Integration of reflection seismic and microseismic data: processing and interpretation

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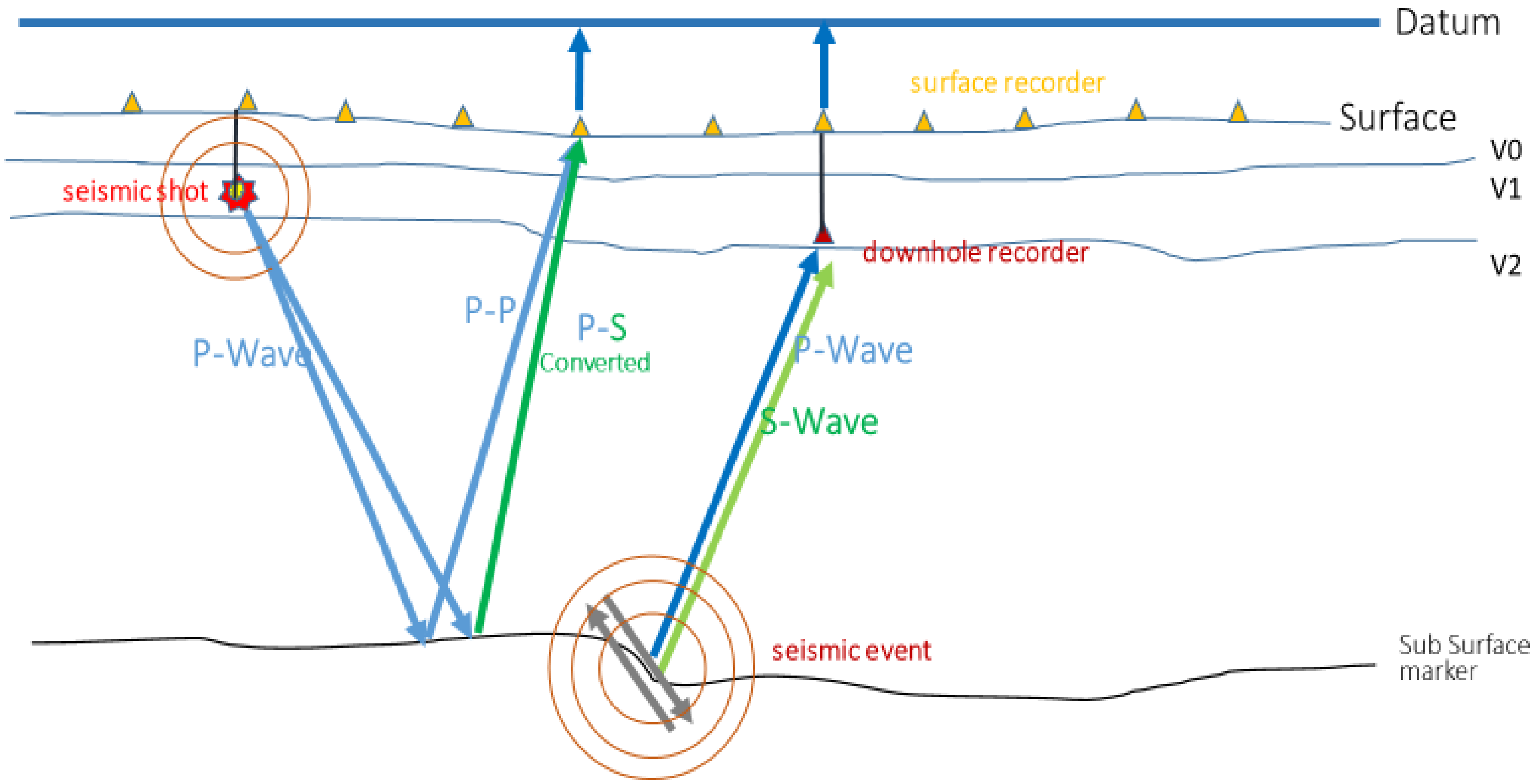
Motivation

- Technologies developed in reflection seismology processing can be applied to continuously recorded microseismic data.
- These will improve the signal to noise ratio of induced seismic events, and increase the number of detected events
- The 3-D data can provide a much improved depth solution, when compared to a 1-D model
- More detected events, increased accuracy of the event locations will greatly aid in the mapping and interpretation of the reservoir.

The raypath through the subsurface



The passive and active seismic waves pass through the same media, to be recorded by surface or near surface geophones

Reflection event arrivals

For P-P reflections:

$$T_{pp}(t|\, x_s, x_r, V_{PP}) = W_p(t) * R_p(t) + Noise$$

For P-S (converted) reflections:

$$T_{ps}(t|\, x_s, x_r, V_{PS}) = W_p(t) * R_{ps}(t) + Noise$$

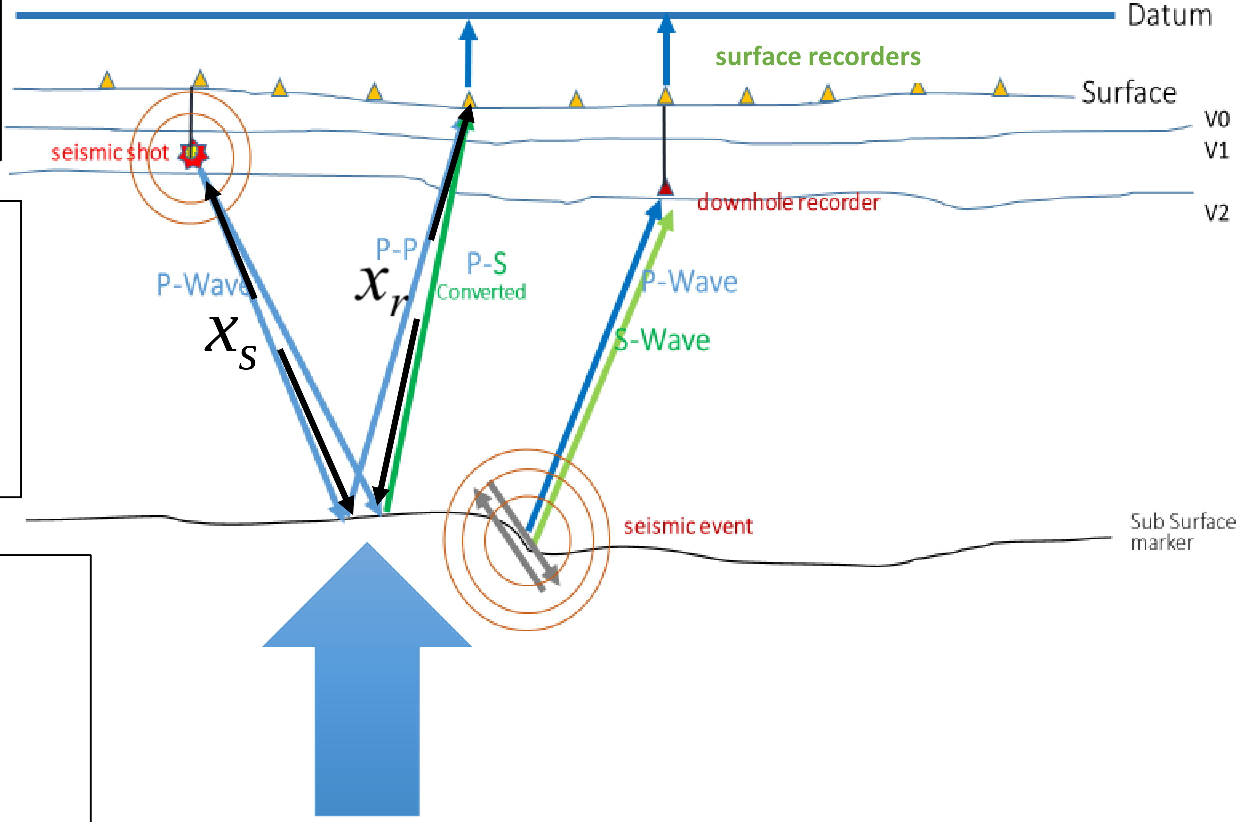
$W_p(t)$ = *source wavelet*

$R_p(t)$ = *reflection coefficient series*

$*$ *Is the convolution operator and*

$R_p(t) \approx \mathbf{G}_p$, $R_s(t) \approx \mathbf{G}_s$ (**G** *is a Green's function*)

