The accuracy of dipole sonic logs and implications

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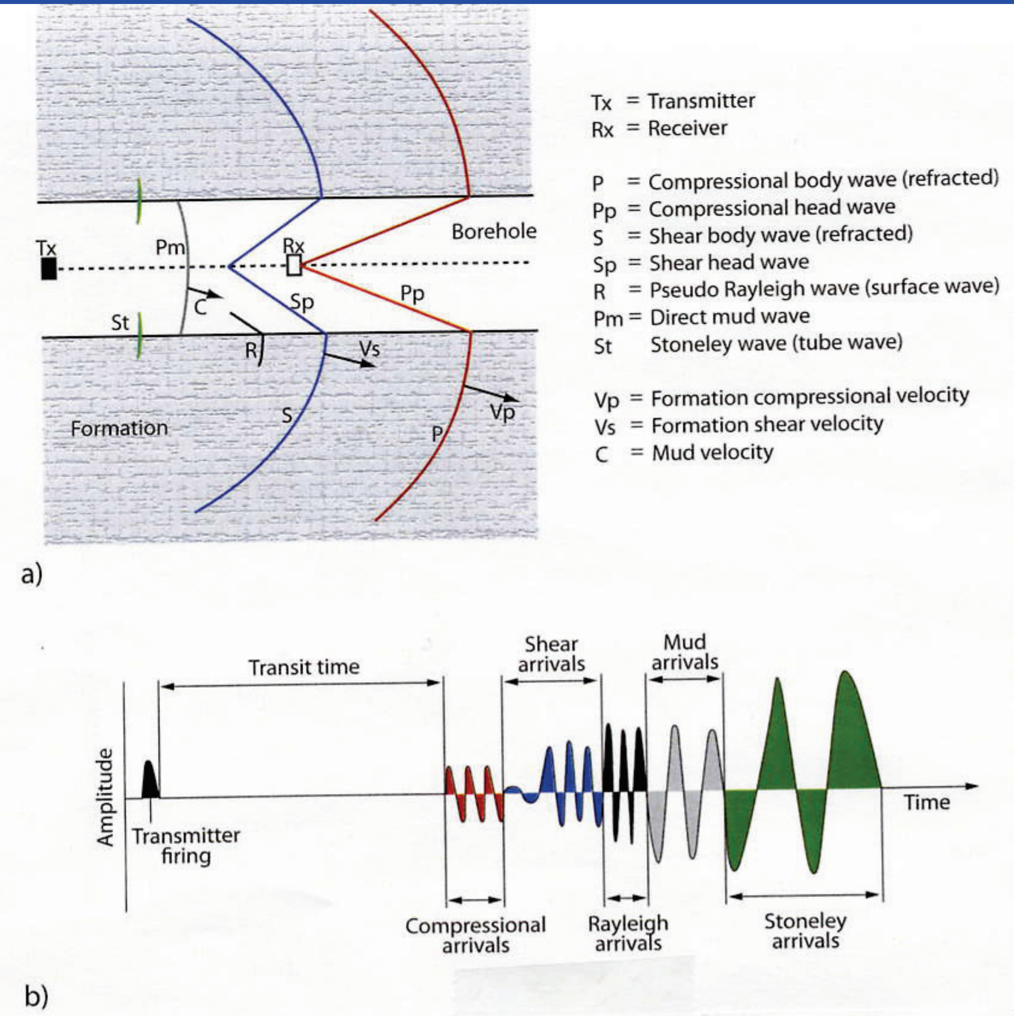
Sonic waveform propagation

- Sonic waveform component propagation
  (Close et al., CSEG Recorder, May 2009)



Why do we make repeat runs of dipole sonic logs?

