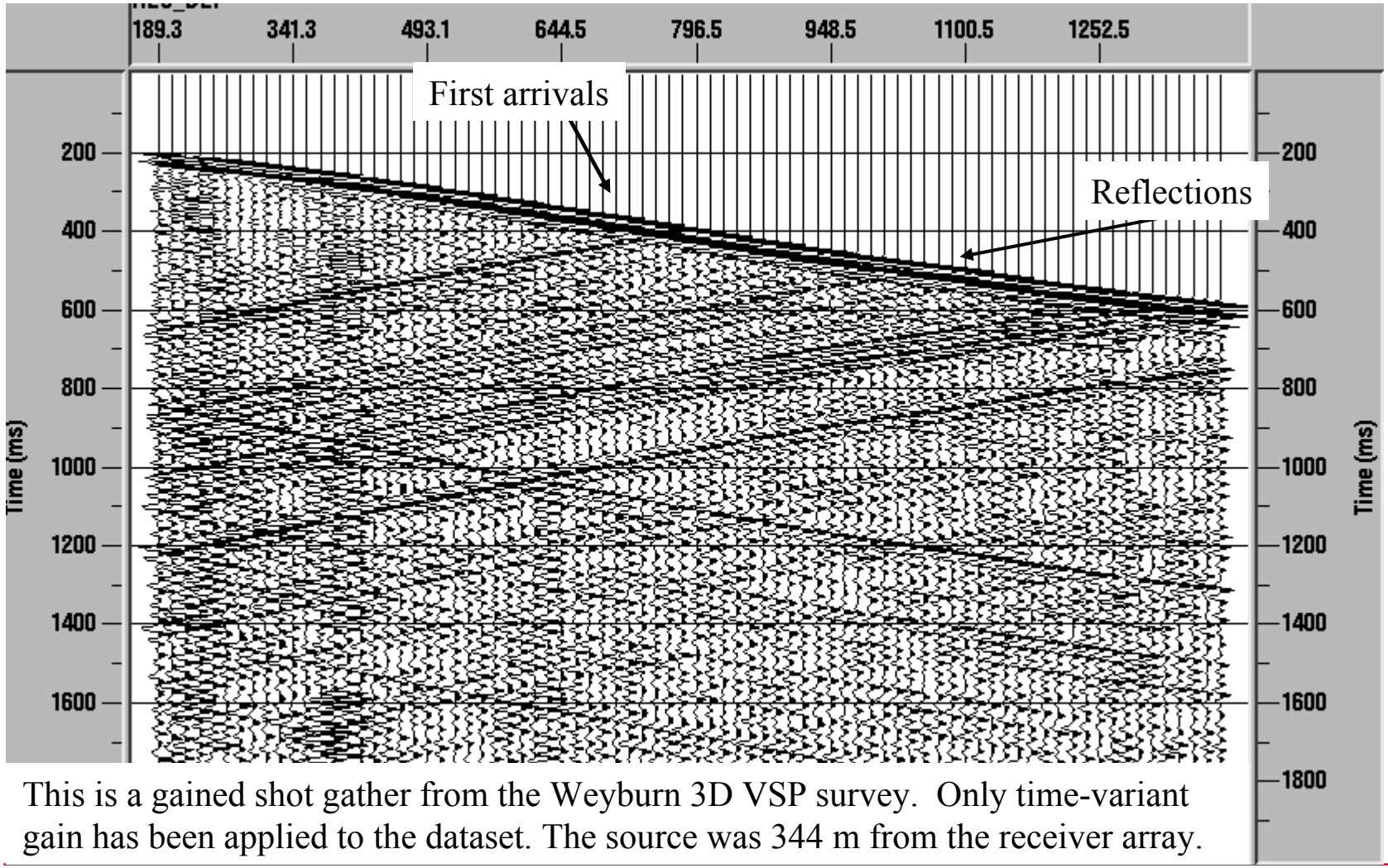
A Massive 4D VSP™ recorded in Saskatchewan, Canada Dec. 1999 and Dec 2001



P/GSI™

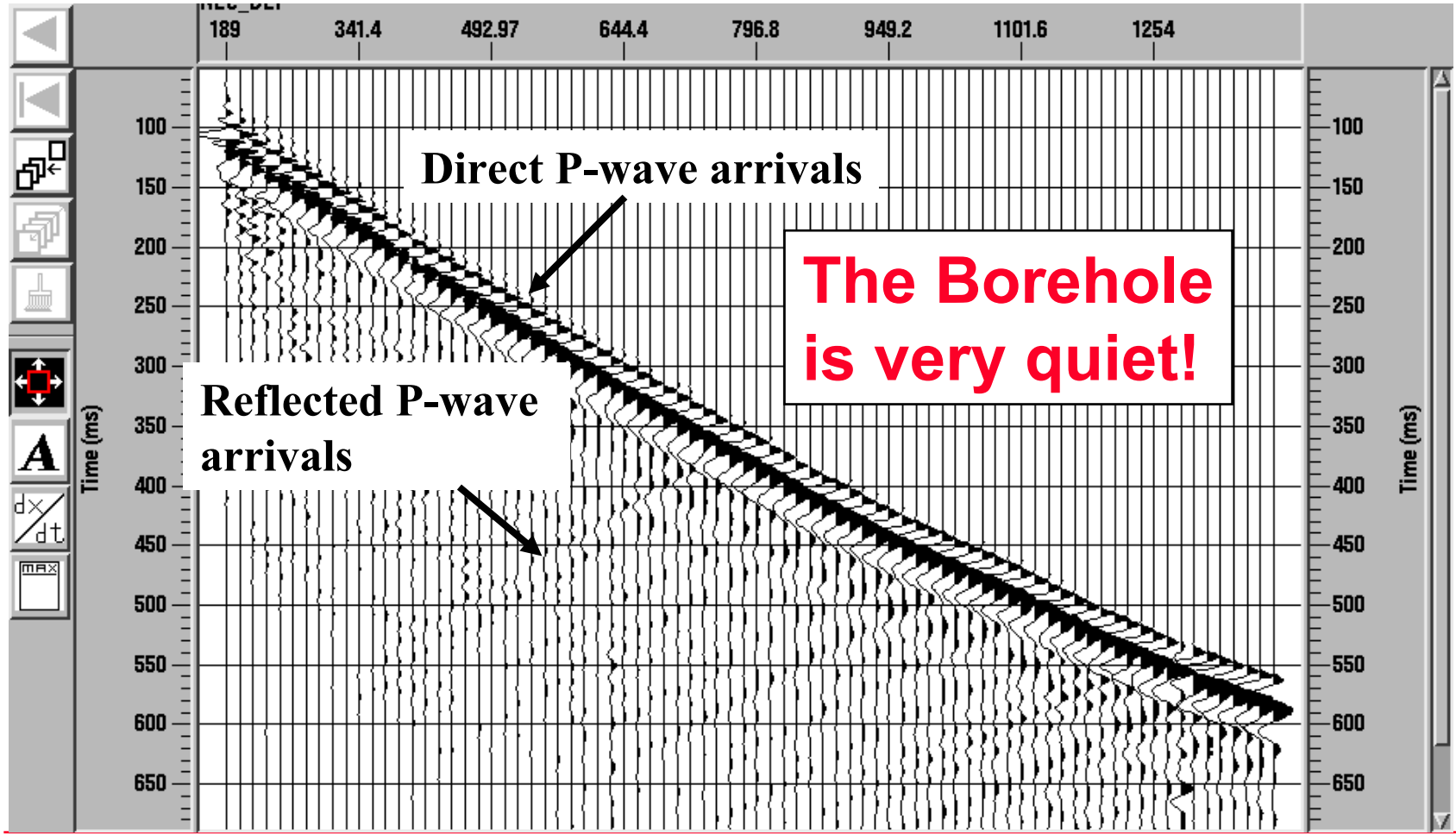
Shot location map of the 635 shots recorded on the P/GSI receiver array. The receiver array location is marked as a small white triangle. The 239 shots within 1,500 m of the receiver array (within red circle) were processed to create an image that was 700 m in radius around the receiver well (inner blue circle).

Weyburn 3D VSP
Dynamite VSP recorded on the 80 level receiver array

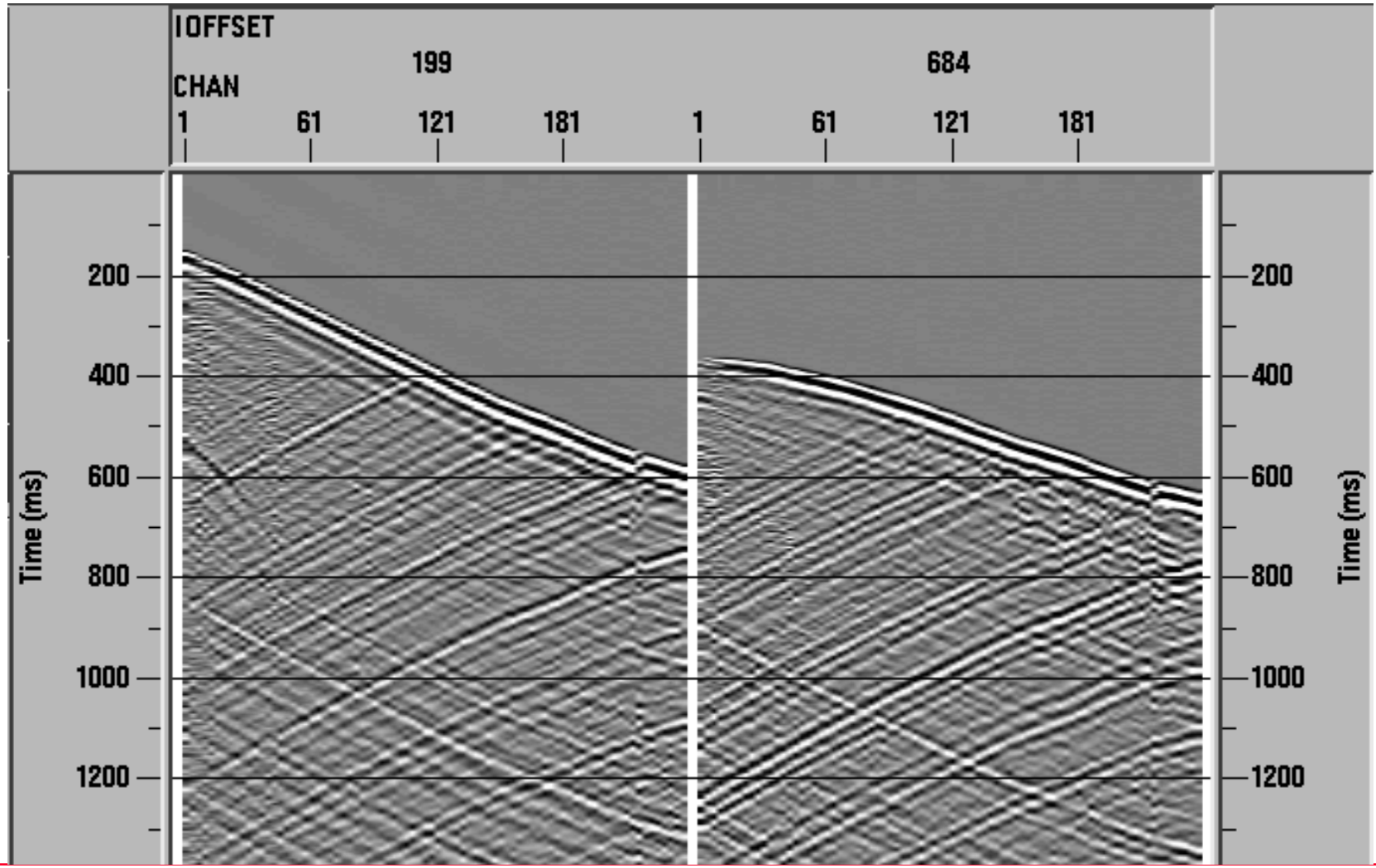


This is a gained shot gather from the Weyburn 3D VSP survey. Only time-variant gain has been applied to the dataset. The source was 344 m from the receiver array.

