Q-factor estimation

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ABSTRACT

Compensation for normal moveout and transmission coefficients in estimating seismic attenuation (Q) by the analytical signal method are investigated. VSP data and surface data acquired at Husky Energy Inc.'s Ross Lake oilfield, Saskatchewan, are used for this study. Major Q-estimate changes are not observed when compared to results obtained from the analytical signal method without this compensation. The minimum Q-estimate of 24 found in the VSP data at approximately 640 m depth, before compensation was applied, shifts to Q=18 for the case with compensation. An adaptation of the analytical signal method for Q-estimation from surface data shows promise with a surface data model.

INTRODUCTION

Seismic quality factors (Q) are sought after because they are useful for amplitude analysis, for improving resolution and for defining lithology as well as reservoir parameters. A number of Q-estimation approaches with considerable error ranges, including the spectral ratio method, were employed in an earlier investigation of the Ross Lake, Saskatchewan, heavy-oil field VSP data analyzed here (Haase and Stewart, 2003). The analytical signal method showed promise when compared to the spectral ratio method because log instantaneous amplitude plots are considerably smoother than log spectral ratio plots (Haase and Stewart, 2004). However, it was suspected at the time that more attention had to be paid to proper moveout compensation. Even for zero- offset VSP surveys the source is not right at the wellhead. What errors are contributed by plane-wave assumptions? It was also noted previously that the assumption of unity transmission coefficients could cause errors in Q-estimates. Ray bending has not been considered up to this point. Could there be ray path problems? At the recent 75th Annual SEG Meeting several authors (e.g. Chichinina et al., 2005, Gray, 2005, and Maultzsch, 2005) presented their investigations of Q-anisotropy. Could some of the Ross Lake results be explained by Q-anisotropy? Is there an experimental problem when acquiring the Ross Lake VSP data? Repeatedly vibrating at the same surface location could cause soil compaction and therefore a change in near surface attenuation. The purpose of this study is to address the first two points on this list of potential Q-estimation error sources: moveout compensation and transmission loss compensation.

In addition, we also attempt to apply the analytical signal method to surface seismic data by adapting the procedure developed by Dasgupta and Clark (1998). Our adapted Q versus offset approach is tested with the aid of a simplified 1D-model (unity transmission coefficients and no spherical spreading) and applied to a surface data shot record.

MOVEOUT COMPENSATION FOR Q-ESTIMATES FROM VSP-DATA

Previous results (Haase and Stewart, 2004) show a Q-factor minimum at approximately 600 m in the Ross Lake VSP data with Q-values rising below and above that depth. Increasing Q-factors toward the surface are surprising, and moveout dependence is suspected as one possible cause. This idea can be put to a preliminary test because offset-VSPs are available at Ross Lake. With an increasing offset the estimated Q at shallow depth is expected to increase as well if our moveout dependence theory is correct. Indeed, this tendency can be observed in Figure 1. Why does moveout make a difference to Q-estimation from VSP data and what can be done about it? The equation given by Tonn (1991) for the analytical signal method is:

$$\ln\left[\frac{a(t_2)}{a(t_1)}\right] = \ln\left[\frac{G_2}{G_1}\right] - \frac{\Delta t}{4Q}\left(\omega(t_1) + \omega(t_2)\right)$$

where $a(t_1)$ and $a(t_2)$ are instantaneous amplitudes at times t_1 and t_2, $\omega(t_1)$ and $\omega(t_2)$ are instantaneous frequencies at times t_1 and t_2, G_1 and G_2 are geometrical spreading factors at times t_1 and t_2 , and $\Delta t = t_2 - t_1$. Q is estimated by selecting Δt-pairs centered on a constant depth location. The original algorithm selected pairs of VSP depth stations instead. For nonzero offset, there is a depth-dependent horizontal component to the wave field. The larger this horizontal component (at shallower depths), the less the apparent attenuation, and Q gets overestimated because of wave front curvature (spherical waves versus plane waves). A solution is the fitting of travel time curves as a function of depth and offset, and then interpolating symmetric Δt-pairs. The result of our moveout compensation attempt is shown in Figure 2. Although we observe the expected decrease of Q-factors between 400 m and 500 m depth following moveout compensation, below 400 m the situation is getting worse. There must be another mechanism at work. One possibility is Q-anisotropy, another is ground compaction by the vibrator.