Photo courtesy of Robert Stewart

Reasons for Repeating Dipole Sonic Measurements

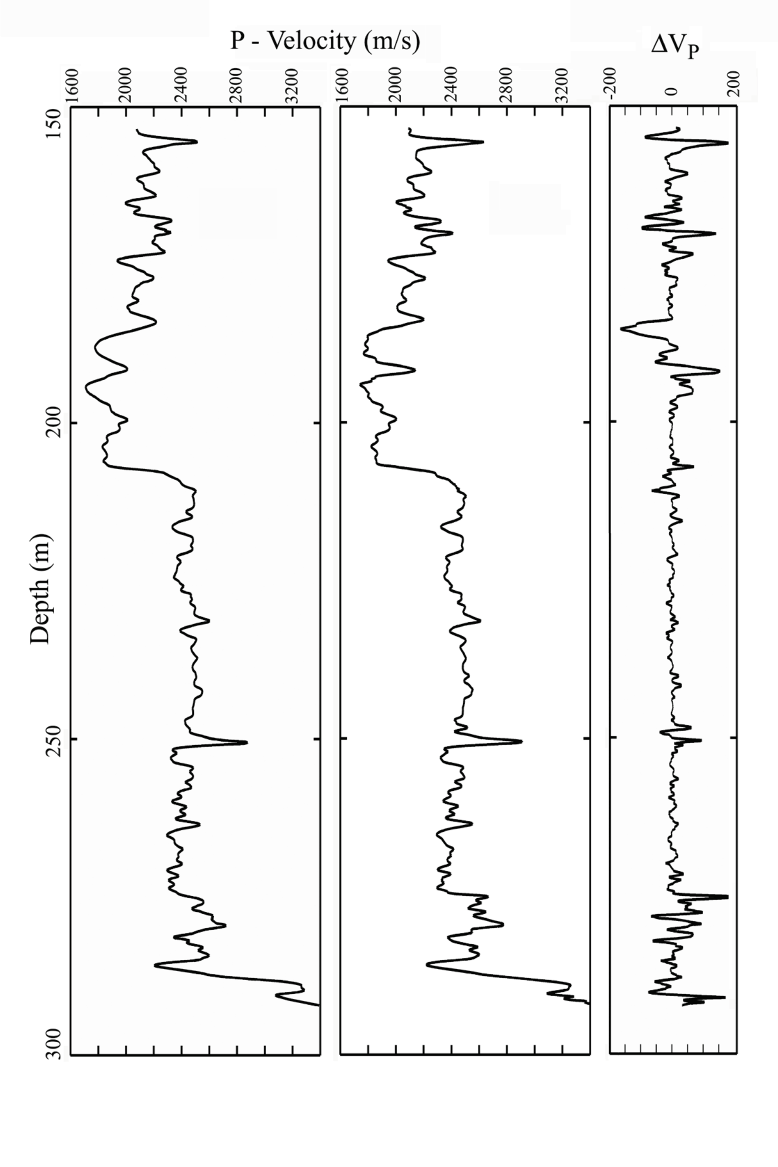
- Once logging equipment has been set up, the incremental cost of repeated measurements is small relative to total costs.
- Repeat runs are often “free of charge” to the customer.
- Provides validation of measurements and data for error analysis.

Analysis of Discrepancies in Repeated Dipole Sonic Logs

- Differences in reflectivity functions
- Differences in synthetic seismograms
- Differences in log-based wavelet (LBW) estimates
- Comparisons of LBW with statistically-based wavelets
- Comparisons of P-wave and shear-wave logs
- Comparisons of VP/VS maps for formations

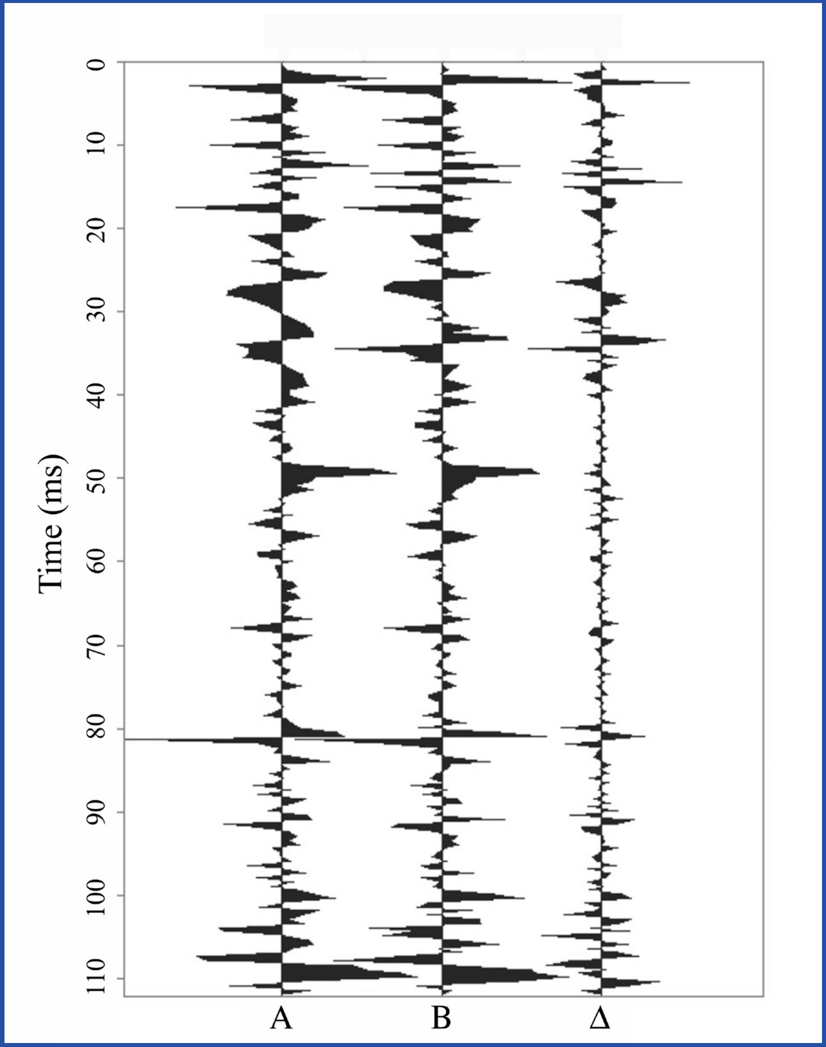
Repeated P-wave sonic logs and discrepancy log

