Estimating Q from VSP data: Comparing spectral ratio and analytical signal methods

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ABSTRACT

Most of our Q-estimation investigations in previous work are based on the analytical signal method. Surprisingly large Q-factors at shallow depths had been observed for a Ross Lake VSP. In this report we are comparing the analytical signal approach to the spectral ratio method for two different VSP data sets. The two Q-estimation methods compare well when equal depth intervals are chosen for the analysis. Stratigraphic (apparent) Q appears to dominate the estimated "Q versus depth" functions in both VSP locations.

INTRODUCTION

In recent years our Q-estimation strategy had been concentrated on the analytical signal method (Haase and Stewart, 2004; *ibid*, 2005). Surprisingly large Q-factors had been observed at shallow depths in these investigations. Error sources like the plane wave assumption and unit transmission coefficients were analyzed. They could not explain high Q-factors at shallow depths. To exclude the possibility of problems with the estimation algorithm and/or problems with our VSP data we decided to compare algorithms and data sets. All of our Q-estimation experiments thus far had been carried out on Ross Lake data. Was there something unique about this data set? Recently we had the opportunity to apply our estimation methods to a second VSP data set and also revisit our Ross Lake files. For this Report we rewrote the spectral ratio estimation routine to bring it in line with our implementation of the analytical signal method estimation approach. For more realistic comparisons all estimates are made over the same depth interval.

SPECTRAL RATIOS REVISITED

Minimum and maximum frequencies required for the spectral ratio method are determined from the magnitude spectrum by inspection. Because we seek to fit straight lines to spectral ratios we try to avoid noisy band edge regions, in particular the noise floor. Spectral ratios are formed by smoothing amplitude spectra of depth station groups "above" and "below" a "target depth" and division at each frequency point. Then a straight line is fitted (in the least square error sense) to the log-ratios as function of frequency. The depth separation between "group above" and "group below" must be sufficient for a linear spectral ratio trend to emerge, usually several hundred meters. For the "target depths" mentioned above we choose all depth stations away from top and bottom; the border region size is controlled by the depth separation of station groups. Thus we are able to compute a Q versus depth relationship comparable to our approach to the analytical signal method.

Q VERSUS DEPTH FOR AN ALBERTA VSP

Figure 1 shows the downgoing P-wave of a zero-offset VSP in Alberta (courtesy Dr. Ron Hinds, Talisman Energy Inc.). The trace amplitudes are seen to decrease with depth because of spherical spreading, transmission losses and attenuation. No reflections are visible, as expected on this downgoing P-wave data. Reflectors are probably present at locations of abrupt changes of the first arrival slope. Tests with the spectral ratio method suggest a depth interval of 360 m to be sufficient for noise suppression. This depth interval is adopted for all computations reported here. The red curve in Figure 2 shows Q(z) as determined by the spectral ratio method. The comparison result for the analytical signal method is given by the black curve. A quality factor range from Q = 20 to 40 is observed above approximately 1500 m of depth. Beyond that, there is a major increase in Q-values. The two Q(z) functions are by no means identical, but they track very nicely considering that we are comparing a frequency domain method to a time domain method.

Q VERSUS DEPTH FOR THE ROSS LAKE ZERO-OFFSET VSP

The downgoing P-wave of the Ross Lake zero-offset VSP is shown in Figure 3 (courtesy Larry Mewhort, Husky Energy Inc.). There are some reflections (up going waves) visible. Again, we note the decay of amplitudes with depth. The red and black curves in Figure 4 give Q(z) estimated with the spectral ratio method and the analytical signal method, respectively . The general trend is the same for both methods. Notably, both methods agree on large Q-values at shallow depths. Included with the Ross Lake date set is a drift-curve, allowing us to employ the drift time equation, given by Stewart et al. (1984), for Q estimation. The green curve in Figure 4 shows the result of that attempt. The general trend agrees with the other two methods, including larger Q-values at shallow depths. There are differences in detail, however. This is not too surprising because the drift method of Q estimation is based on seismic versus sonic time delays whereas the other two methods are based on amplitude decay. To obtain the same Q-factor range for three different estimation methods increases our confidence in the algorithms utilized.

DISCUSSION AND CONCLUSIONS

Q versus depth estimated by spectral ratios (SRM) and analytical signals (ASM) are quite similar for both VSP data sets. There are apparent depth shifts between the two Q(z) estimates that are inconsistent with depth. SRM smoothing is done by averaging amplitude spectra of a group of depth stations. For ASM smoothing we average the maximum instantaneous amplitudes of a group of depth stations. Some of the differences seen in the estimated Q(z)-functions could well be caused by differing smoothing techniques. An interesting feature of "Q versus depth" for both VSP's is the succession of peaks and valleys. Figure 3 gives a hint at one possible explanation. Major valleys in Q(z) are observed at approximately 600 m depth and just above 1000 m depth (Figure 4). At these depths there are reflections visible in Figure 3. When the Q estimation depth interval brackets a reflector, then the deeper station receives less energy which leads to a lower Q estimate unless the acoustic impedance decreases substantially across the interface. This stratigraphic (apparent) Q has to be removed from the effective (measured) Q to arrive at the intrinsic (formation) Q.