TRANSMISSION LOSS COMPENSATION FOR Q-ESTIMATES FROM VSP-DATA

The instantaneous amplitude display in Figure 3 shows an amplitude increase with depth at approximately 700 m (before smoothing, green curve). In previous work (Haase and Stewart, 2004), Q-estimation is done with smoothed amplitudes (red curve in Figure 3) because such an amplitude increase with depth leads to negative Q. However, depending on acoustic impedance changes, amplitudes can increase with depth, and Q-estimation must take this effect into account. Figure 4 displays a running product of transmission coefficients versus depth, computed from the Ross Lake well log. At approximately the 800 m mark an upward trend is observed, which constitutes a decrease of transmission loss or, in this case, an amplitude gain. Transmission loss compensation and smoothing result in the weighted instantaneous amplitudes displayed in Figure 5. A shift parameter is introduced here to account for the depth-misalignment between Figures 3 and 4. Q-factor estimation with these weighted instantaneous amplitudes gives the result shown in Figure 6 together with the previous estimate. There are changes in detail, but the general character of the new Q versus depth curve did not change.

APPLICATION OF THE ANALYTICAL SIGNAL METHOD TO A 1D SURFACE DATA MODEL

Dasgupta and Clark (1998) developed a procedure to estimate Q from offset-dependent seismic data by applying the spectral ratio method. A similar approach, but using the analytical signal method, is taken in this modelling study. 1D-model-traces (no spherical spreading and a unity reflector) are generated for a reflector at 500 m depth, assuming a range of offsets (0 to 2000 m) and Q-factors (25, 50 and 100). The reference velocity is set to 3 km/s at 10 kHz and a zero phase 8/12-80\100 Hz Ormsby wavelet is assumed. Figure 7 shows model traces for Q=50 (in black) and their instantaneous amplitudes (in red). Amplitude decay with offset and time delay with offset are apparent. Trace envelope maxima as a function of offset are displayed in Figure 8 for all three Q-factors considered. Note the decay of maximum amplitude with offset and 1/Q. Model Q-factors are derived by fitting the amplitude curves in Figure 8 and employing the equations reviewed in previous work by the authors (Haase and Stewart, 2004). Table 1 compares Q-values thus determined and initial model Q's. The departure is thought to be caused by less than perfect fitting of amplitude curves in Figure 8. Note that a cubic fit is used here.

Table 1.

Q_{model}	25	50	100
$Q_{estimate}$	23.4	49.4	103.1
Percent Error	-6.4	-1.2	3.1

APPLICATION OF THE ANALYTICAL SIGNAL METHOD TO A SURFACE DATA SHOT RECORD

Figure 9 gives a seismic line from a 3D shot record acquired in close proximity of the Ross Lake well under investigation. Figure 10 shows the analysis window selected; displayed are five-trace averages of instantaneous amplitudes. The depth of this reflection event is approximately 1.3 km. As before in the surface data model situation, trace envelope maxima are extracted. Envelope maxima for the selected analysis window (Figure 10) are plotted in Figure 11. Also shown in Figure 11 is a cubic fit of the envelope maxima. The trend of this cubic fit leads us to expect a low Q-factor value for large offsets. Indeed, this expectation is born out by the Q-factor estimated from the cubic fit of Figure 11 as displayed in Figure 12. Considering the noisy amplitude curve given in Figure 11, we are pleased to find an estimate that is at least in the ball park. What have been ignored thus far are surface consistent amplitude variations as well as AVO-effects. These topics are planned for future research.

CONCLUSIONS

Q-estimates obtained by the analytical signal method do depend on VSP-source offset to some degree. Moveout compensation attempted in this study modifies the Q-estimate insignificantly.

Transmission coefficients computed from Ross Lake well-log data are consistent with an observed anomaly of instantaneous amplitudes (amplitude increase with depth over a narrow depth range). Transmission coefficient compensation does not substantially change Q-estimates. Neither moveout compensation nor transmission loss compensation reduced the large Q-factors estimated for shallow depths. There must be another mechanism at work. One possibility is Q-anisotropy. Another reason could be ground compaction under the vibrator pad(s) which would enhance the high frequency content as time progresses, thereby mimicking increased Q-factors.

Q-factors of surface data models can be recovered with reasonable accuracy employing a modified version of Dasgupta and Clark's (1998) "Q versus offset" method. Applying this modified method to an actual surface data shot record gives a Q-value in the "ball park" even though surface consistent amplitude variations and AVO-effects have been ignored.