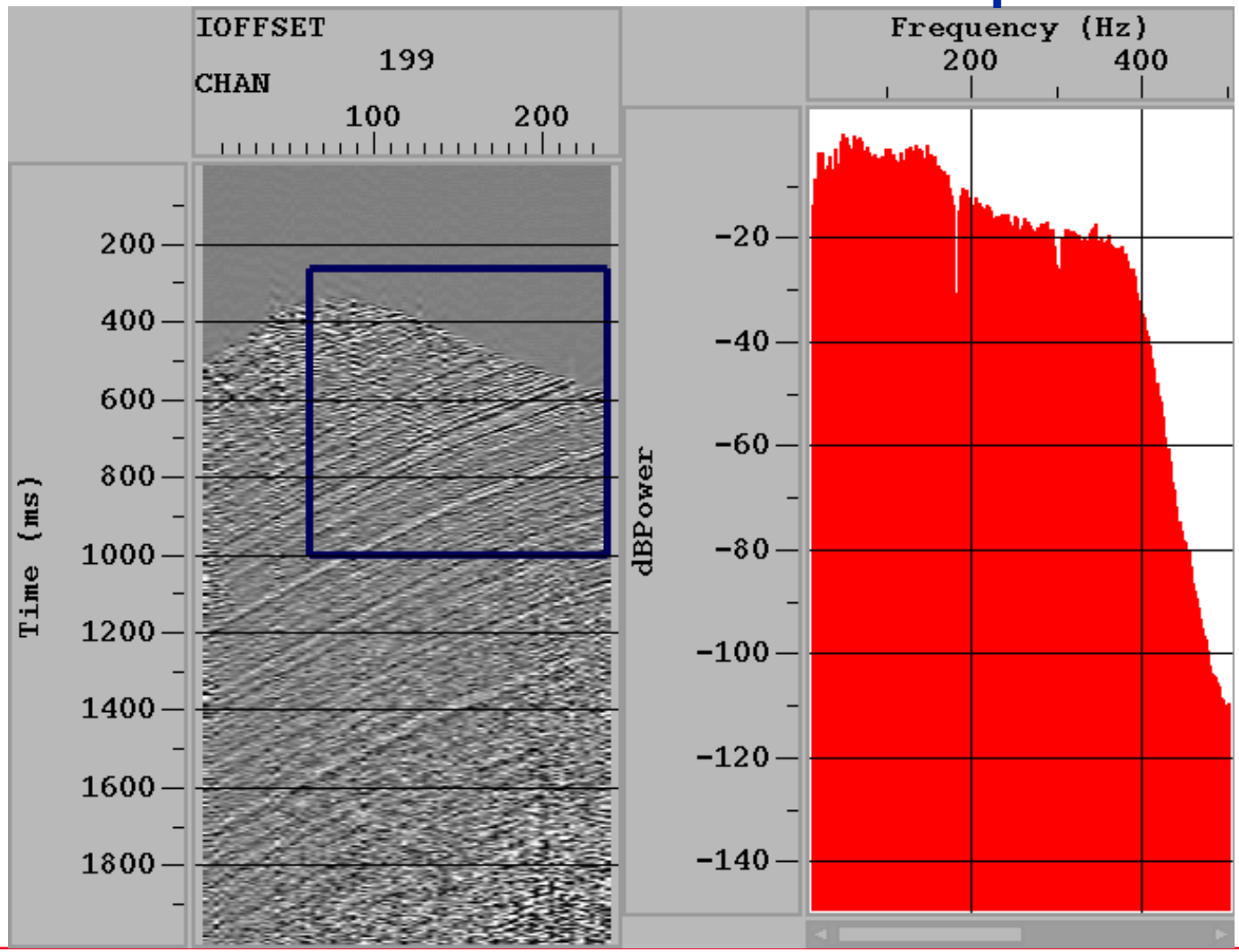
Weyburn 3D VSP
Close up of a P-wave shot recorded on the 80 level array



Weyburn 3D VSP. Data from 199 m and 684 m offsets before decon and wave field separation