- Two P-wave logs for Long Lake well between depths of 153.5-292m. And the discrepancy log between them (at expanded scale).



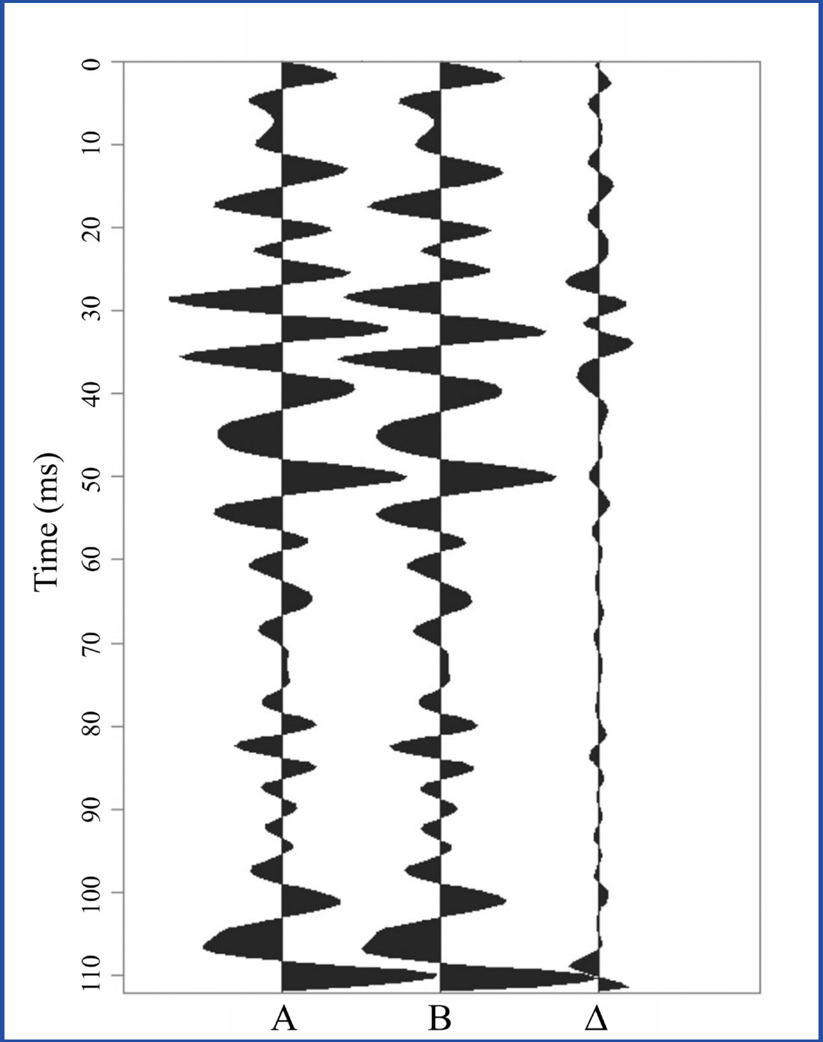
Reflectivity for P-wave sonic logs for Long Lake well

- Reflectivity functions for wells A and B and the difference of reflectivities for B-A.
- The semblance for the two reflectivities = 0.93.
- Sample interval=0.5ms



Synthetic Seismograms for P-wave sonic logs

- Synthetic seismogram using minimum phase equivalent of 150 Hz Ricker wavelet.
- The semblance for the two traces is 0.98
- Sample interval=0.5ms



Log-based Wavelet Estimation

- Two basic assumptions:
  - The wavelet estimated at the well is consistent for the entire seismic line.
  - The reflectivity can be reliably estimated from the well log.

$$W(f) = \frac{Y(f)}{R(f)} \qquad \left[W(\omega) = \frac{Y(\omega)}{R(\omega)} \right]$$

Log-based Wavelet Estimation

- Effect of logging errors on the wavelet estimate.