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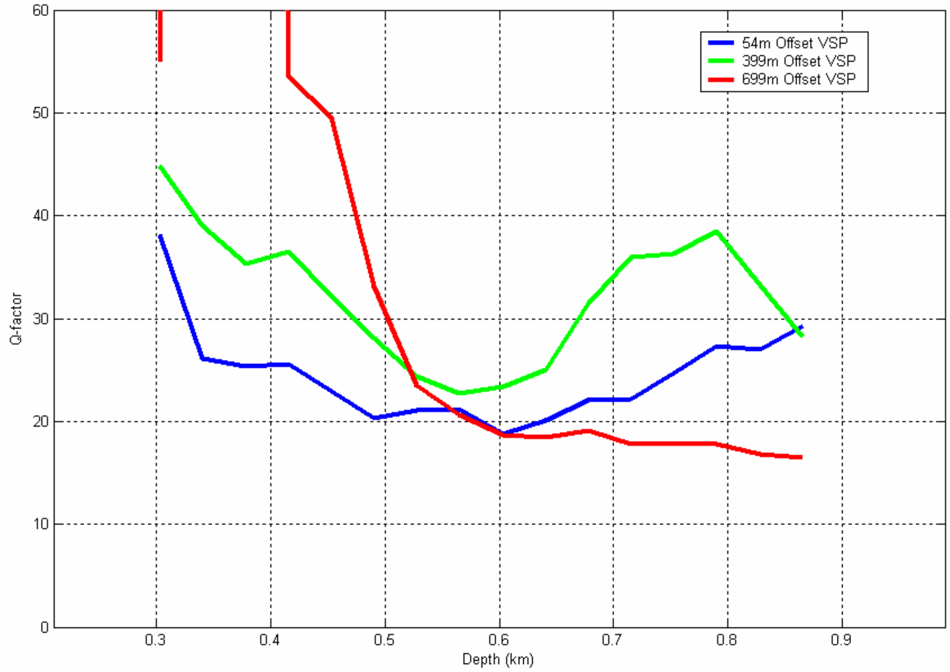

FIG. 1. Q-estimate versus depth.

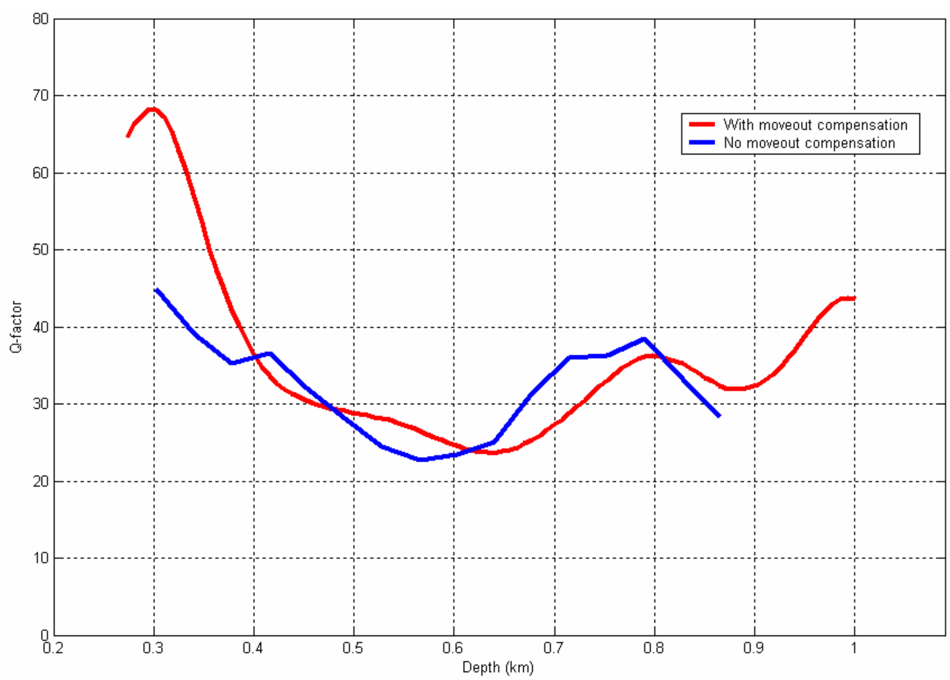

FIG. 2. Q-estimates versus depth (399m offset VSP).