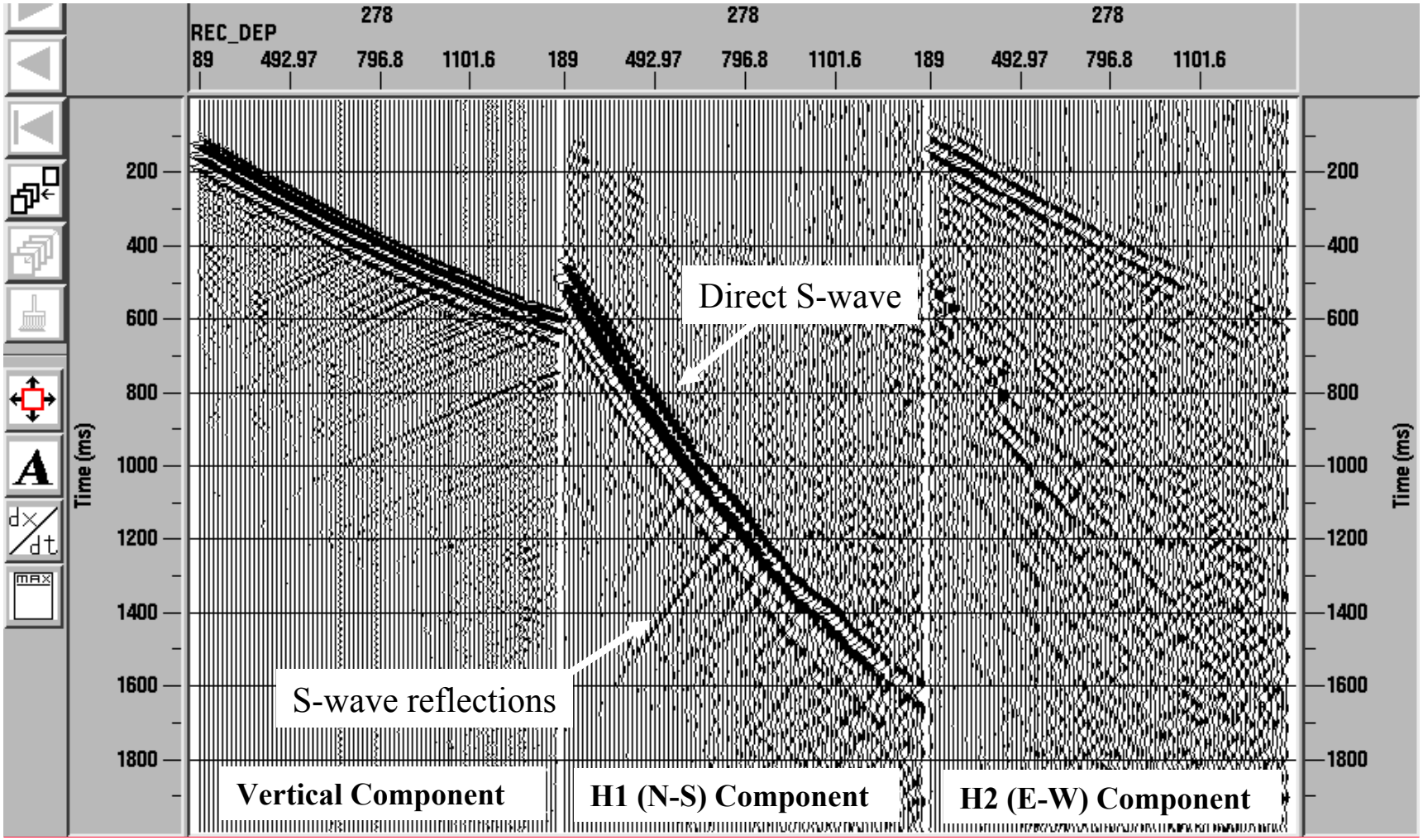


Weyburn 3D VSP. Data from 199 m offset after decon and wave field separation

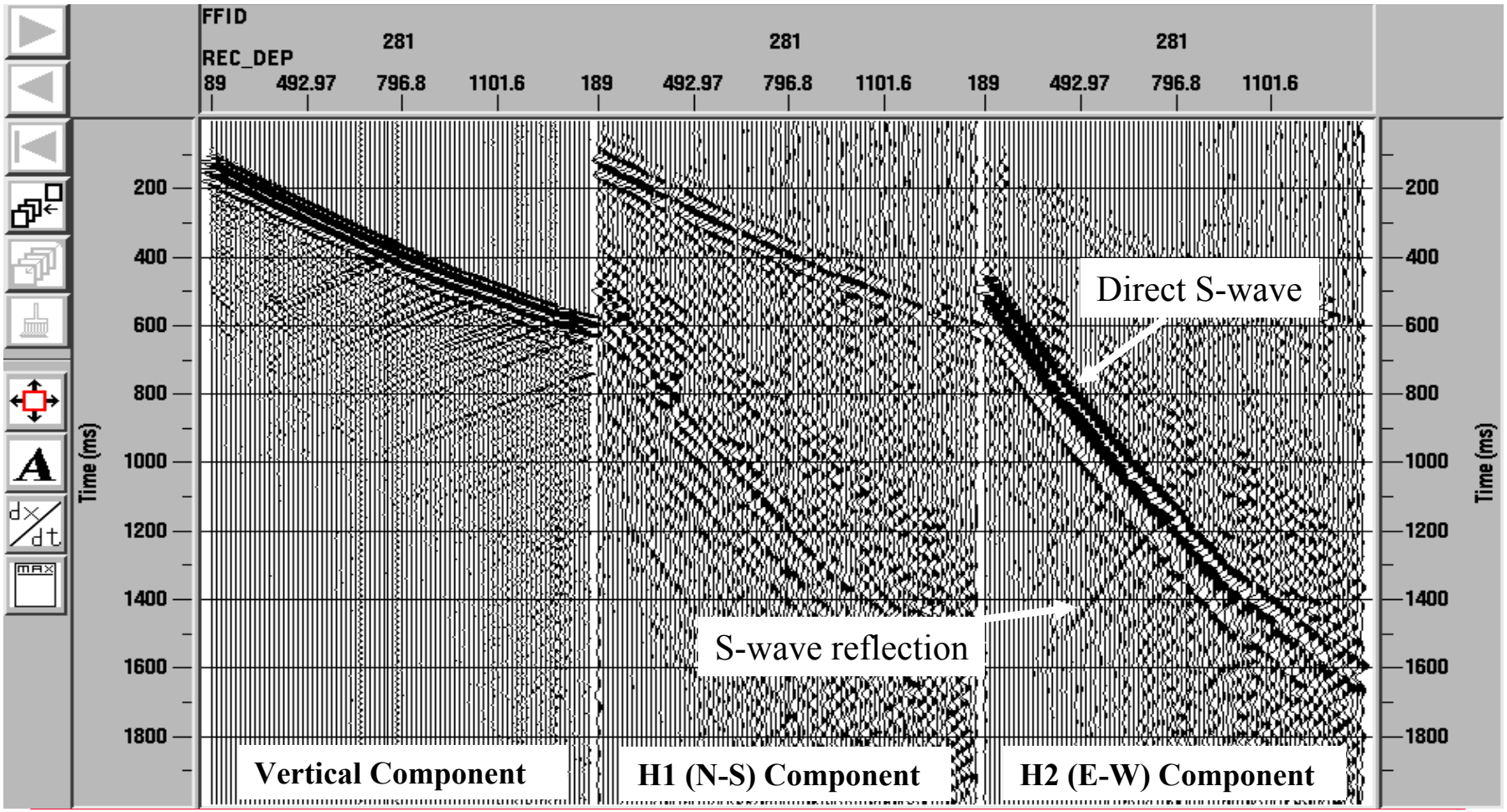


Amplitude spectrum of a shot record from offset 199 m with time variant gain, spiking decon, and median filter applied.

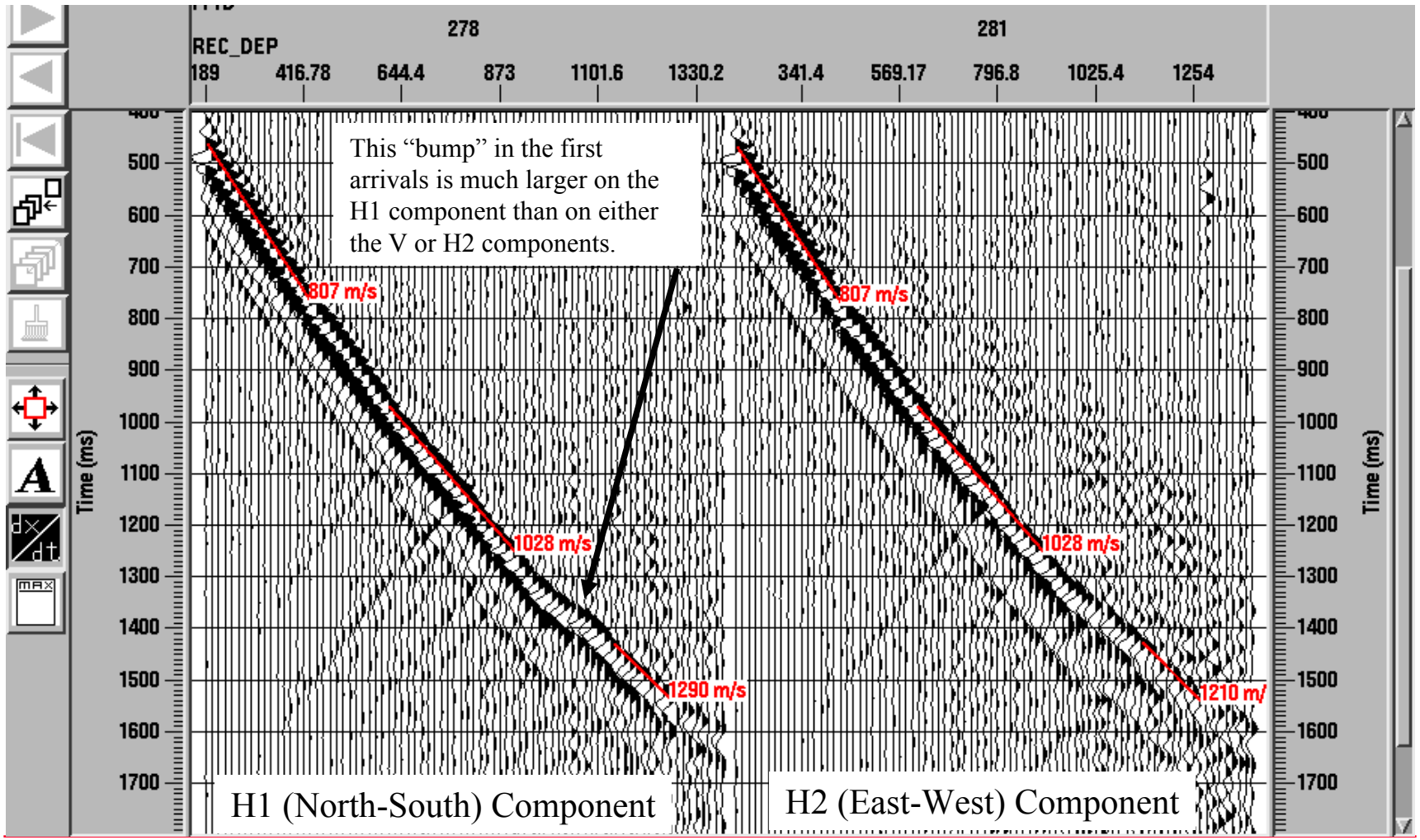
N-S Primacord VSP recorded on the 80 level receiver array



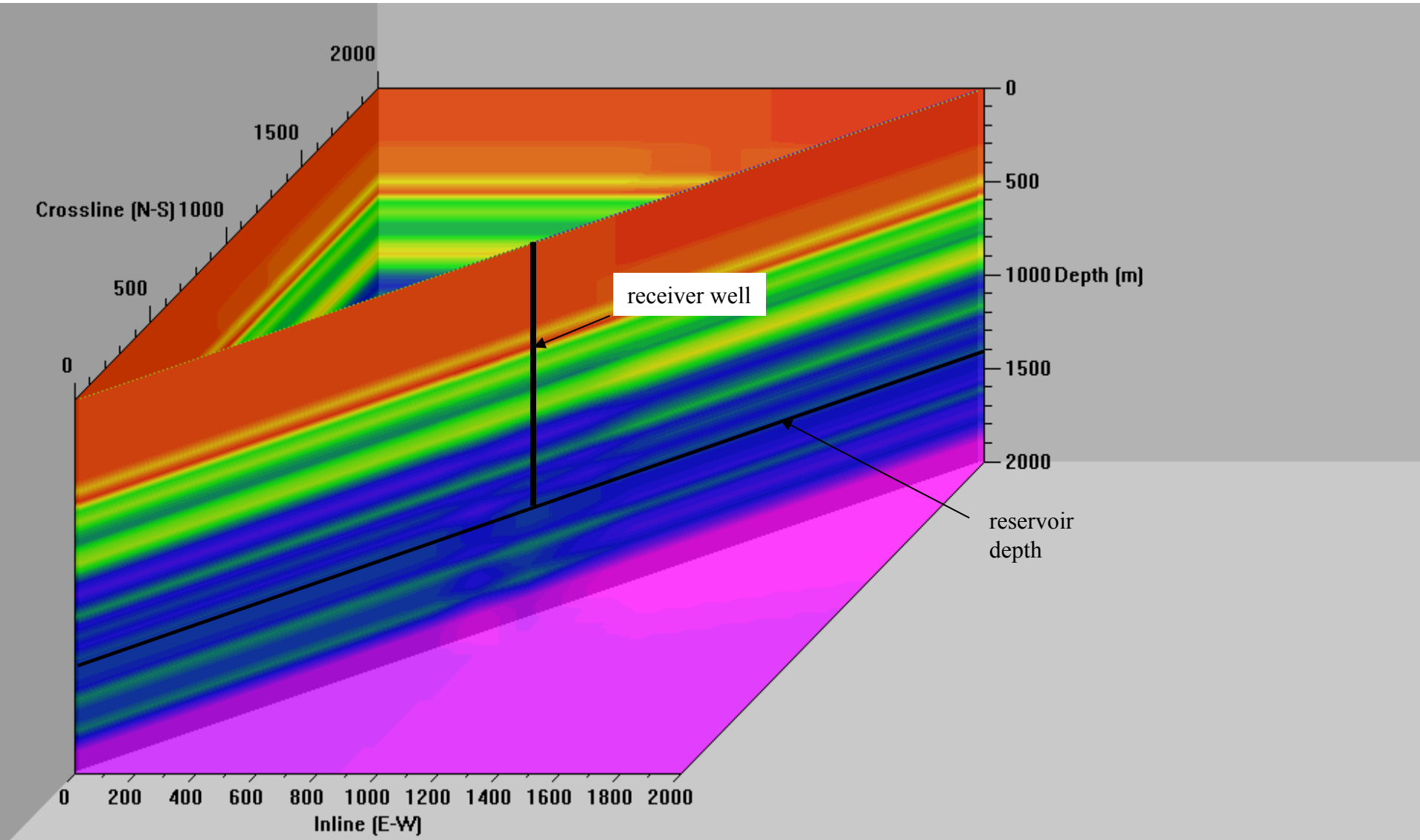
E-W Primacord VSP recorded on the 80 level receiver array