Reflection data



Passive event arrivals

For P arrivals:

$$\boldsymbol{T}_p(t \mid x, t_0, V_P) = \boldsymbol{W}_p(t) * \boldsymbol{G}_p + Noise$$

For S arrivals:

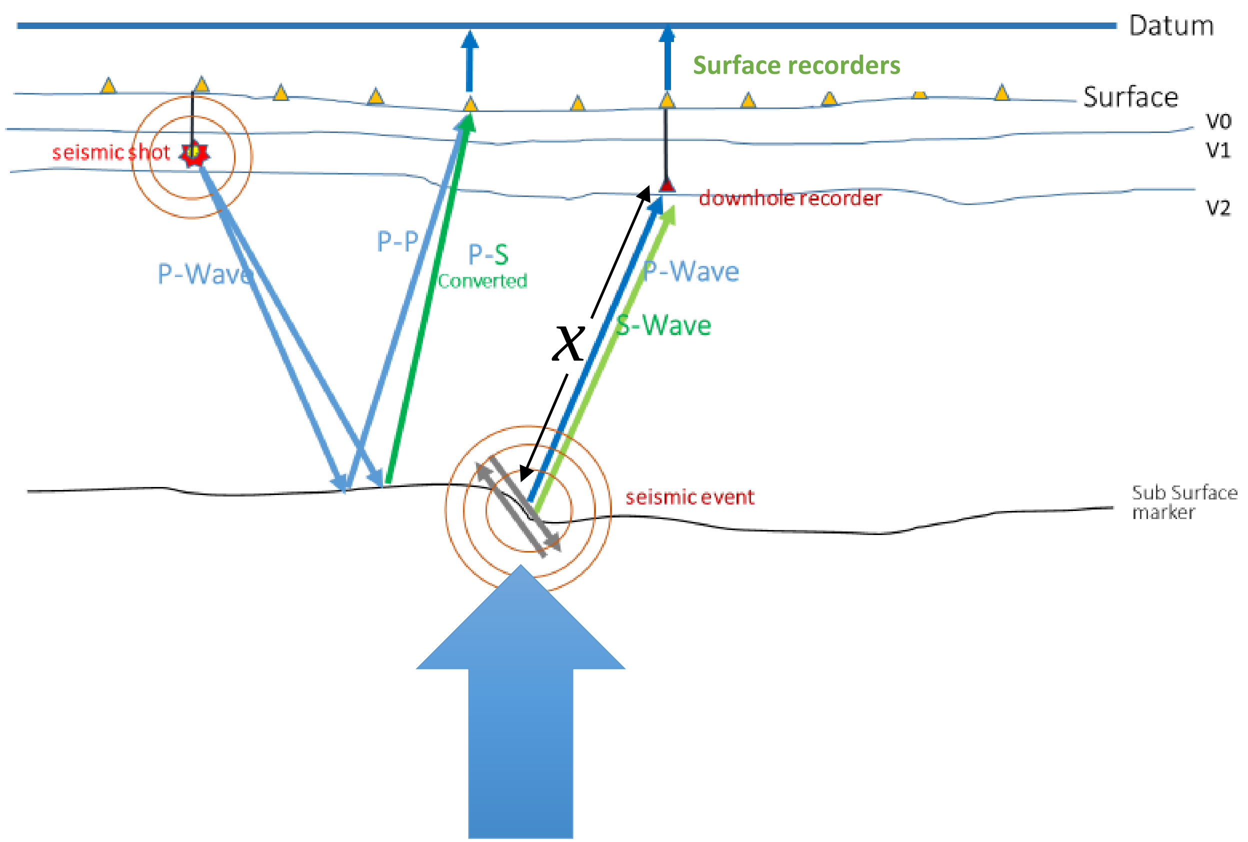
$$\boldsymbol{T}_s(t \mid x, t_0, V_S) = \boldsymbol{W}_s(t) * \boldsymbol{G}_s + Noise$$

$\boldsymbol{T}_p(t)$, $\boldsymbol{T}_s(t)$ = *recorded seismic events*

$W_p(t)$ = *source wavelet*

$\boldsymbol{G}_p$, $\boldsymbol{G}_s$ = *Green's function*

Passive data arrival

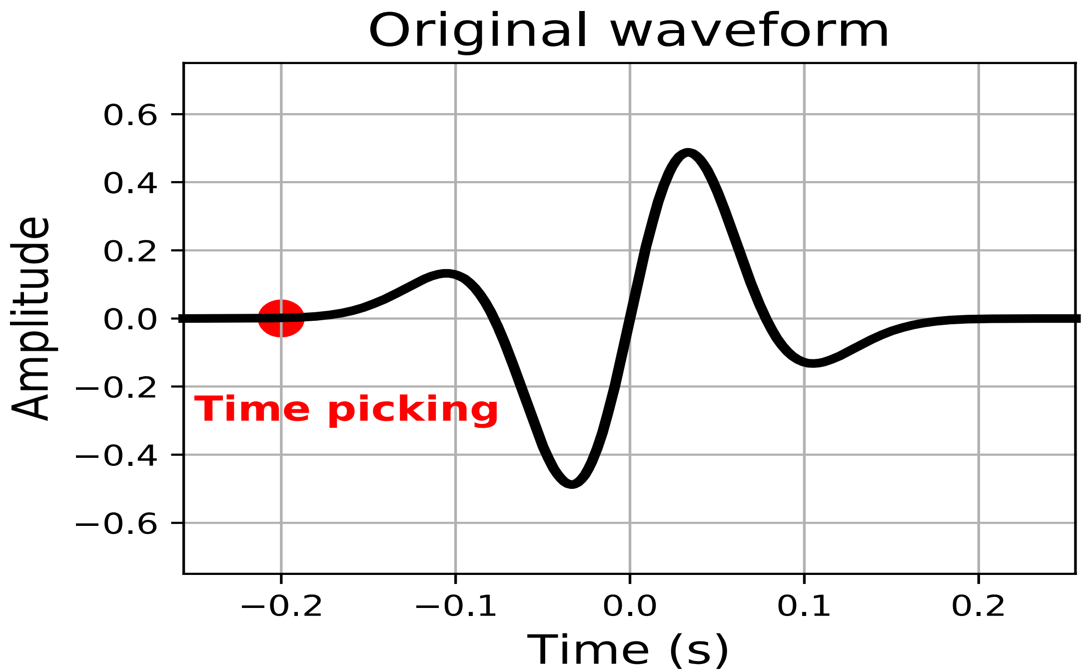


Part 1.