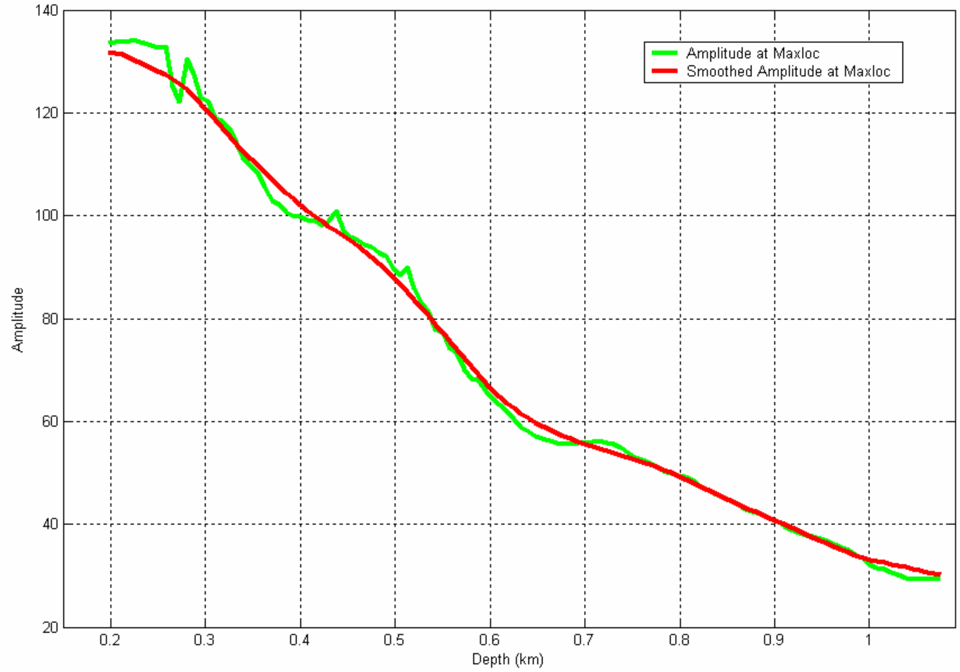

FIG. 3. VSP-data instantaneous amplitudes.

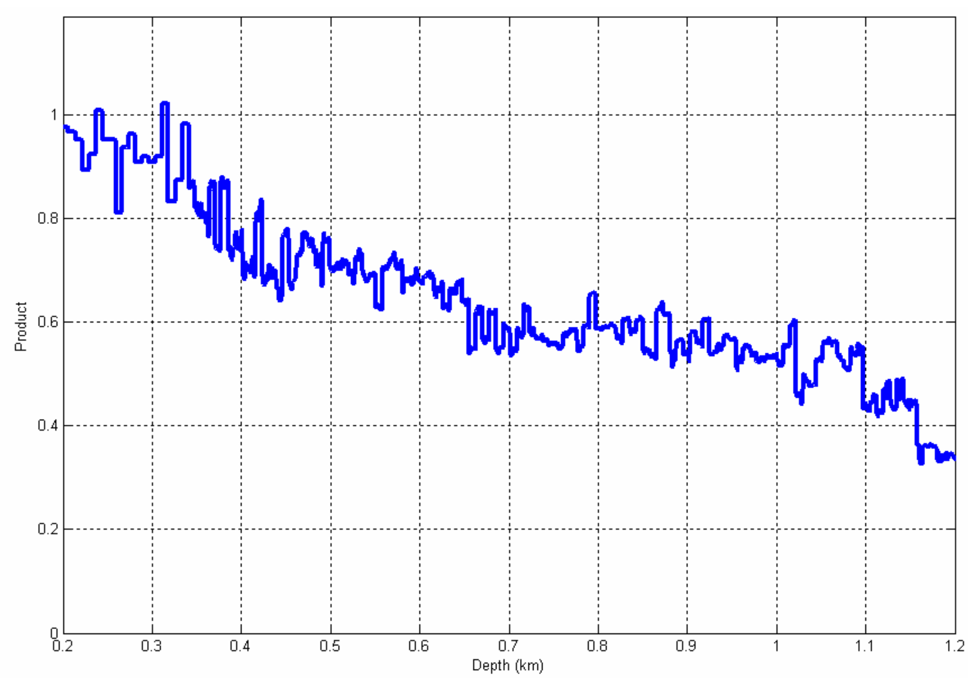

FIG. 4. Cumulative transmission coefficient.