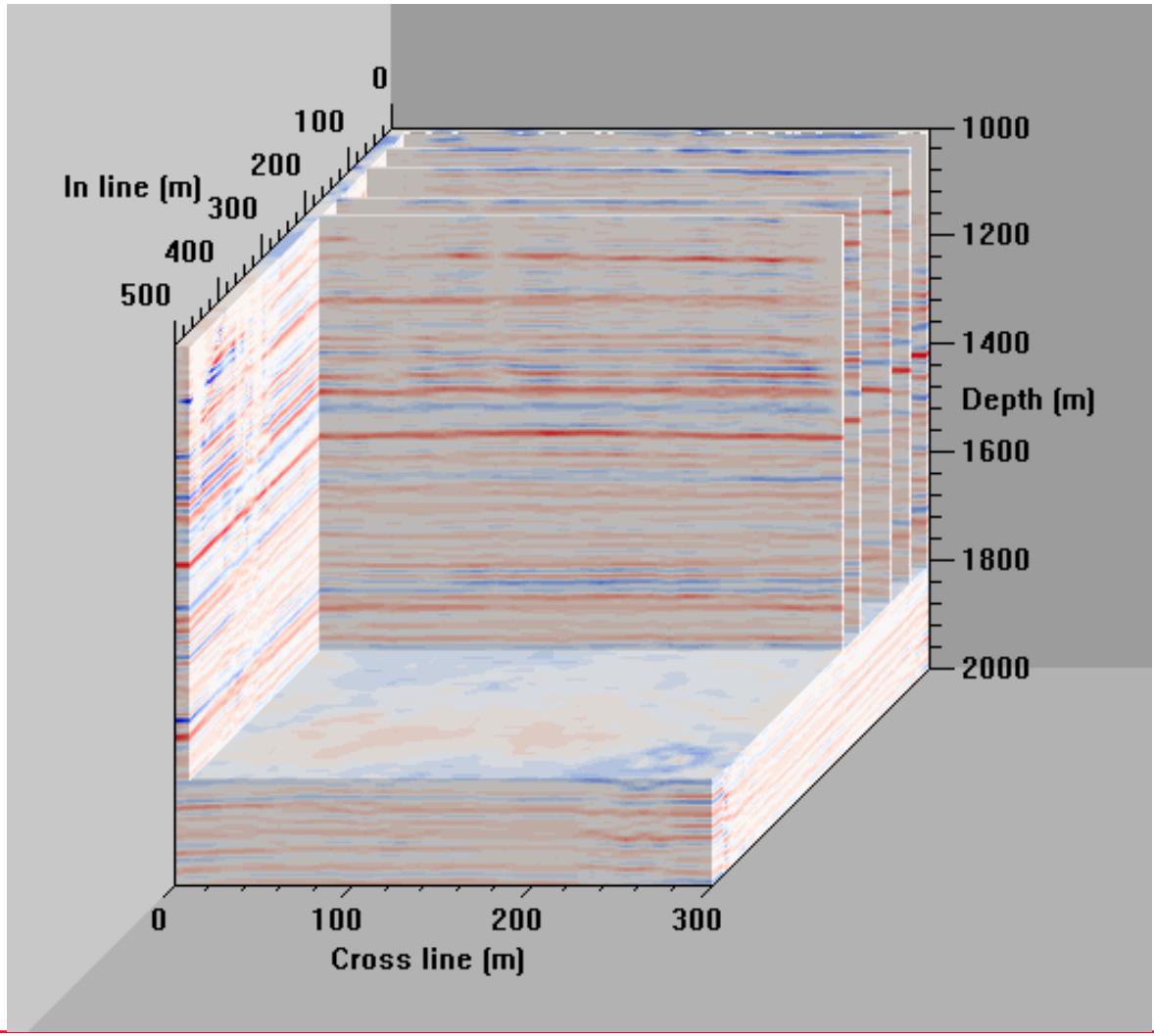
Comparing two S-wave records on the 80 level array

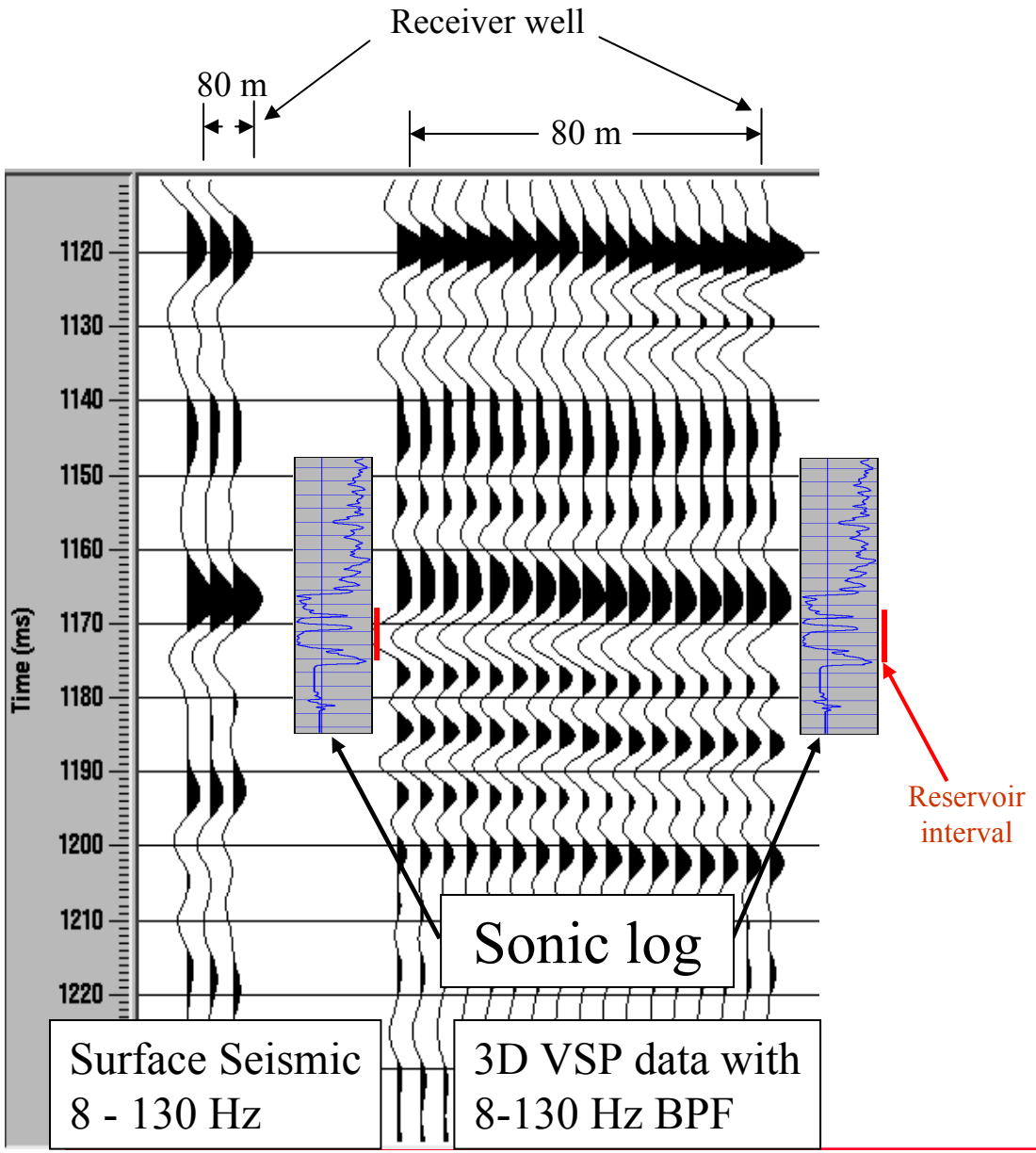


Velocity field derived from 3D VSP data.