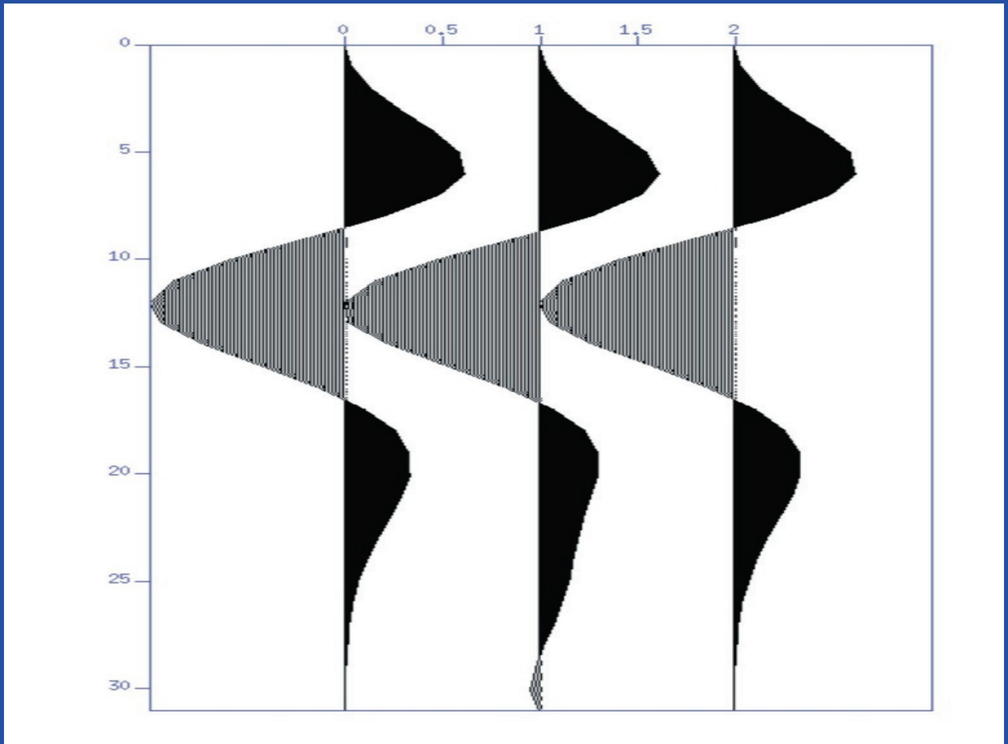
$$W(f) = \frac{Y(f)}{R(f)} \qquad \left[W(\omega) = \frac{Y(\omega)}{R(\omega)} \right]$$

$$\hat{W}(f) = \frac{Y(f)}{R(f) + \varepsilon(f)} \qquad \left[\hat{W}(\omega) = \frac{Y(\omega)}{R(\omega) + \varepsilon(\omega)} \right]$$

$$\hat{W}(f) \cong \frac{Y(f)}{R(f)} \left(1 - \frac{\varepsilon(f)}{R(f)} \right) \qquad \left[\hat{W}(\omega) \cong \frac{Y(\omega)}{R(\omega)} \left(1 - \frac{\varepsilon(\omega)}{R(\omega)} \right) \right]$$

Log-Based Wavelet Estimates for P-wave Logs

- Wavelets derived from log-based wavelet estimation:
- W(f)=Y(f)/R(f)
- Left: actual wavelet
- Centre: Wavelet using “incorrect” log
- Right: Wavelet using “correct log”
- Error for centre wavelet =3.58%
- Excellent consistency for these estimates