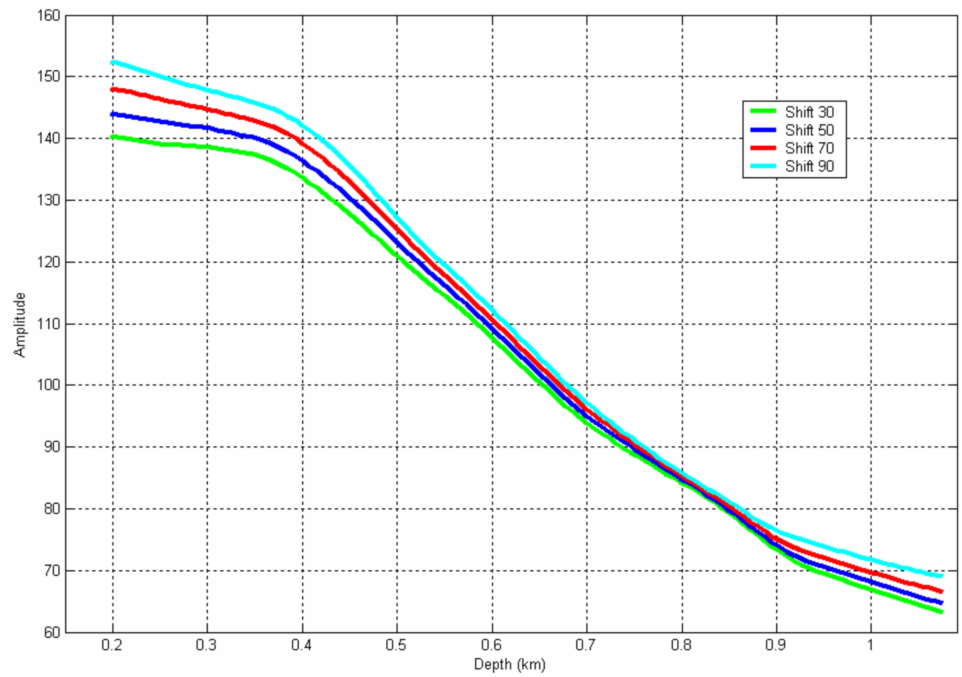

FIG. 5. Weighted and smoothed instantaneous amplitudes.

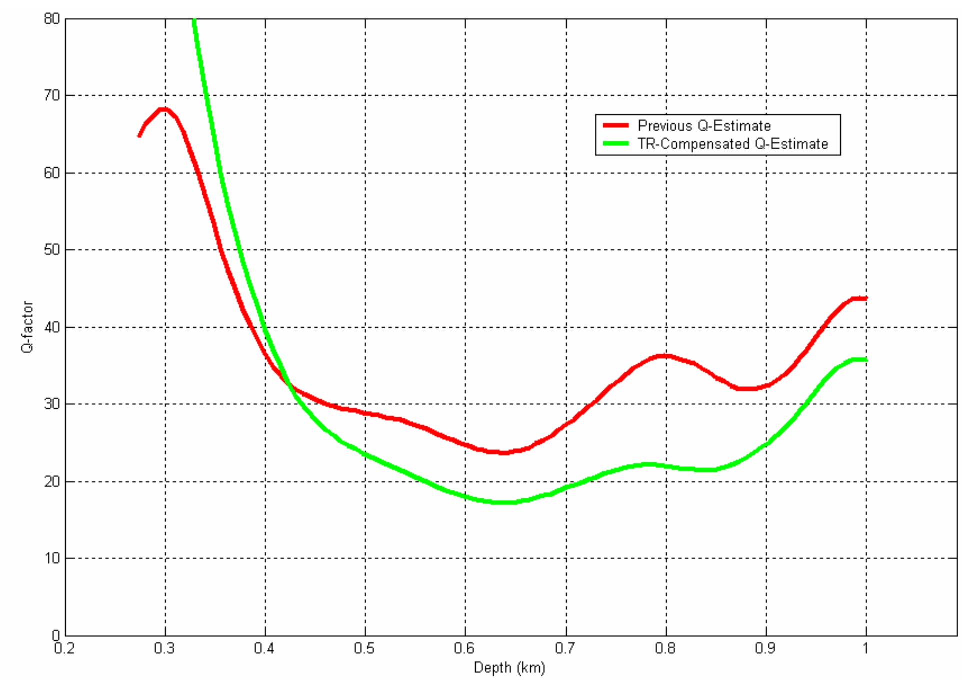

FIG. 6. Compensated Q-estimates versus depth (399m offset VSP).