The use of reflection seismic processing to enhance continuously recorded microseismic data

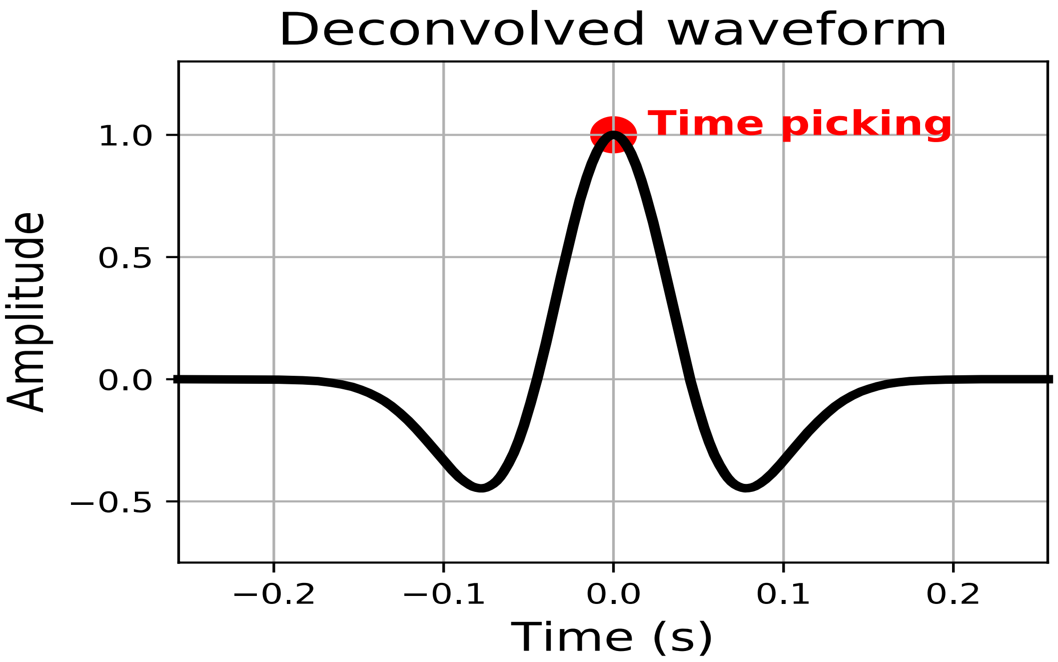
The effect of zero phase deconvolution

BEFORE



Apply spiking deconvolution, including a zero phase operator

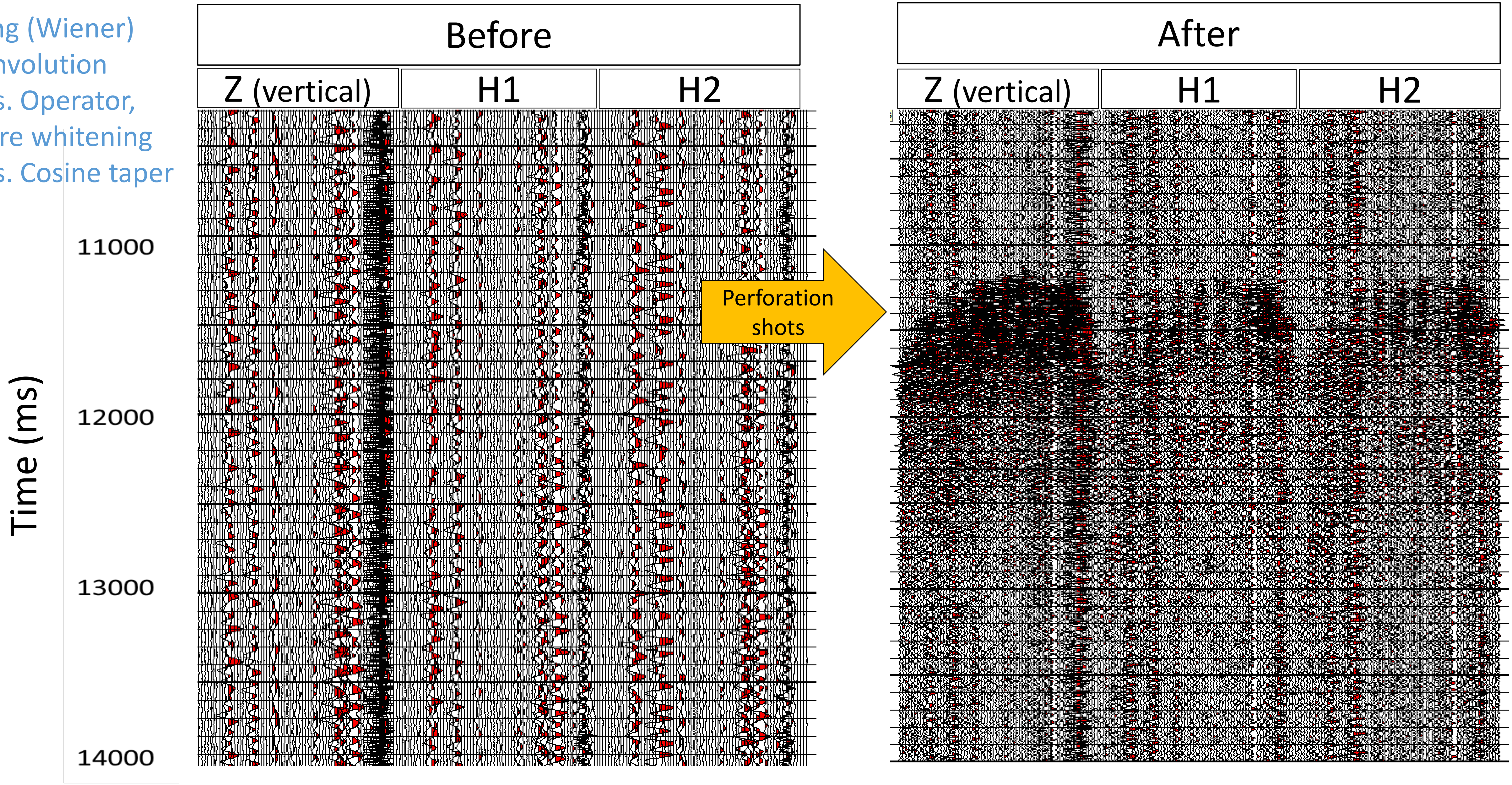
AFTER



Time event picking becomes a much simpler operation

Perforation shot before and after deconvolution

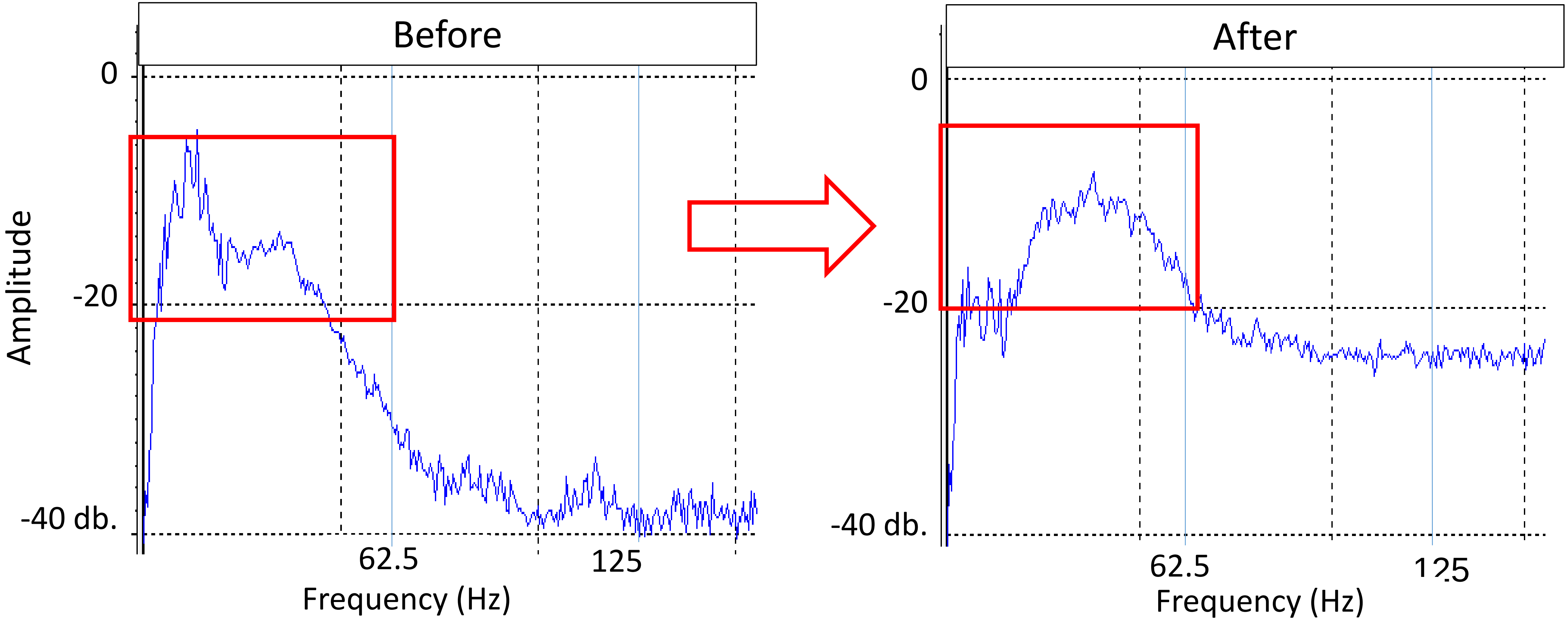
Spiking (Wiener) deconvolution
80 ms. Operator,
1 % pre whitening
20 ms. Cosine taper



Spiking deconvolution

Flatter amplitude spectrum and broadened bandwidth up to over 60 Hz

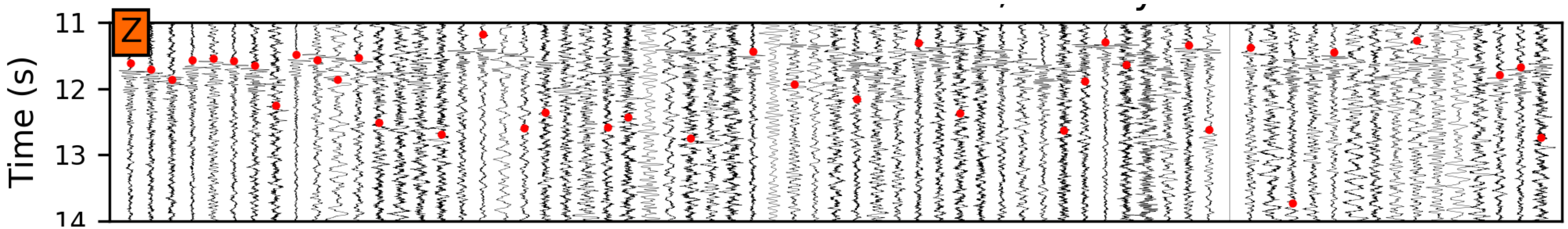
80 ms. operator, 20 ms. cosine taper, 1 % pre-whitening



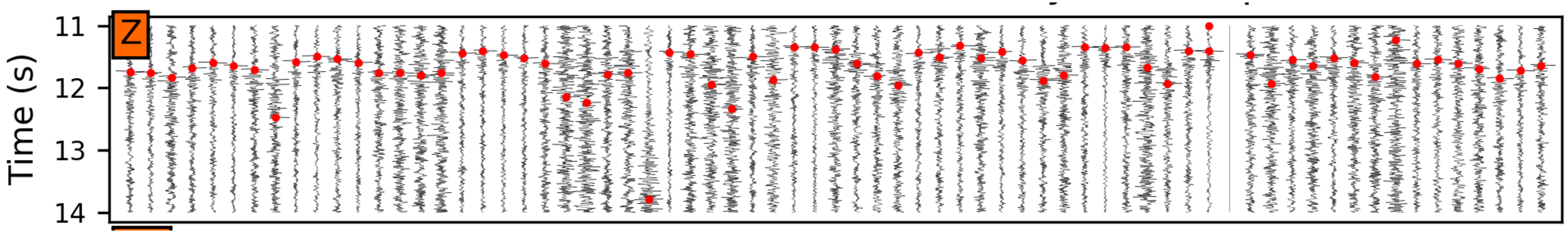
Auto picking results on the vertical recording channels