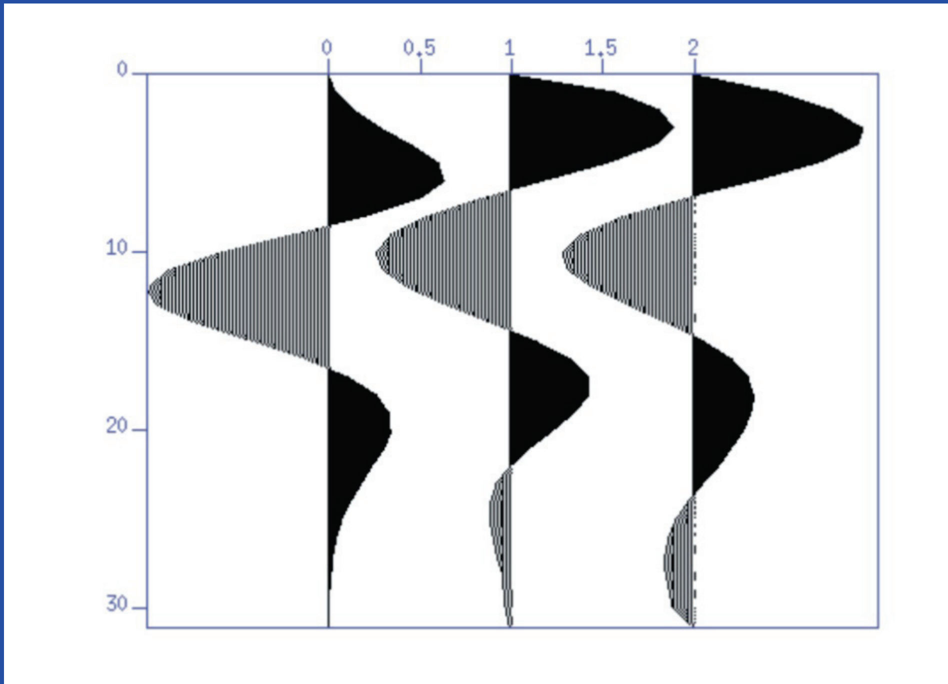


Minimum-phase Wavelet Estimation

- Two basic assumptions:
  - The wavelet is minimum phase, and hence can be derived from the log amplitude spectrum by Hilbert transform.
  - The reflectivity is random.

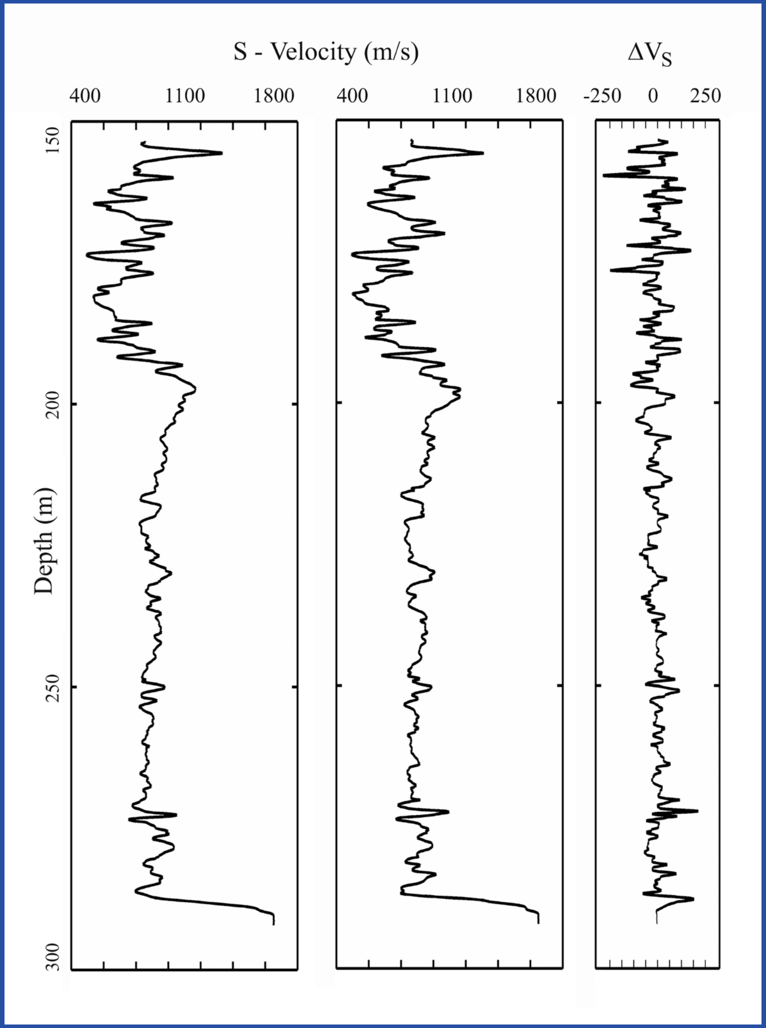
Minimum-phase Wavelet Estimates for P-wave Logs

- Wavelets derived from traces using minimum phase assumption and random reflectivity assumption.
- Fractional errors less than 3.50%
- Actual wavelet (left)
- Minimum phase wavelets from traces (middle, right)
- Errors about the same for log-based and statistical estimates.