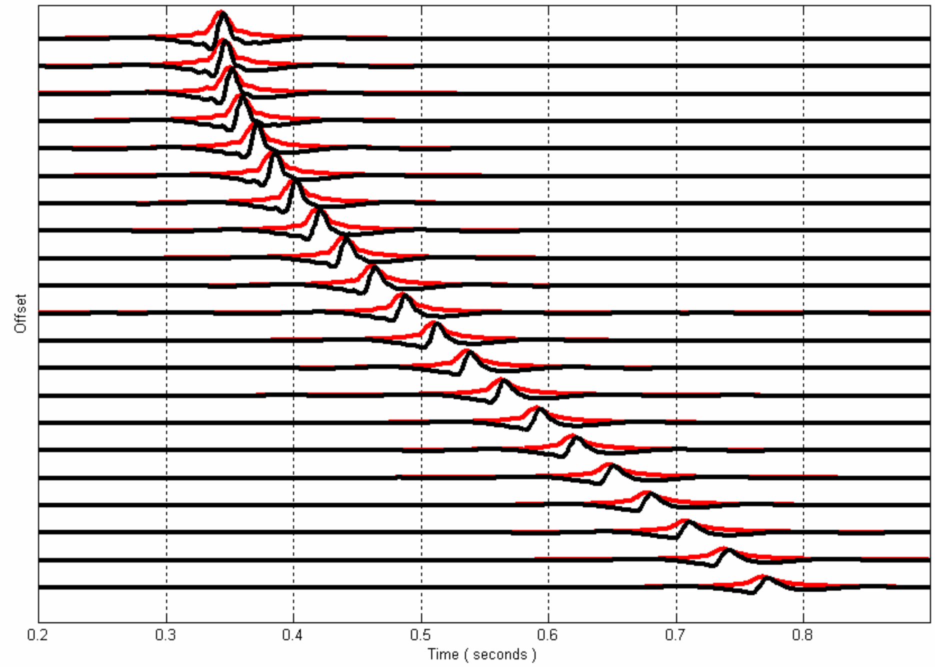

FIG. 7. Offset-dependent model traces(Q=50, 8/12-80\100 Hz Ormsby at z=500m).

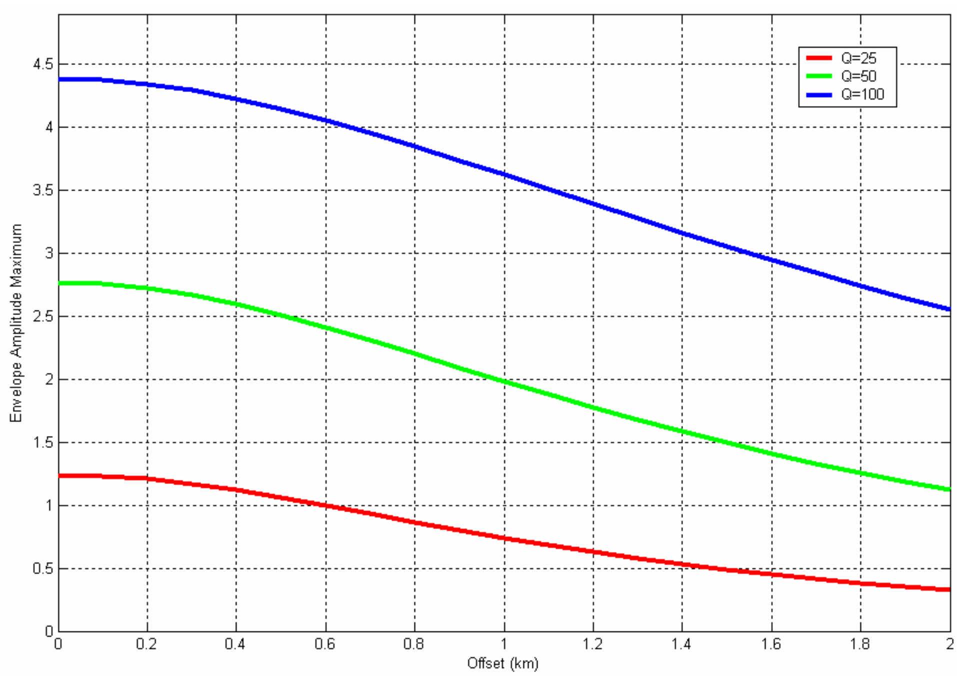

FIG. 8. Peak envelope as function of offset for 8/12-80\100 Hz Ormsby at z=500m.