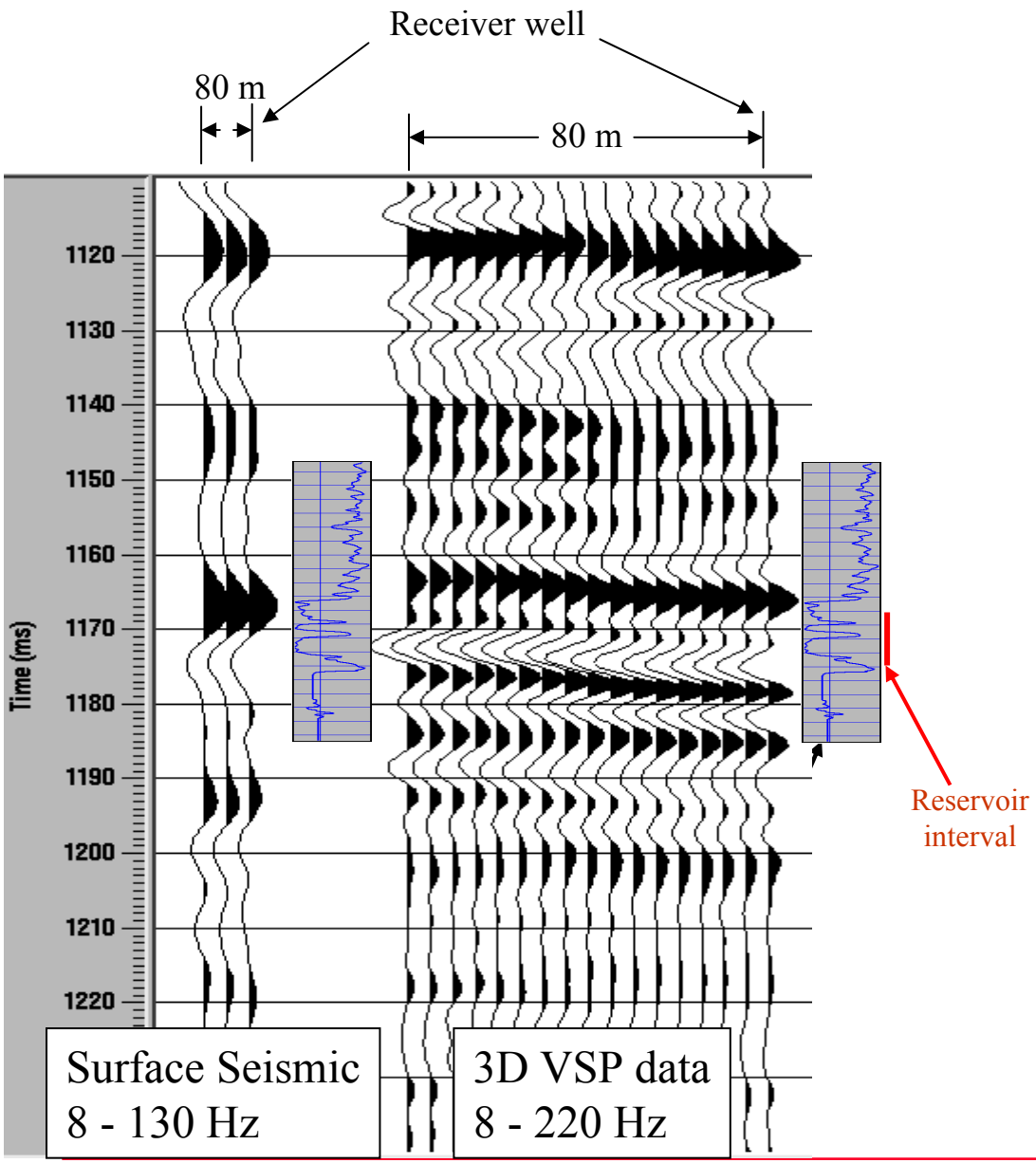


3D View of the image volume around the 3D VSP well



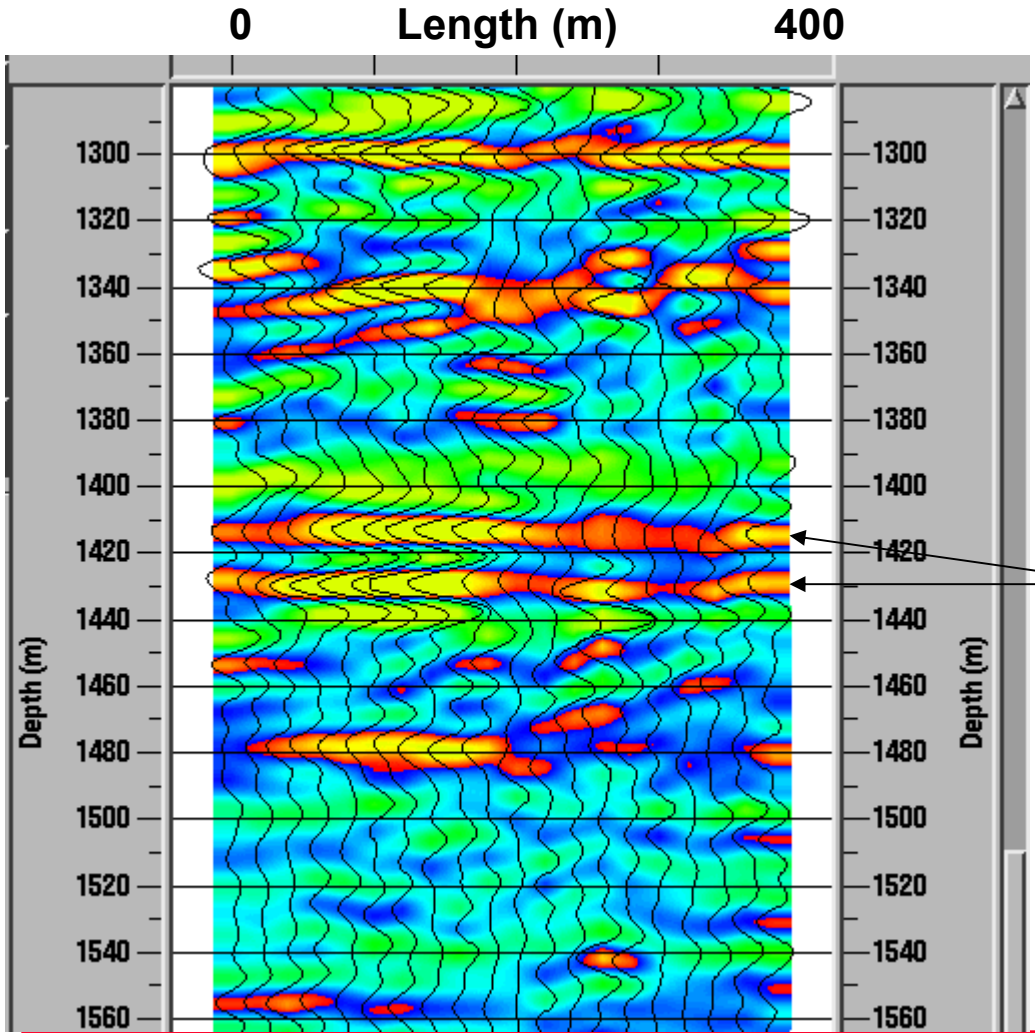


Comparison of surface seismic and filtered borehole seismic data at Weyburn Field. These two images cover exactly the same ground from the receiver well to 80 m southwest of the receiver well. The VSP data has been bandpass filtered to match the frequency spectrum of the surface data



Comparison of surface seismic and borehole seismic data at Weyburn Field. These two images cover exactly the same ground from the receiver well to 80 m southwest of the receiver well. The receiver well is at the right hand side of both images.

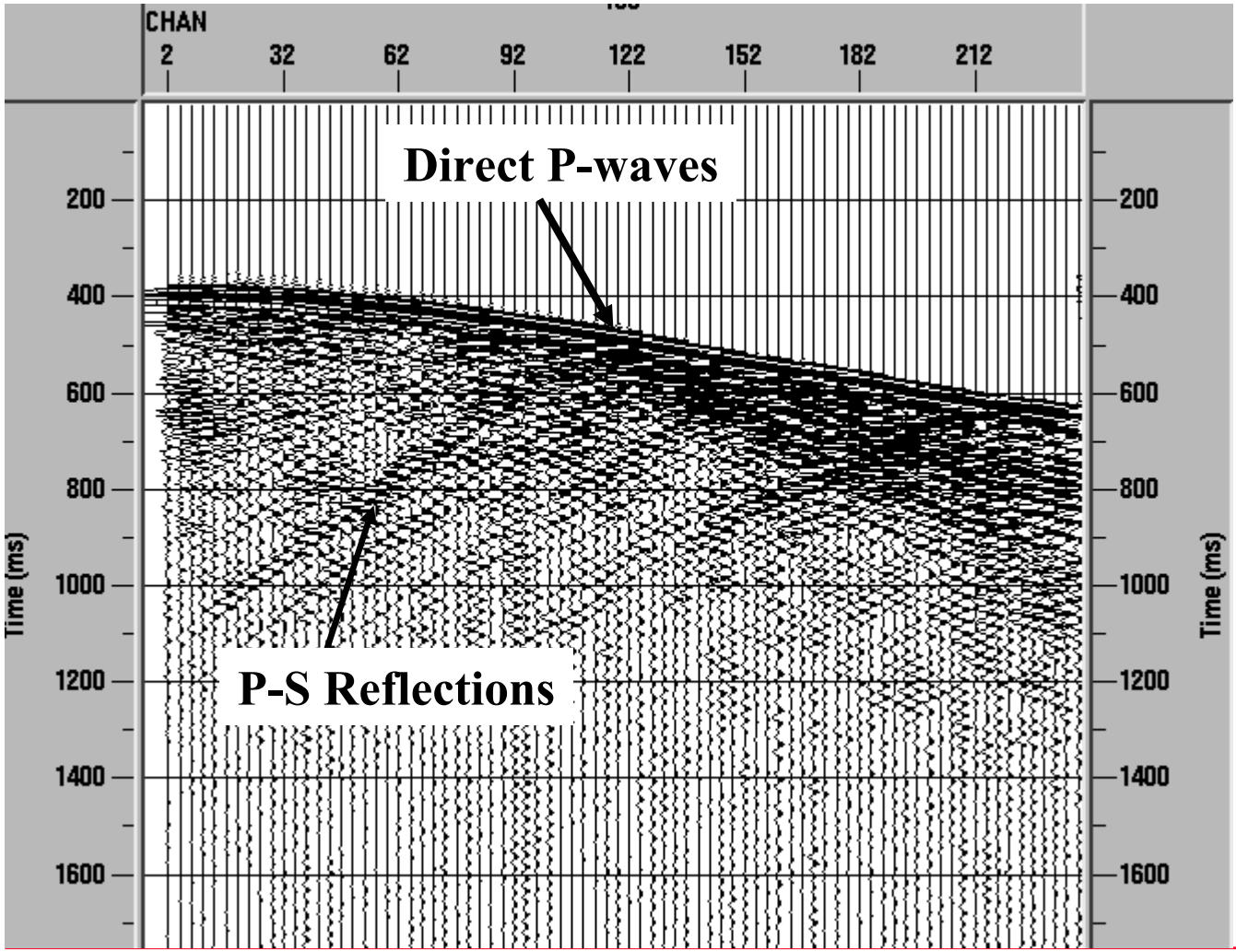
East-West slice through the 3D volume.



Trace spacing is 20 m.
The Maximum frequency is 210 Hz with the wavelength as short as 14 m.

Reservoir level

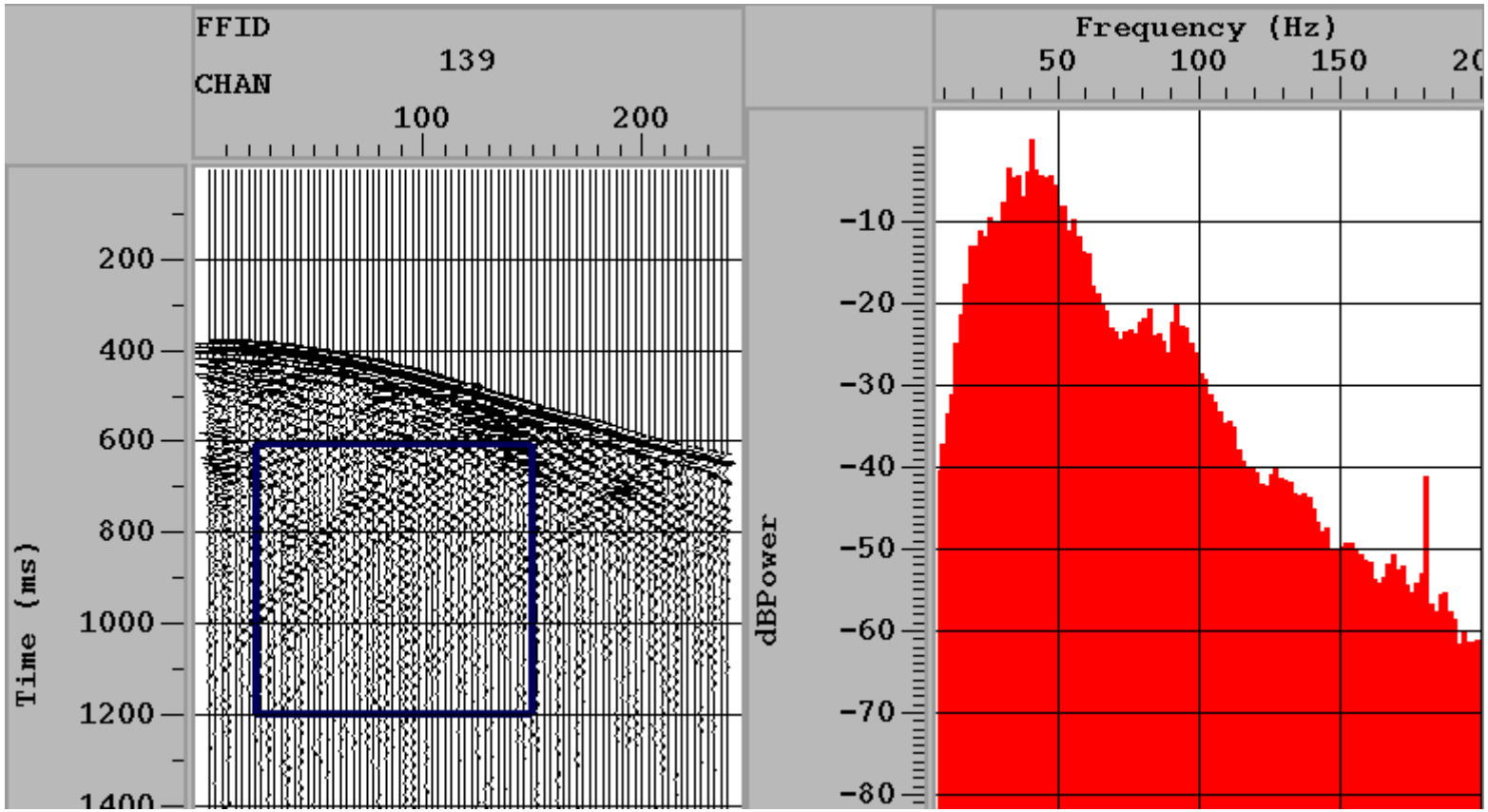
Converted Shear waves



Inline horizontal component showing P-S reflections.