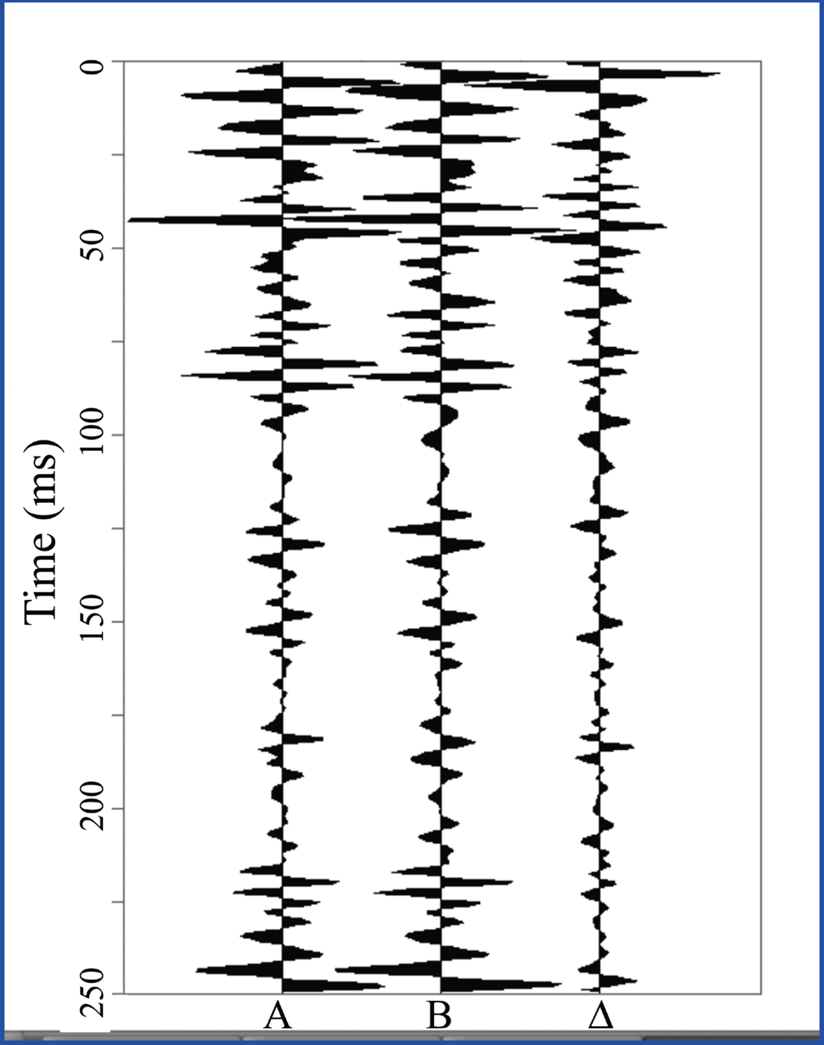
Shear-wave logs for Long Lake well (repeated log and original)

- Two shear-wave logs for Long Lake well between depths of 153.5-292m and the discrepancy log (on expanded scale).



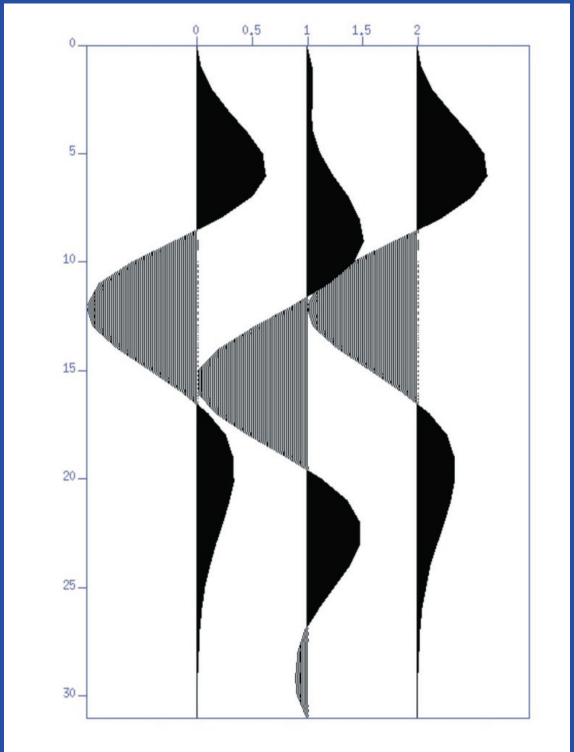
Synthetic Seismograms for Shear-wave sonic logs