P-wave picks in Z (vertical) component

Before processing
Poor performance



After processing
More consistent picking

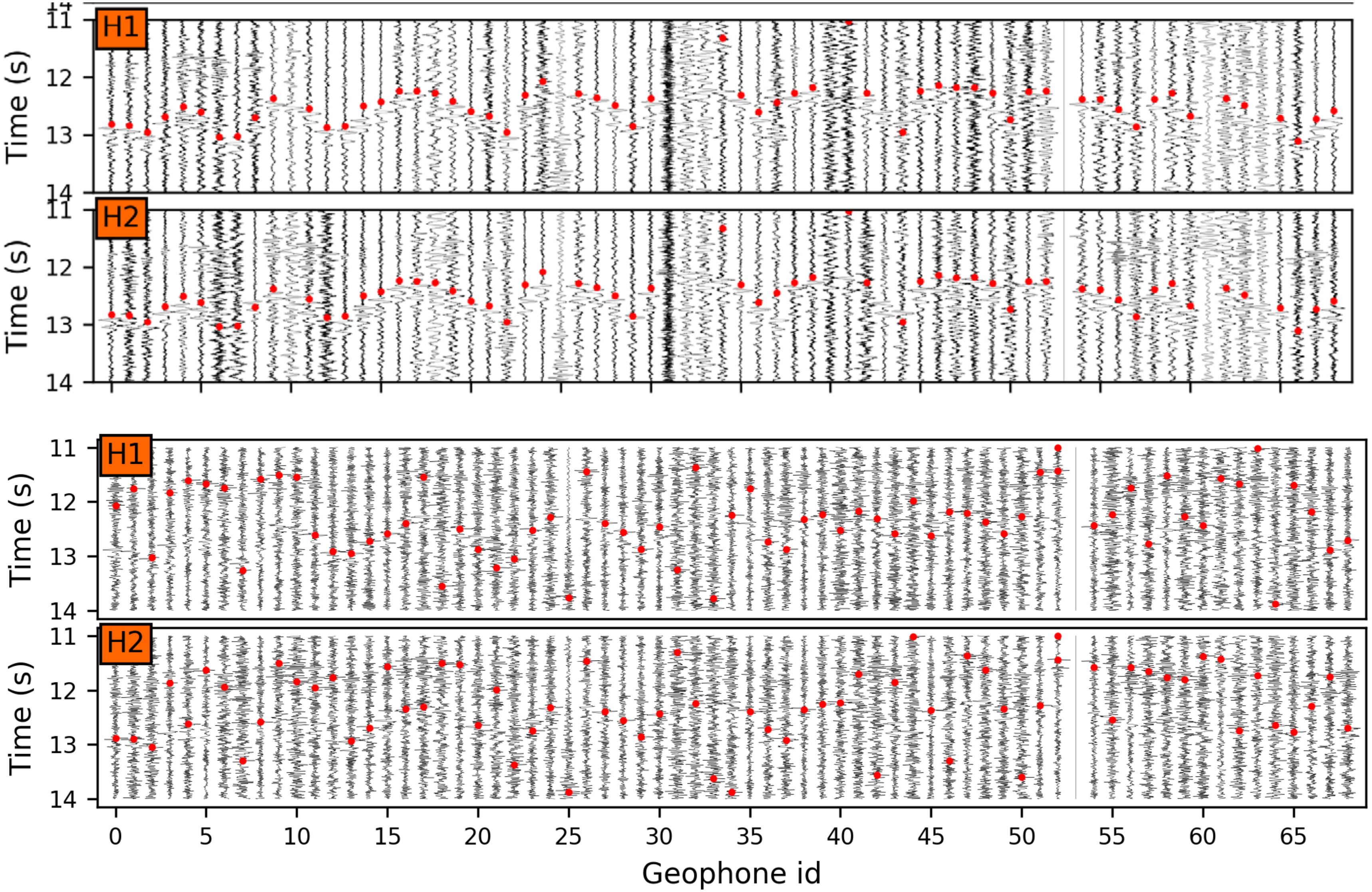


Auto picking results on the horizontal recording channels

S-wave picks on horizontal (H1, H2) components

Before processing
Consistent picking

After processing
More consistent performance

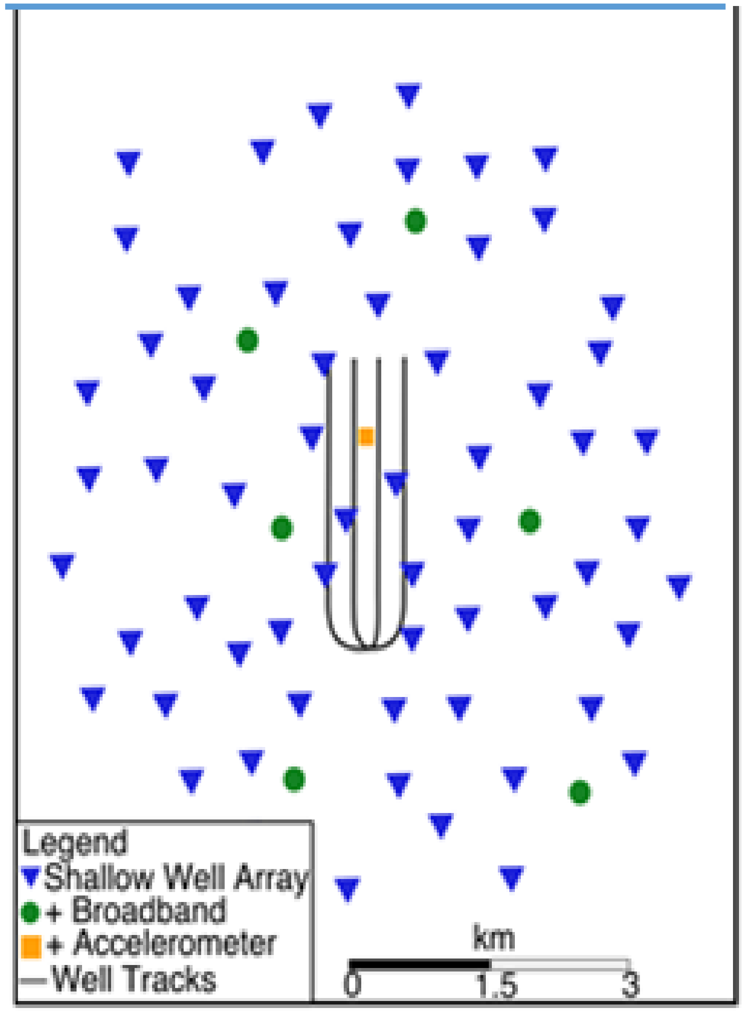


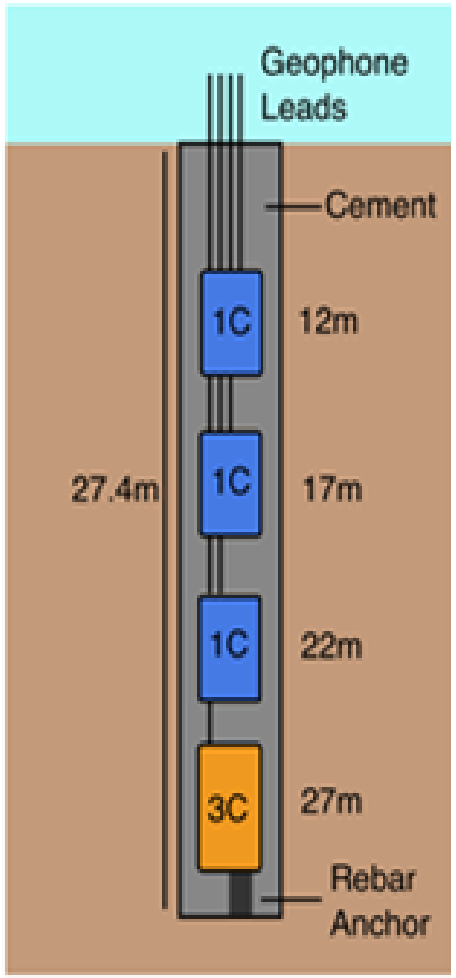
Part 2.

Using reflection seismic P and S velocities to determine hypocenter depths

The 3-D/3-C data are co-located with the micro seismic array

10 Km.





A comparison of the travel time solutions

$$t_P(x_S, x_R) = t_0 + \int_{L_P} \frac{dx'}{V_P}$$

$$t_S(x_S, x_R) = t_0 + \int_{L_S} \frac{dx'}{V_S}$$

$$\Delta t_M(z') = \frac{\langle V_P \rangle - \langle V_S \rangle}{\langle V_P \rangle \langle V_S \rangle} z'$$

=

$$t_{PP}(z) = \frac{2z}{\langle V_P \rangle} = \frac{2\langle V_S \rangle}{\langle V_P \rangle \langle V_S \rangle} z$$

$$t_{PS}(z) = \frac{z}{\langle V_S \rangle} + \frac{z'}{\langle V_P \rangle} = \frac{\langle V_P \rangle + \langle V_S \rangle}{\langle V_P \rangle \langle V_S \rangle} z'$$

$$\Delta t_S(z) \equiv t_{PS} - t_{PP} = \frac{\langle V_P \rangle - \langle V_S \rangle}{\langle V_P \rangle \langle V_S \rangle} z'$$