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ACKNOWLEDGEMENTS

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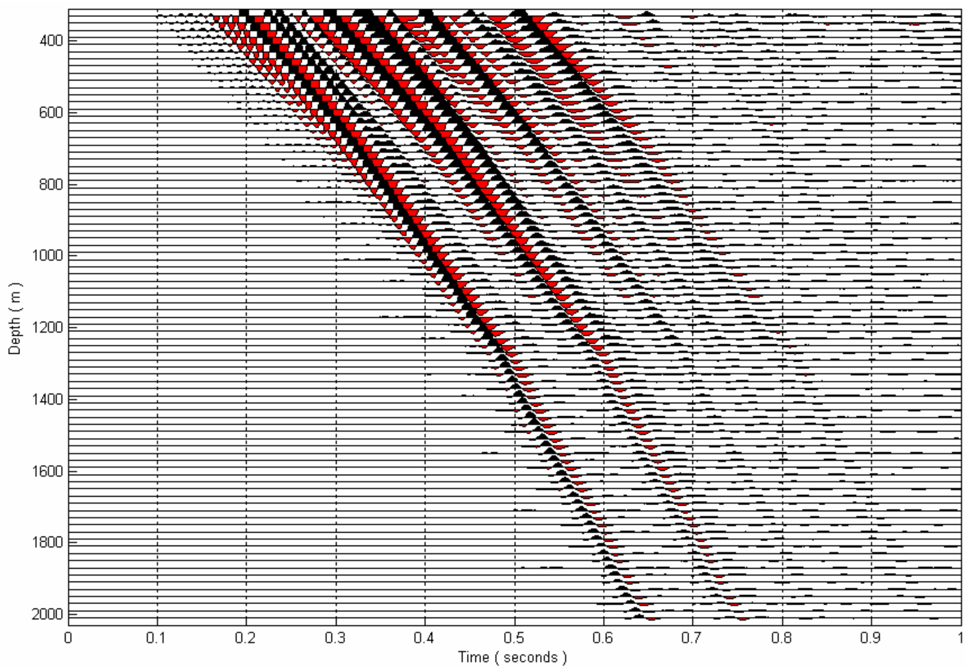

FIG. 1. Alberta VSP (downgoing P-wave).

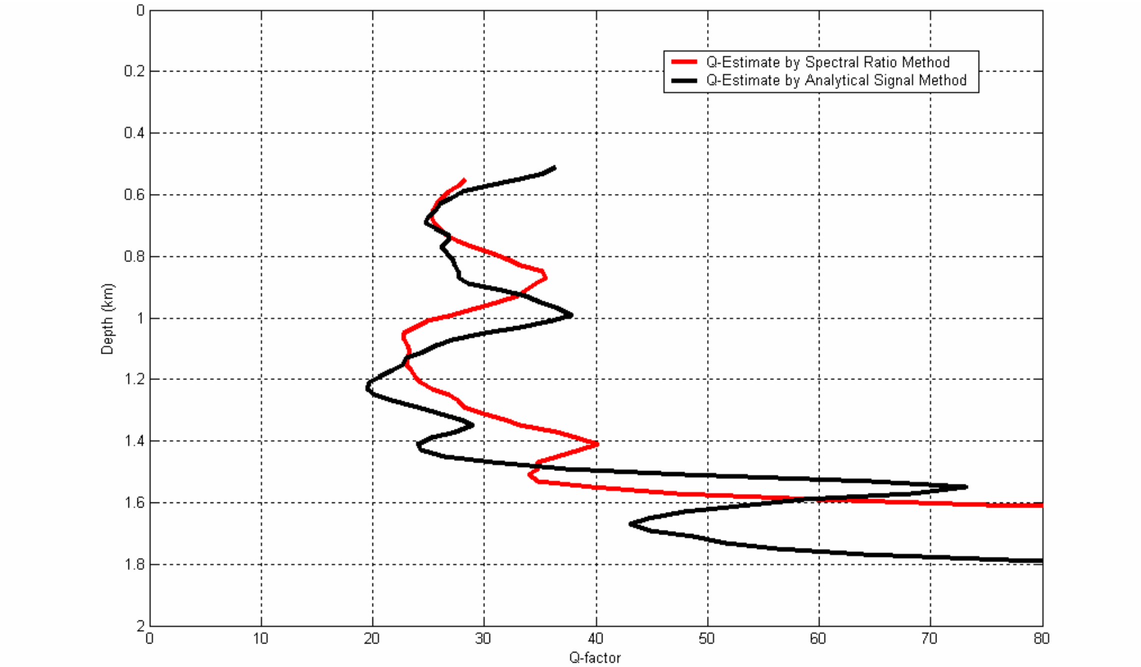

FIG. 2. Q versus depth for zero offset Alberta VSP (360 m estimation interval).