FFID 139 is offset 718 m south of the receiver well. The components were rotated so that one of the components was pointed toward the source. This shot record shows the inline horizontal component with strong converted S-wave reflections. The data has had no other processing beyond rotation. The traces are displayed with individual trace scaling.b

Converted Shear waves



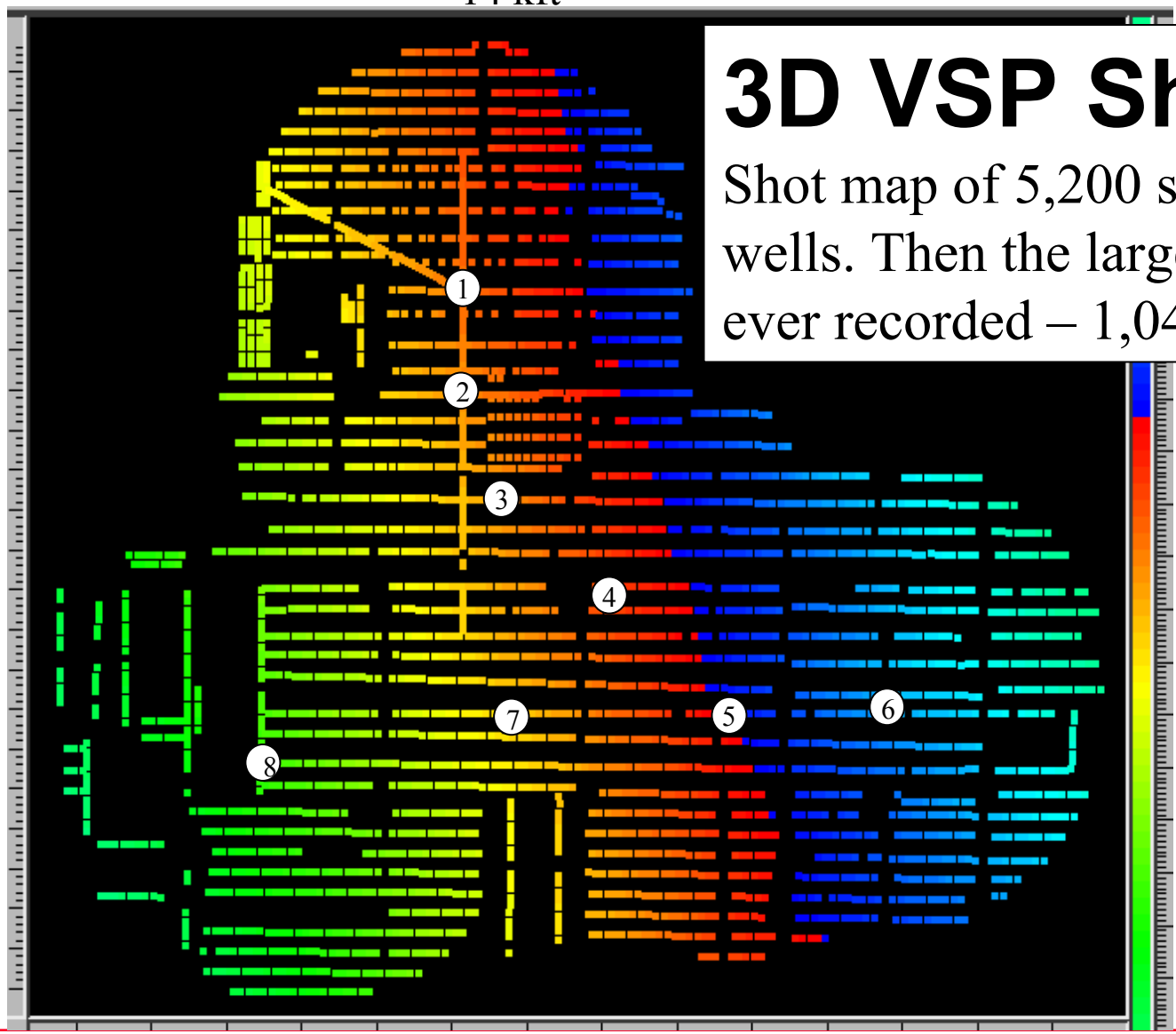
Spectrum of P-S converted reflections. The amplitude spectrum of P-S converted reflections is shown on the right. The reflection amplitudes are -30 dB at 104 Hz. The apparent velocity of the S-wave reflection is 850 m/s. The wavelength of the 100 Hz component is therefore 8.5 m.

Multi-Well 3D VSP
September, 2000

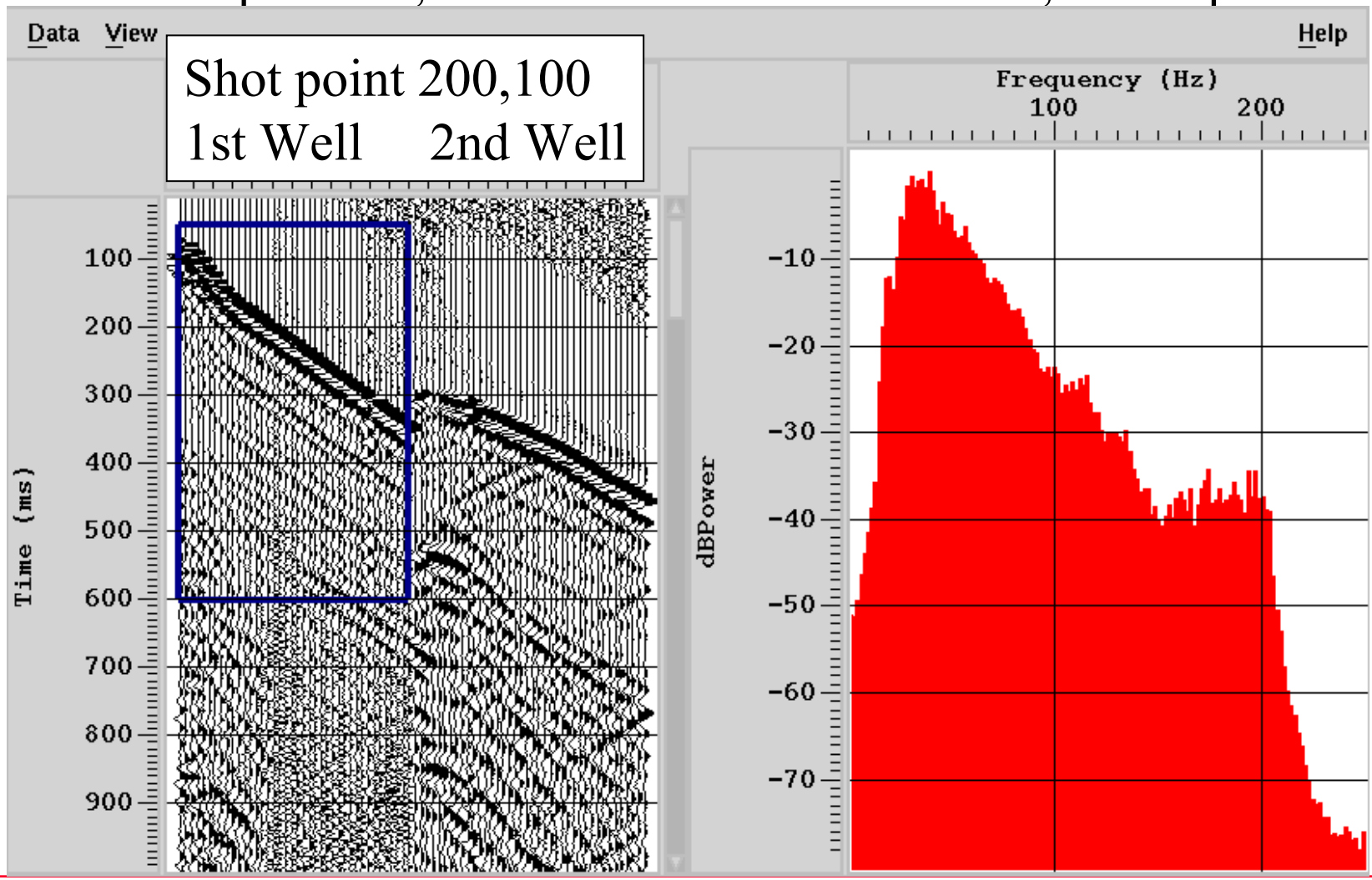
- A one million trace, 5,000 source point, 8-well 3D VSP data set recorded in 14 days
- 150 Hz 3D VSP vs 25 Hz for surface seismic

3D VSP Shot Map

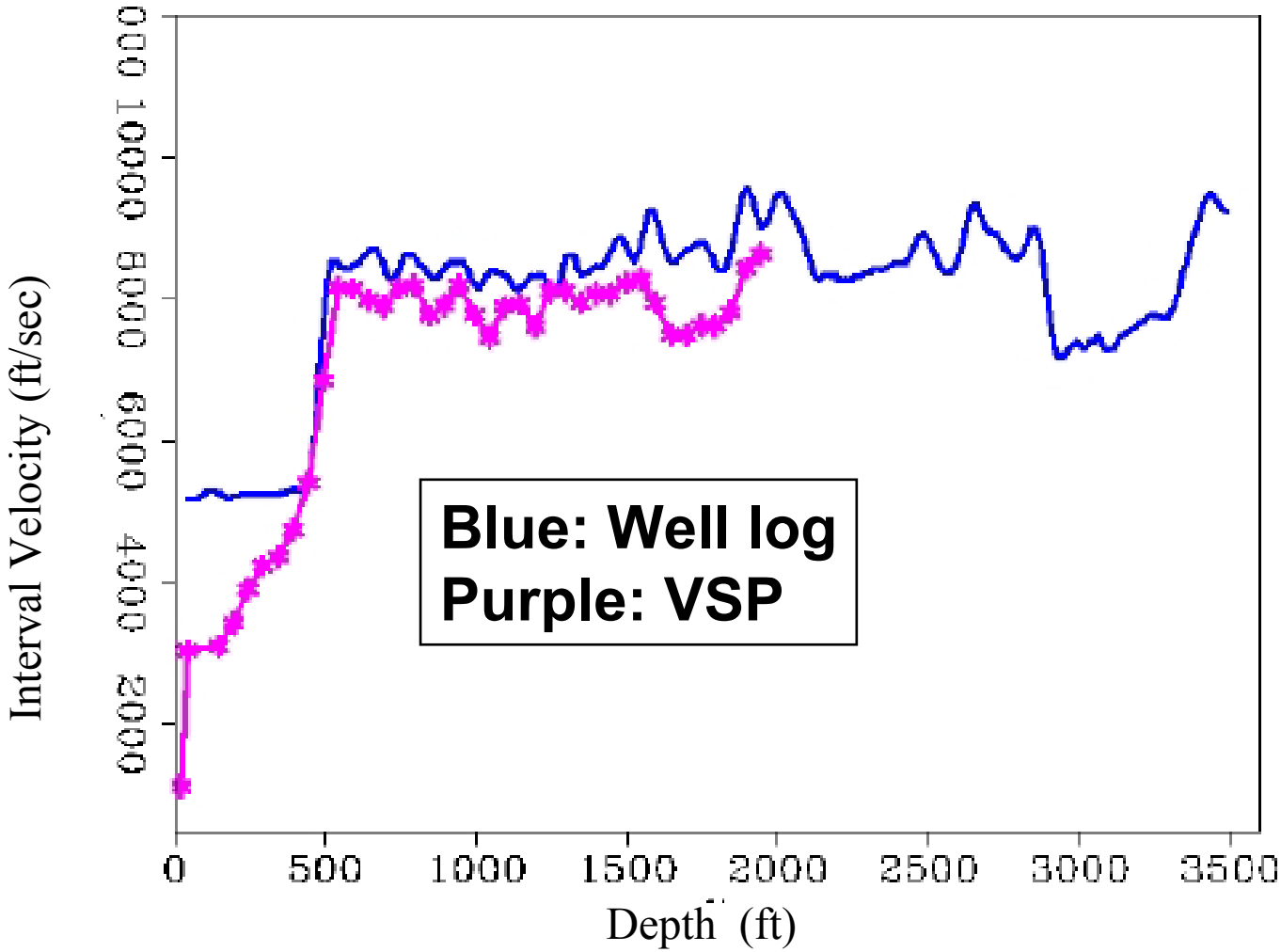
Shot map of 5,200 shots into 8 wells. Then the largest 3D VSP ever recorded – 1,040,000 traces.