Direct travel time for Microseismic

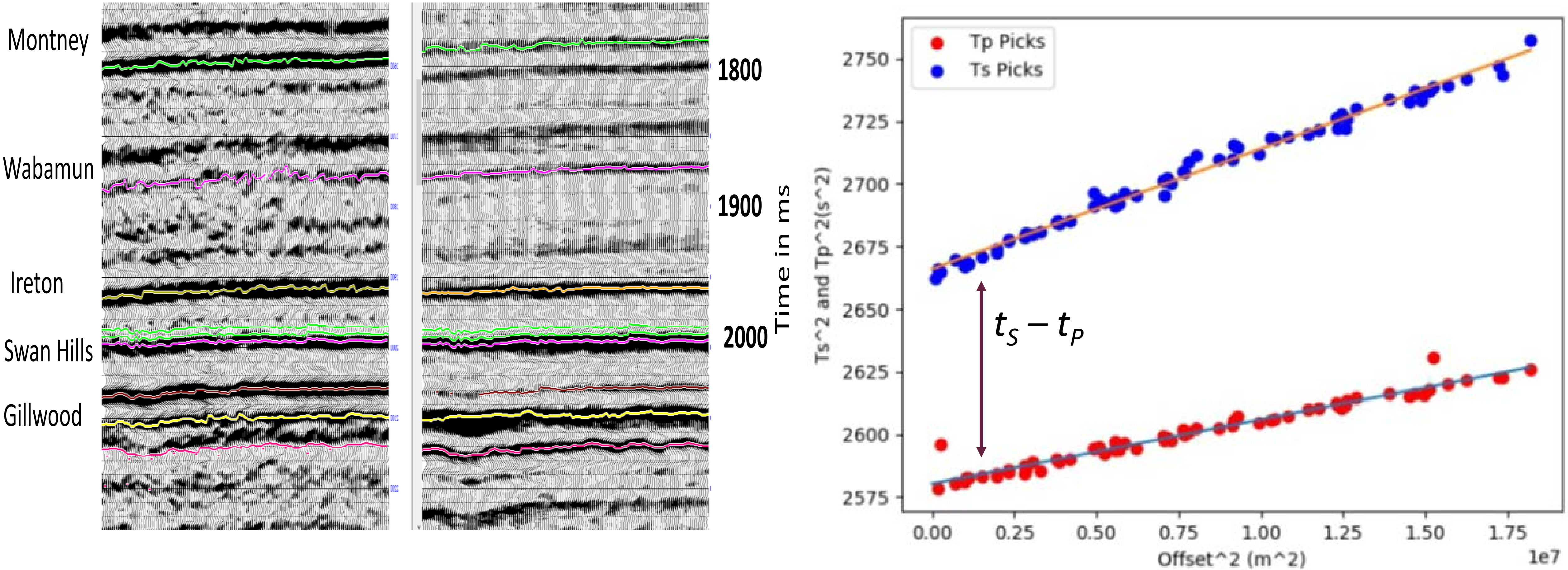
TWT for 3D reflection seismic

$$\frac{\langle V_P \rangle}{\langle V_S \rangle} = 2\left(\frac{t_{PS}}{t_{PP}}\right) - 1$$

- This Relates to Vp/Vs via the Garotta Equation

Focal-time estimation

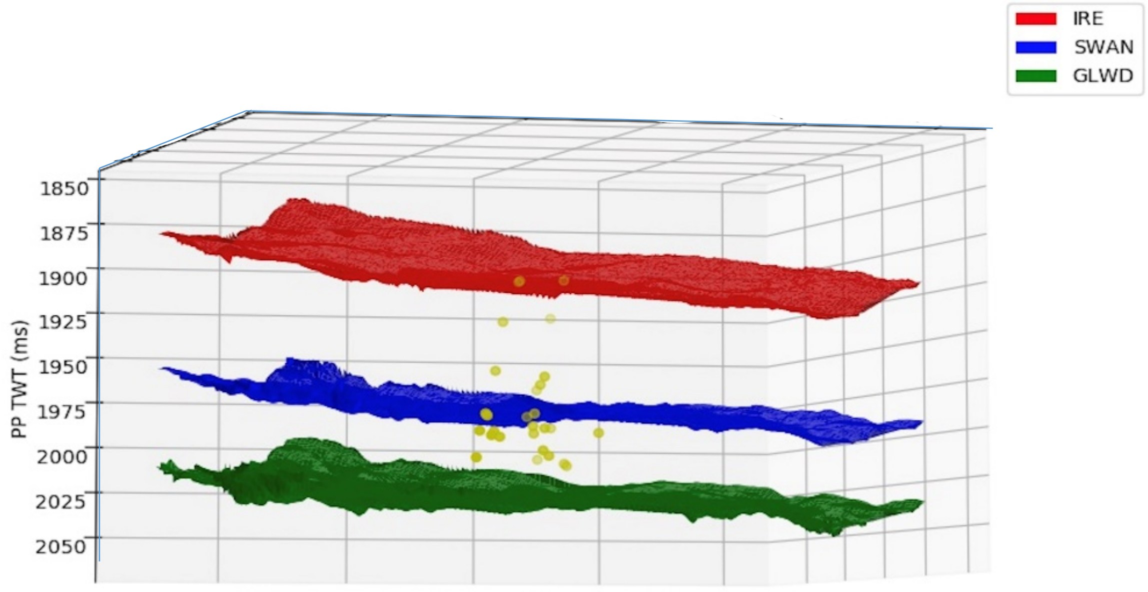
$t_{PS} - t_{PP} = t_S - t_P \,|x = 0$



Courtesy Dave Eaton, GeoConvention (2018)