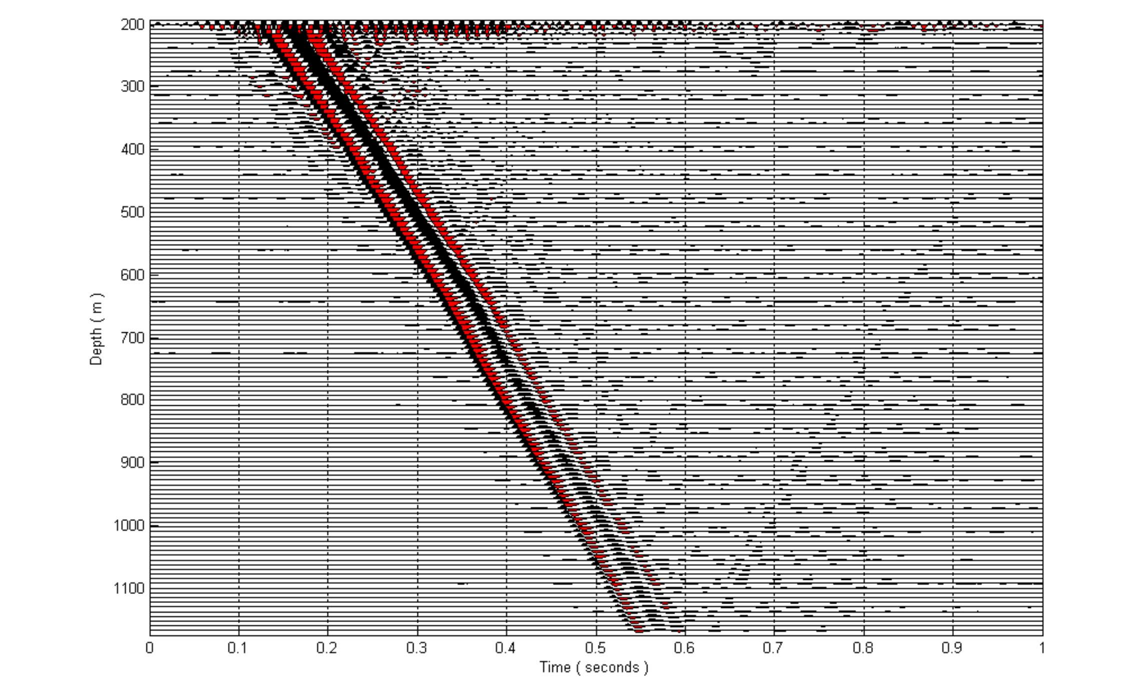

FIG. 3. Ross Lake VSP (downgoing P-wave).

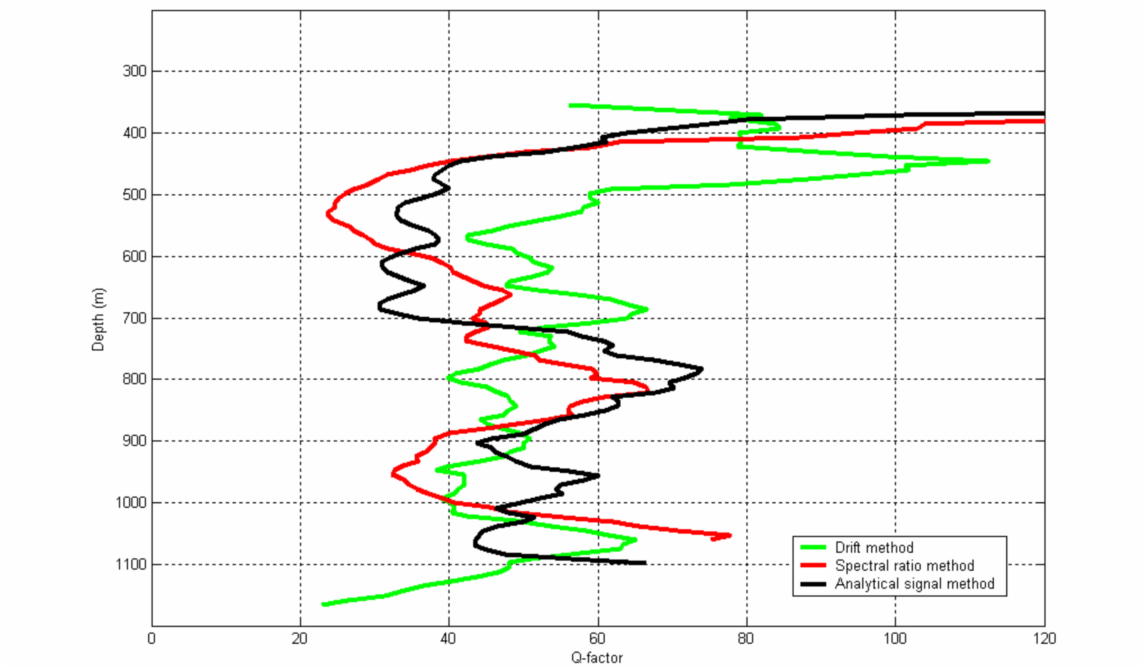

FIG. 4. Q versus depth for zero offset Ross Lake VSP (360 m estimation interval).