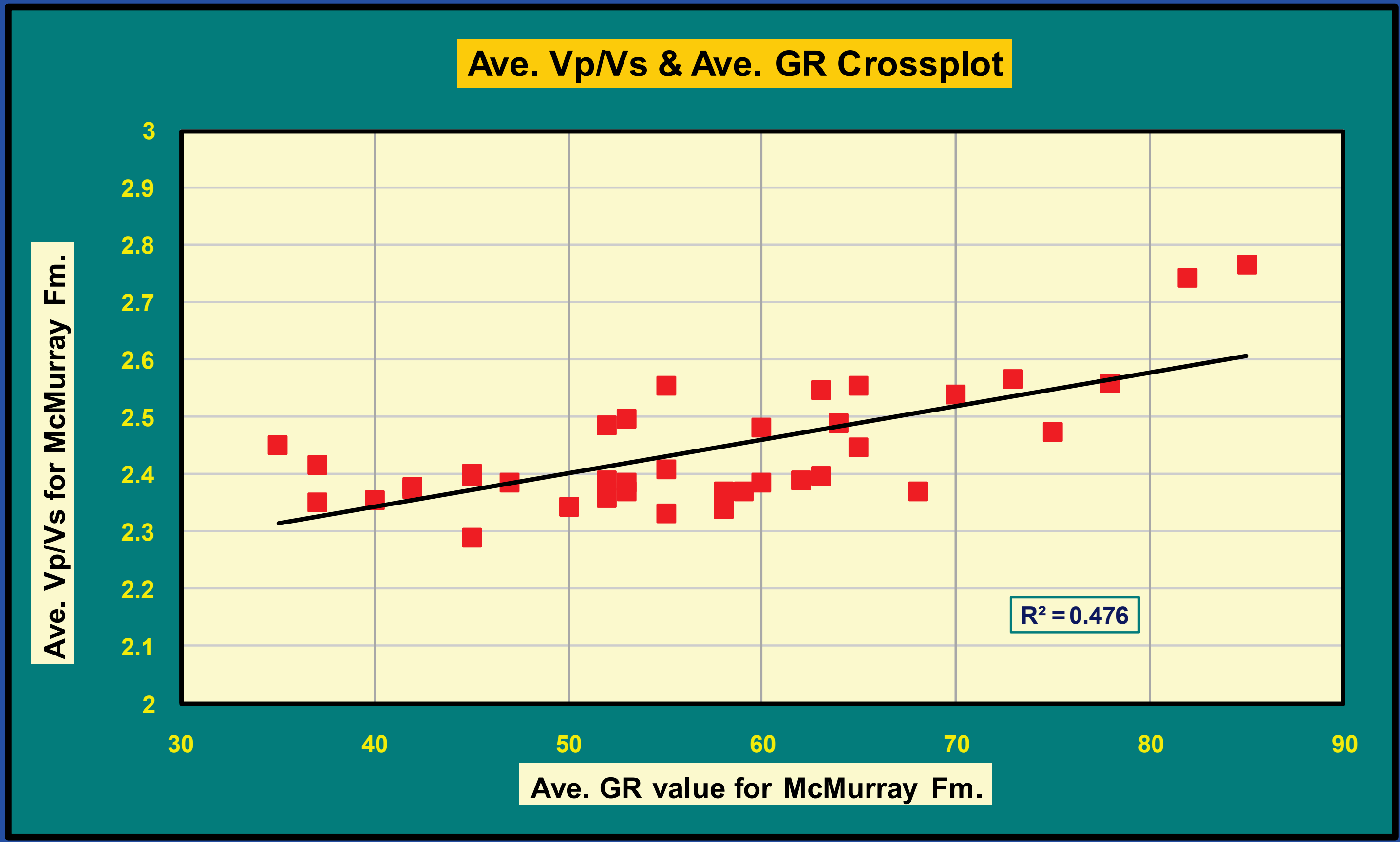
- Synthetic seismogram using minimum phase equivalent of 150 Hz Ricker wavelet.
- Semblance for the two traces is 0.88
- Sample interval=0.5ms