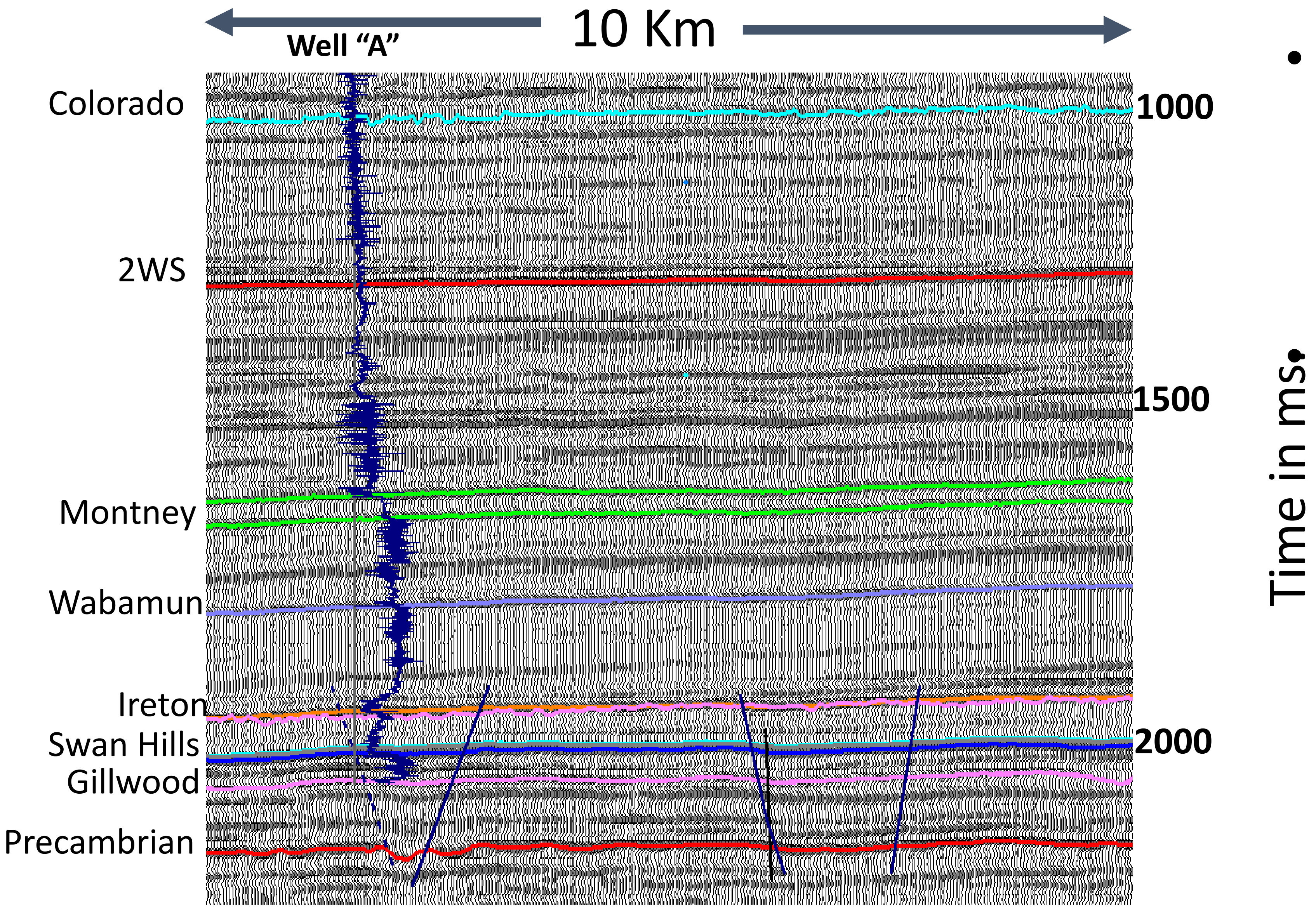
Focal Time Methodology

- Registered PP and PS horizons are extracted from the P-P and P-S 3D seismic data.
- Linear regression is used to extrapolate Ts - Tp time of the microseismic events to zero offset.
- Datum shifts are applied to the microseismic events to match with the 3D seismic datum.
- 3D Ts-Tp horizons are created using the 3D registered PP and PS horizons.
- MS events are interpolated using the horizons from Ts-Tp time to PP time
- Resultant MS events are depth-converted using a well tie.