Multi Well 3D VSP
1st well spectrum, 50 ft Source Offset from 1st, Raw Spectra

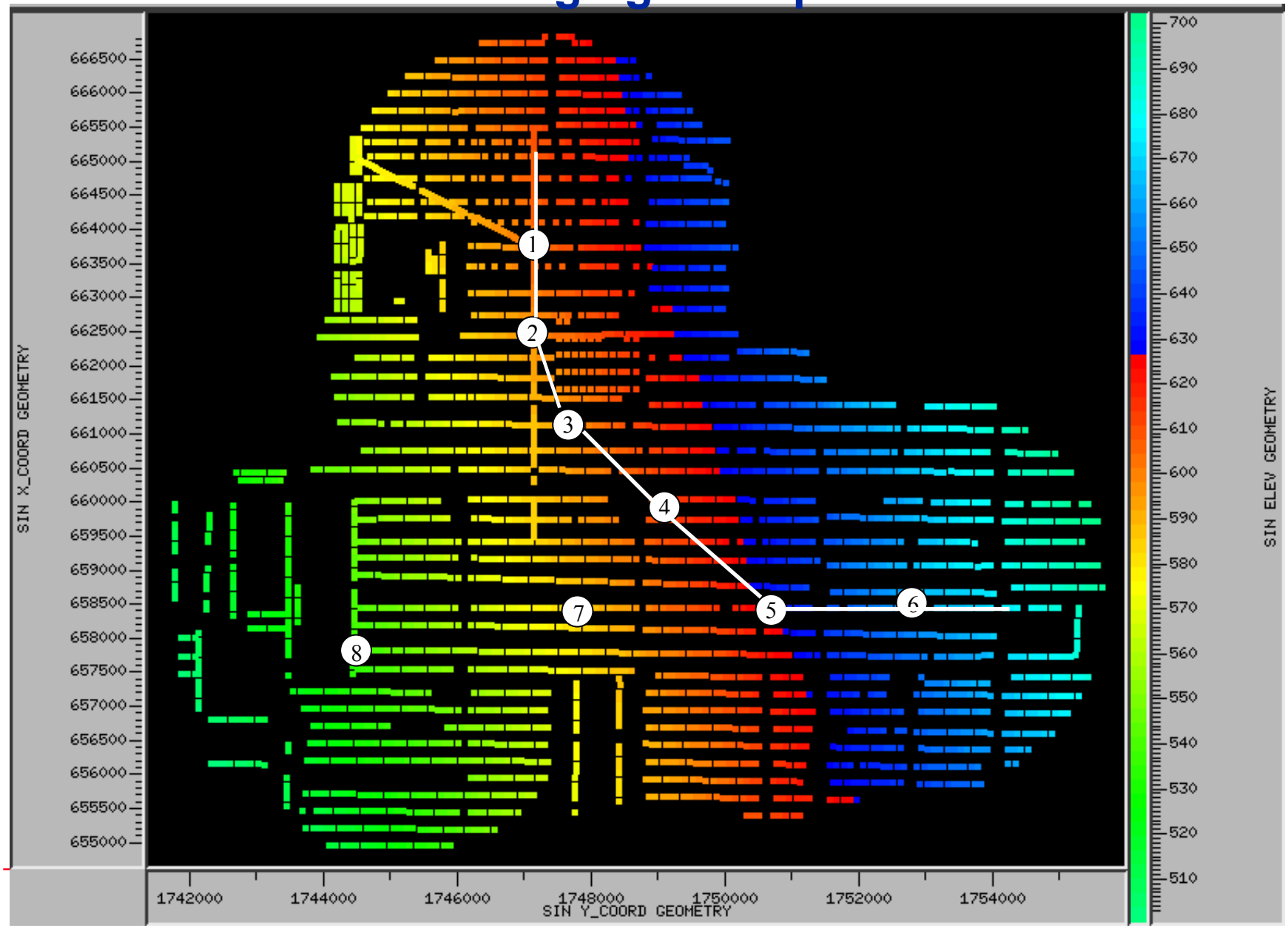


Multi Well 3D VSP: Interval Velocities from log and VSP

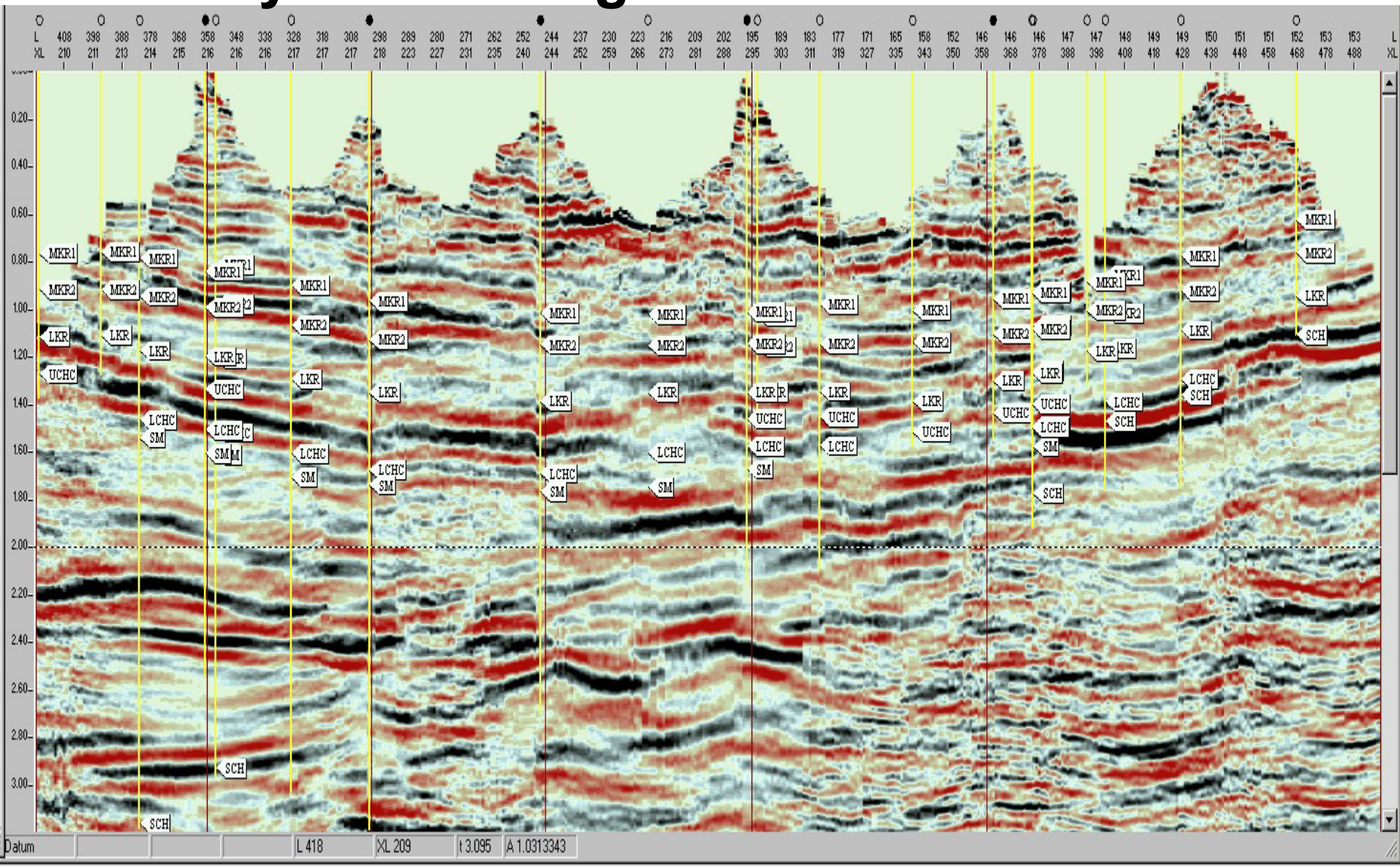


Multi Well 3D VSP Imaging Examples

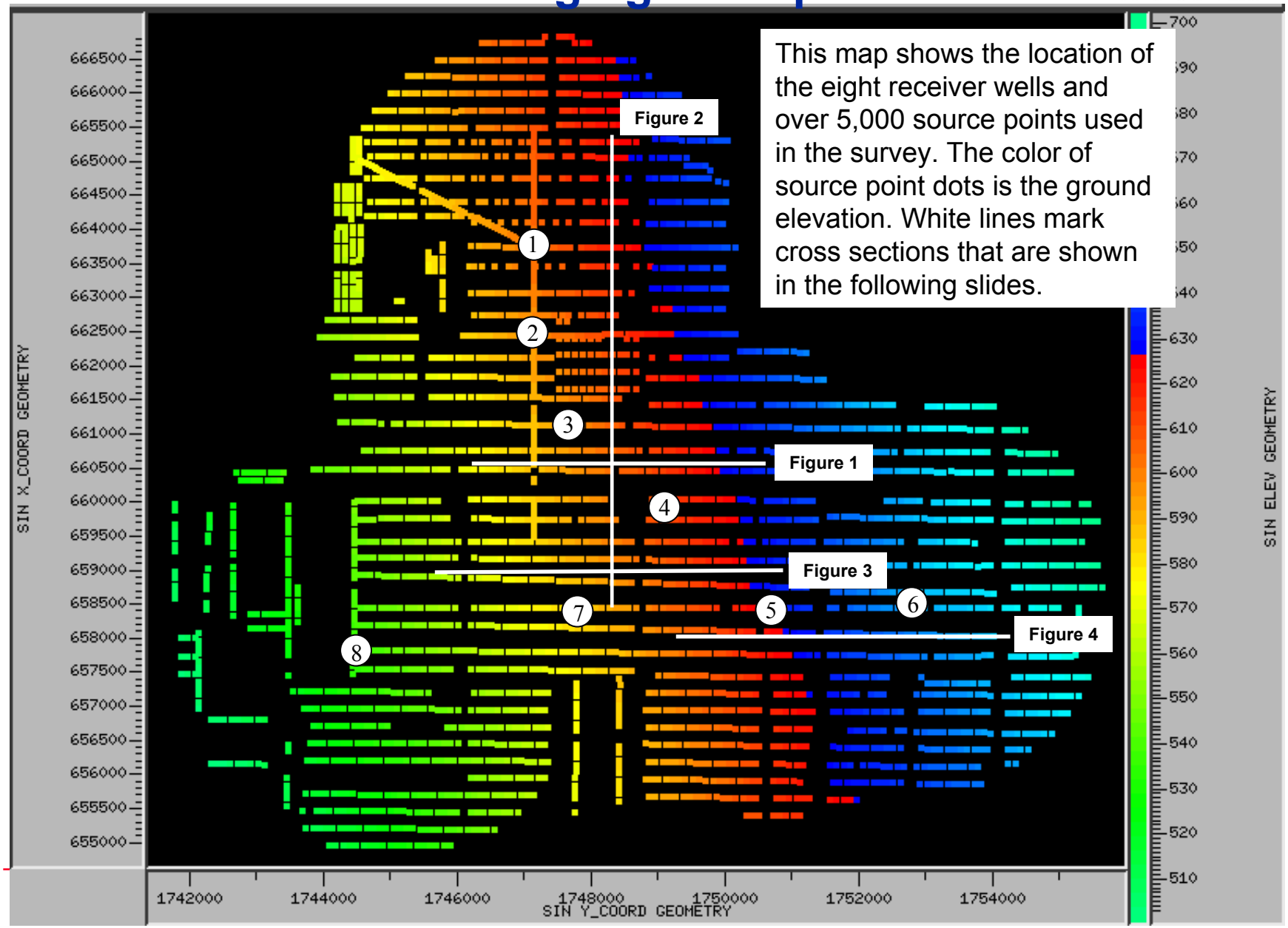
Multi Well 3D VSP: Imaging Examples



Arbitrary Line through wells 1 - 6



Multi Well 3D VSP: Imaging Examples



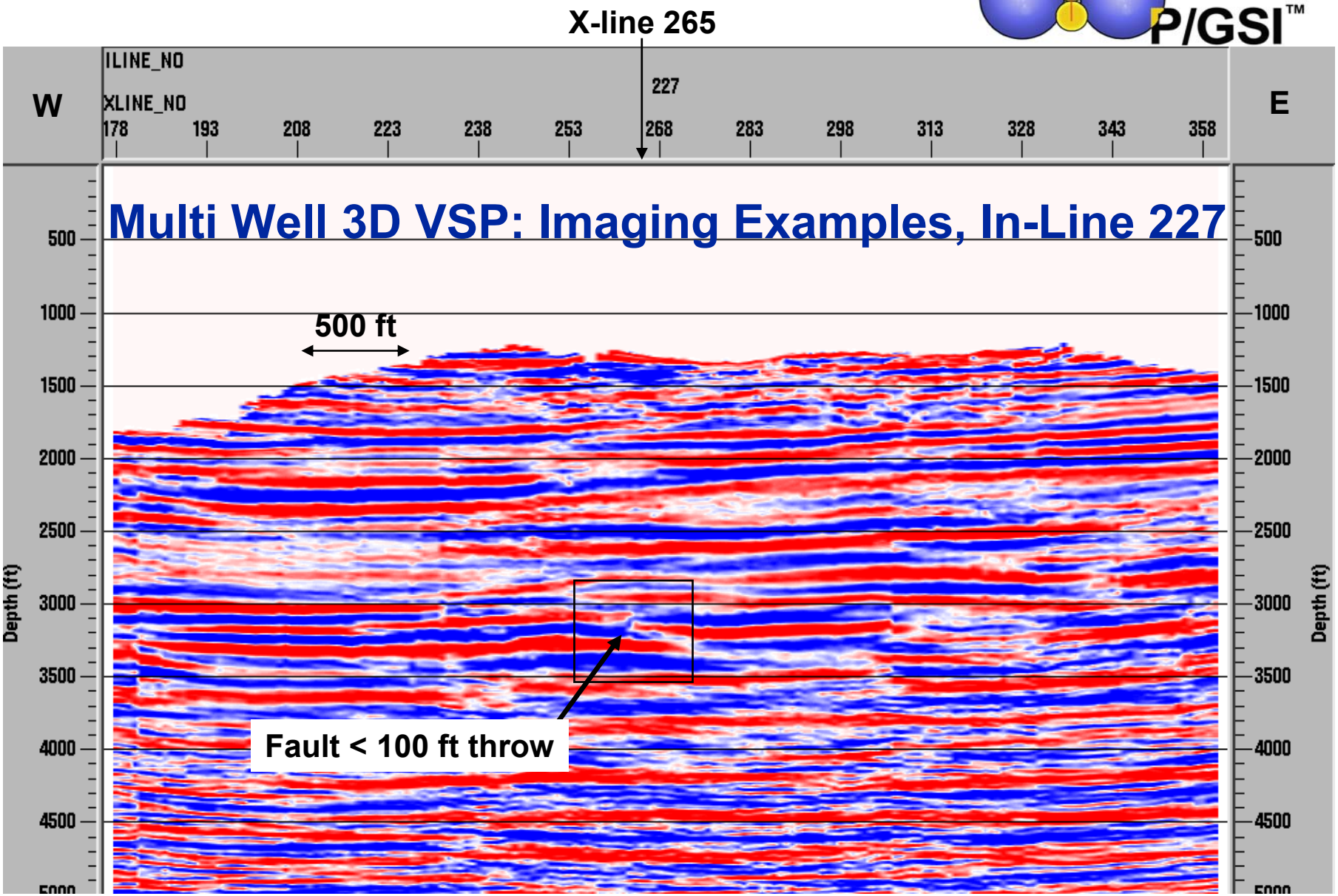


Figure 1. This line extends from West (left) to East (right) and shows a fault with 75 to 100 ft of throw. The crossing line on the next slide also covers the fault.

Multi Well 3D VSP: Imaging Examples

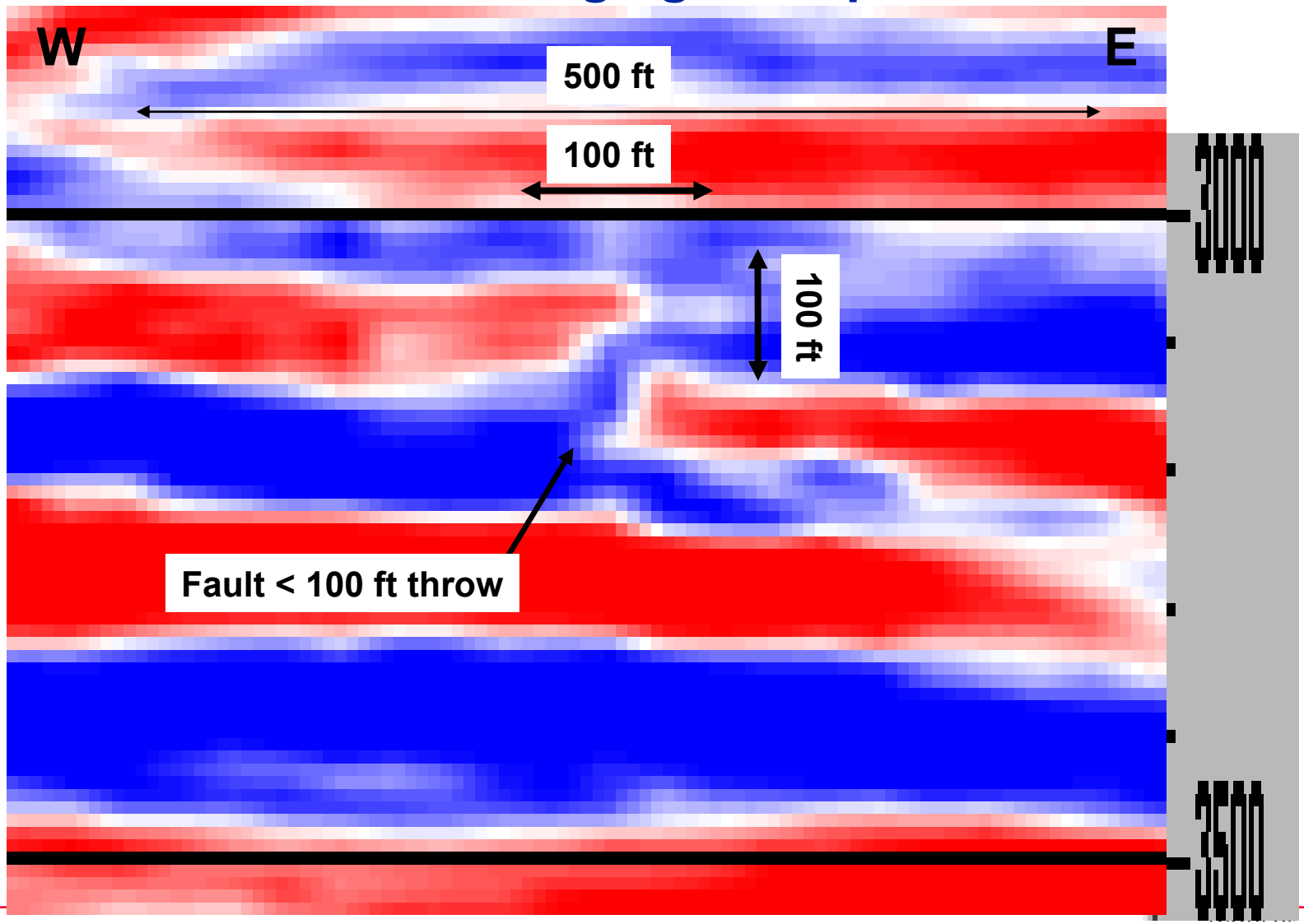


Figure 1B. This line extends from West (left) to East (right) and shows a fault with 75 to 100 ft of throw.

Multi well 3D VSP - Summary

- The 3D VSP method has been shown to be able to image complex geology and has identified a number of new drilling targets.
- Using the 3D VSP technique we recorded 150 Hz high quality data in an area where surface seismic recorded a low S/N ratio 25 Hz.

The Massive 3D VSP™ Technology provides (recap):

- An improved lateral and vertical resolution in the 3D image with a factor of two - eight, compared with surface seismic.
- An ability to Image in areas that previously were “non seismic”.
- An ability to map small scale faults with displacements less than 10 ft (3 m)
- A detailed velocity model through 3D tomography.
- A capability to image to 25,000 ft (7.6 km) and below.
- The highest resolution 3D imaging technology in the oil and gas industry today.

Observations & Conclusions

- Borehole Seismology can now be used for 3D imaging.
- Borehole Seismology complements surface seismology by providing focused high resolution images.
- Borehole seismology is still seismology so all the normal interpretation and processing tools apply - special adaptation is needed however.
- The key to the improved Borehole seismic imaging is the data quality and data volume that now can be achieved with new data acquisition tools.

We acknowledge

PanCanadian Petroleum LTD. and the Weyburn Partners

for the permission to show the data and the images from the Weyburn field displayed in this presentation.

In particular we acknowledge
Dave Cooper and Guoping Li, PanCanadian Petroleum for making the 3D VSP survey possible.

Paulsson Geophysical Services, Inc. (P/GSI) acknowledges

Vaquero Energy, Inc.

for permission to show data and images from the Edison Field displayed in this presentation.

For more information visit us at:

www.paulsson.com

End of Presentation