Log-BasedWavelet Estimates for Shear-wave Logs

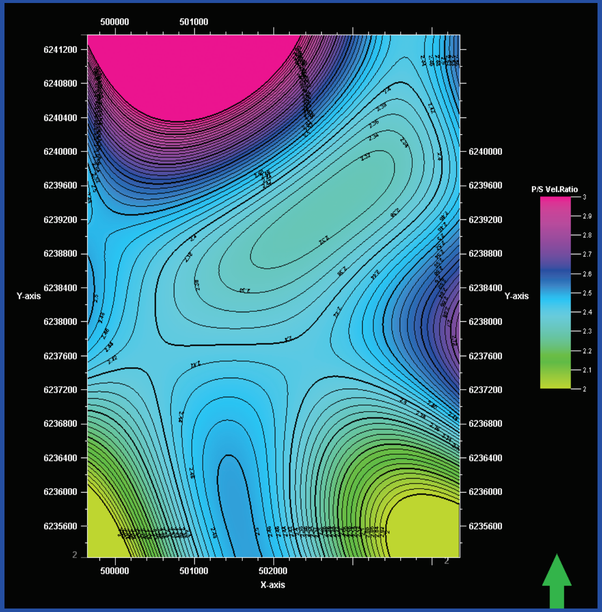
- Wavelets derived from log-based wavelet estimation:
- W(f)=Y(f)/R(f)
- Left: actual wavelet
- Centre: Wavelet using “incorrect” log
- Right: Wavelet using “correct log”
- Fractional error for middle wavelet =3.58% (after time shifting)

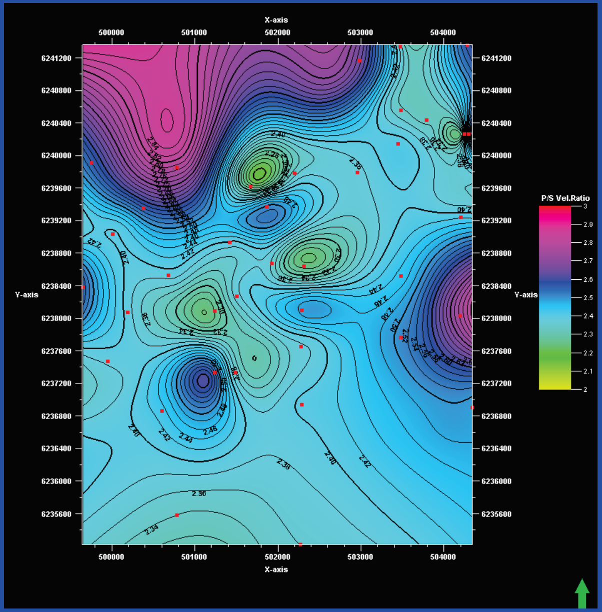


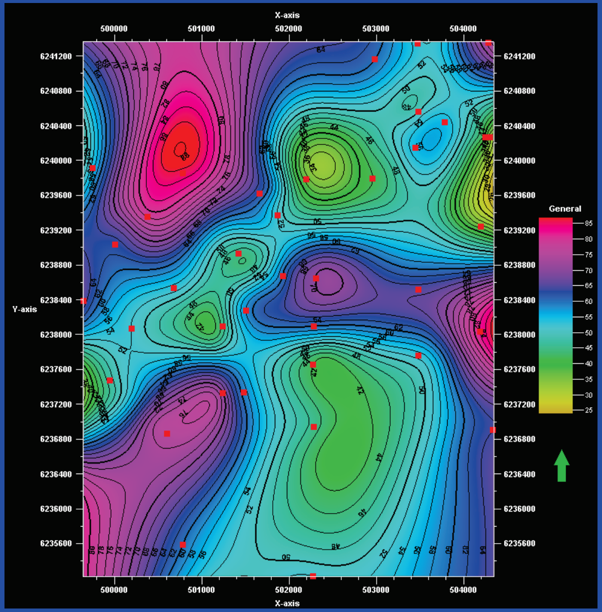


Ave. Vp/Vs & Ave. GR Crossplot
Ave. Vp/Vs for McMurray Fm.
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
30
40
50
60
70
80
90
Ave. GR value for McMurray Fm.
R² = 0.476

Vp/Vs Ratio Map for the McMurray Formation using original dipole sonic logs (left), repeated dipole sonic logs (middle) and gamma ray logs (right).







Conclusions

- Repeated dipole sonic measurements allow us to evaluate reliability.
- For our data analysis, the repeatability of P-wave information appears to be excellent whereas repeatability of S-wave information appears to be very good.
- Log-based wavelet estimation shows excellent repeatability for P-wave information and very good repeatability for S-waves.
- Log-based wavelet estimates and statistical wavelet estimates show similar reliability.
- The VP/VS maps show some variability for logging runs with generally good agreement with gamma ray log maps.
- Given the small incremental costs, repeated dipole sonic measurements are worthwhile.

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