Calculated uncertainty to be +/- 30m

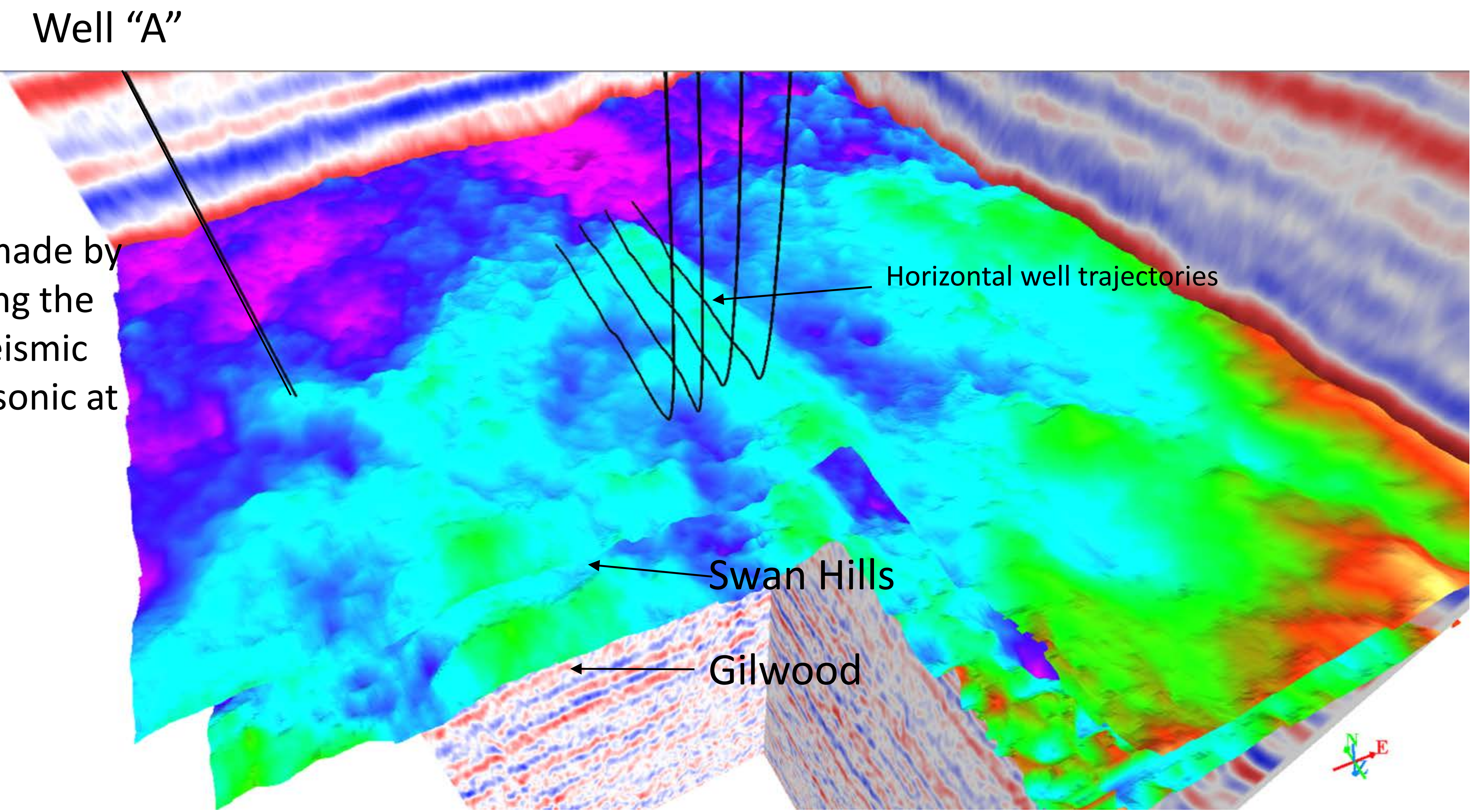
E-W 3-D seismic cross section



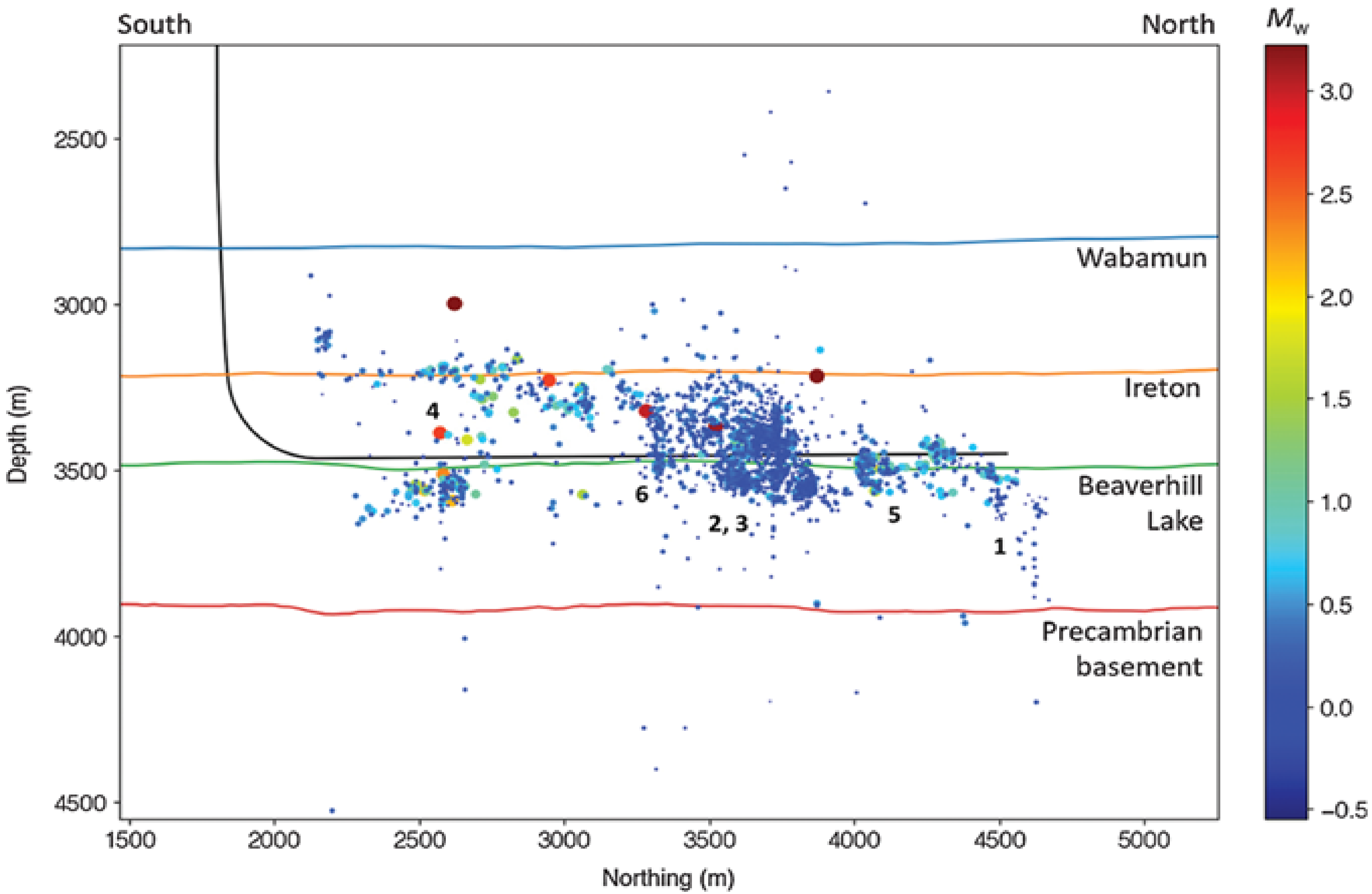
- Sonic well to reflection data tie
  - Ireton = 1933 ms
  - Swan Hills = 2000 ms
  - Gillwood = 2068 ms
- This well tie is used to convert the PP time section to depth

Swan Hills Formation depth map, with well trajectories

This map was made by depth converting the PP reflection seismic data using the sonic at well “A”

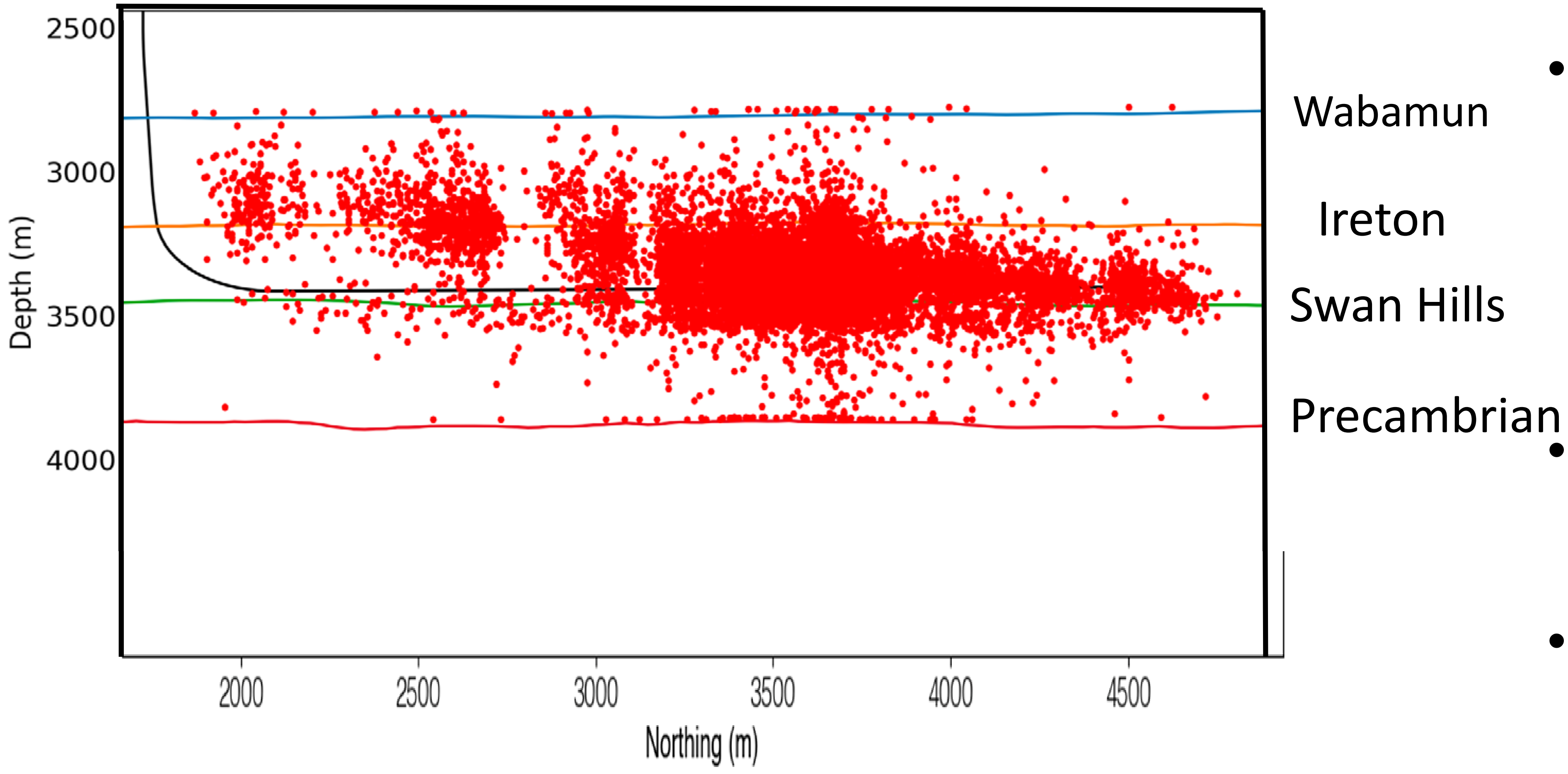


The event catalogue using MFA method



- Focal Time improved the depth accuracy of the events
- Clusters of events have been repositioned closer to well bore
- Fault ligament at toe of well bore better imaged
- Less outliers compared to MFA

The current event catalogue using focal time method



- Focal Time improved the depth accuracy of the events
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Conclusions and Recommendations

- Refection seismic technology can benefit passive seismic recording in the following ways:
  - Improve the signal to noise ratio by using deconvolution filtering and scaling
  - Define a 3-D velocity field within a survey for hypocenter depth determination
- Microseismic hypocenter determination can benefit seismic interpretation:
  - Identify faults that are difficult to see in seismic volumes
  - Locate geological trends within the seismic volume such as preferred paths for fracture growth

Acknowledgements

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