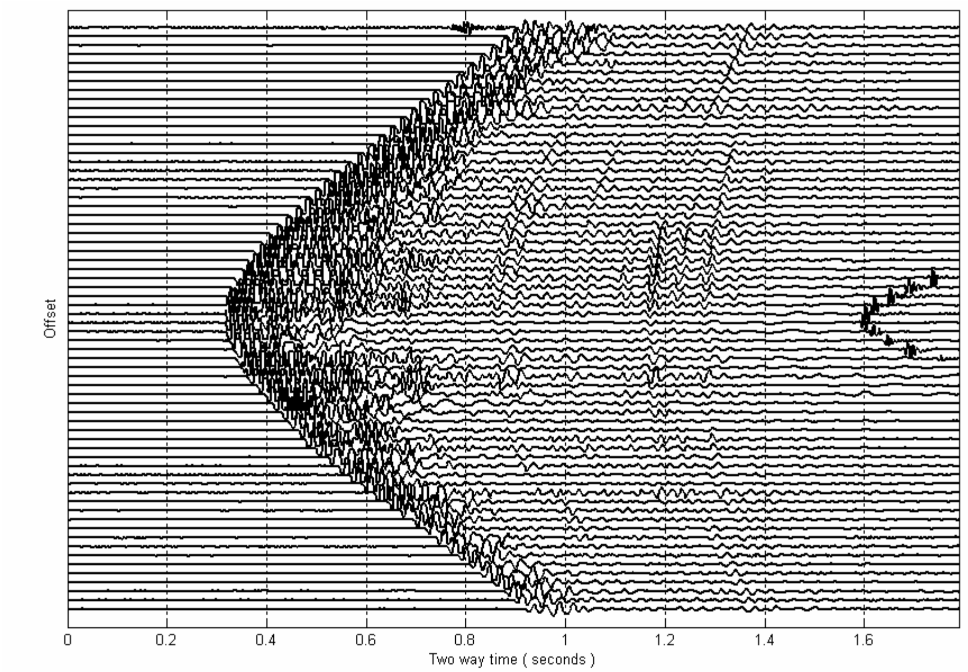

FIG. 9. Surface data shot record (clipped wiggle trace).

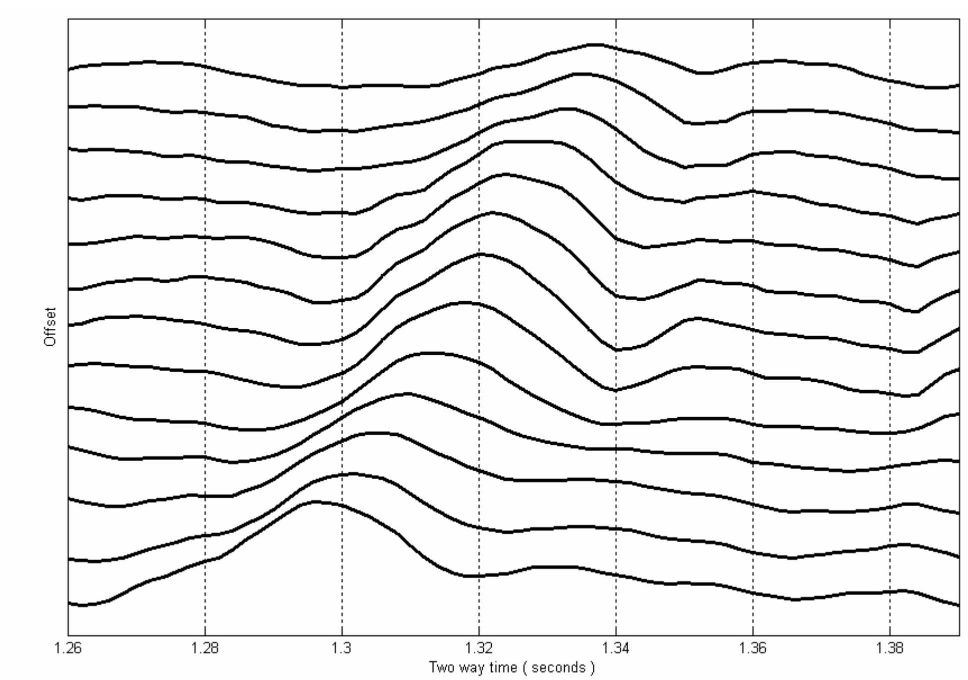

FIG. 10. Surface data analysis window (five trace envelope average).

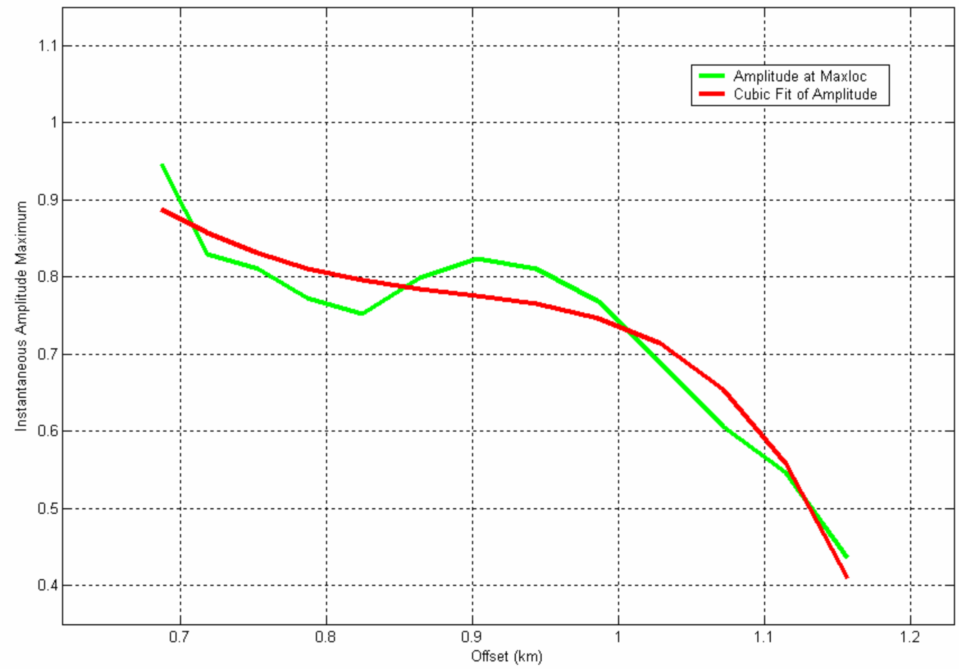

FIG. 11. Instantaneous amplitude versus offset (surface-data).

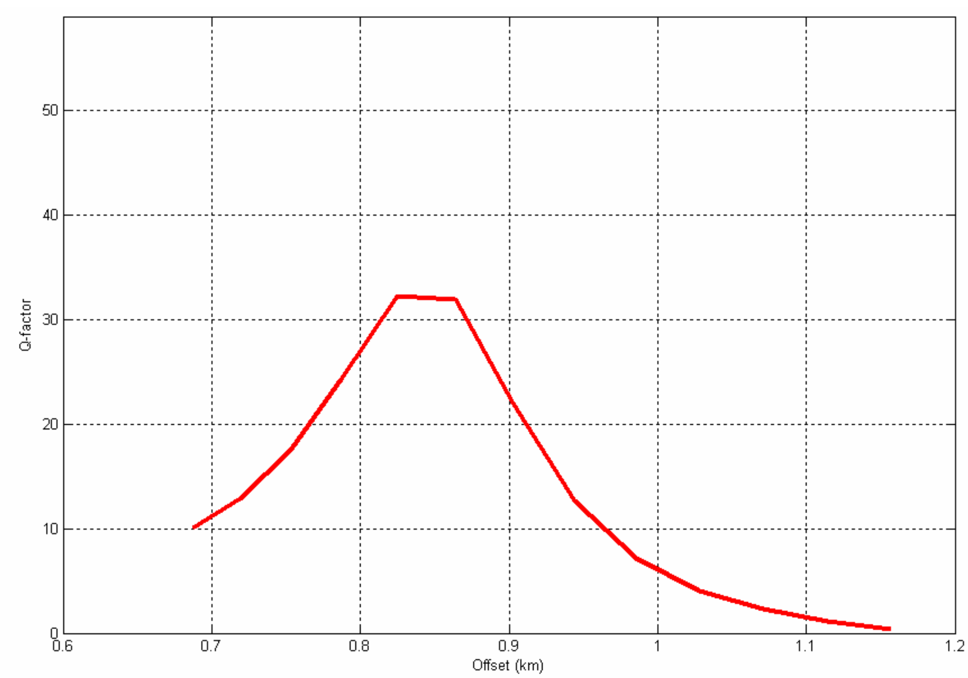

FIG. 12. Q-estimate versus offset (surface-data).