A three-component field study of the low-velocity layer
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Summary
A field experiment was devised to study shear-wave attenuation in the low-velocity surface layer by burying three 3-C geophones at approximately 6m, 12m, and 18m depths, and placing one on the surface. The geophones collected data during the shooting of a regular dynamite-source three-component line. A frequency analysis of the regular and converted-wave reflections showed that P-S reflections were already substantially attenuated compared to P-P reflections even at a depth of 18m. No difference in attenuation was observed between the different geophone depths. Uphole interval velocity calculations, based on reflected arrivals, showed the presence of the water table between 12 and 18m depths. Above the water table, Vp/Vs was 2 to 3, while below the water table, Vp/Vs had a very large value of 10.7. The experiment should be repeated with geophones that preferably reach the top of the bedrock.

Introduction
Converted-wave (P-S) surface seismic data is usually more attenuated compared to P-P seismic data (e.g. Zhang et al., 1994). In VSP data, however, the bandwidth of P-P and P-S data has usually been found to be comparable (e.g., Geis et al., 1990; Zhang et al., 1994). An important difference between VSP and surface seismic surveys is that, in surface surveys, the waves pass through the low-velocity layer. This layer is almost certainly highly attenuative to shear waves, as indicated by field experiments (e.g. Kudo and Shima, 1970), and provides an explanation as to why the high frequencies of converted waves are lost between the bedrock and the surface.

This experiment was designed to determine if shear-wave attenuation could be detected through the low-velocity layer and, if possible, estimate a shear-wave attenuation constant (Q_s) for the layer. The low-velocity layer was studied by burying 3-component geophones at different depths in the overburden and examining the frequency content of upgoing converted-wave reflections. If a value for Q_s can be determined, then it is possible to design inverse Q_s filters that could recover at least part of the lost bandwidth, thereby improving data quality. Calculations of short interval uphole P- and S-wave velocities are also possible with the data. This should improve our understanding of this important but often underappreciated layer.

Description of Experiment
The experiment coincided with the shooting of a 3C-2D seismic line in southern Alberta by a CREWES sponsor. The source was 4kg of dynamite detonated at a depth of 18m, with a nominal shot interval of 40m, and receiver interval of 20m. Three groups of buried geophones were placed at receiver stations of the 2D seismic line, and spaced far enough apart so as to have no shot points in common.

The 3-C geophones were buried by affixing them to planting poles, aligning them visually so that the radial channel paralleled the 2-D line, and then lowering them down augured holes of about 15 cm deep hole, leveled and aligned by hand, and then covered to reduce wind noise. The contractor brought the buried phones up live when the receiver location became part of the active spread. Three seconds of data were collected at a sample rate of 2ms, which was stored by the contractor as a separate line, and later delivered to CREWES.

Results and Analysis
The entire dataset consisted of 36 common receiver gathers (3 groups×4 receiver depths per group×3 channels per receiver), each containing an average of 65 traces. Figure 2 shows data for all depths and channels of group 1 (the rectangles represent frequency analysis locations, discussed below). These data have been passed through a 10-20Hz Ormsby highpass filter to reduce ground roll, followed by a 500ms AGC for display purposes. On all vertical channels, high-frequency events between 500 and 1100ms displaying hyperbolic moveout are P-P reflections corresponding approximately to the Bow Island to Elk Point formations. The P-P reflections have a similar appearance at all geophone depths. The radial and transverse channels are, on the whole, relatively uncontaminated by P-P mode leakage. For reasons not completely clear, there is generally more P-P mode leakage on the transverse channels than the radial channel. On the radial channels, the hyperbolic low-frequency events at mid- to far-offsets from about 900 to 2000ms are converted-wave reflections corresponding approximately to the Second White Specs to Mississippian formations. There is, overall, more converted-wave energy on the radial channels than the transverse, and so the frequency analysis was performed on the radial channels. As with the P-wave reflections, the converted-wave reflections appear very similar for geophones placed at different depths. Similar observations can be made for the data from groups 2 and 3.
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Figure 3 shows the frequency spectra of the f-k filtered comparable bandwidth at all depths, with no evidence of differential attenuation. The radial channels show that the converted-wave reflections have a narrow 10-20 Hz bandwidth, and no additional shear-wave attenuation is evident between 18m and surface. These same observations hold for the frequency spectra of the raw and 10-20Hz highpassed data.

**Uphole Interval Velocities**

Reflections ascending through the low-velocity layer will reach shallower geophones at progressively later times. The exact lag time between any two geophone levels is determined by the lag time of the maximum value of the trace-to-trace cross-correlation function, over a portion of the traces that contains numerous clear reflections. Because the depth of the geophones is known, interval velocities can, in this way, be calculated directly. Several intervals correlated rather poorly, and no time lag could be determined for these. Figure 1 shows schematically the P and S-wave velocities between every interval it could be confidently calculated, for all three groups. Where both interval P and S-wave velocities have been determined, the Vp/Vs ratio for that interval is given in the right-hand column.

The results show a dramatic drop in P-wave velocity between the 12m depth and 6m depth, indicating the presence of the water table. S-waves do not experience as great a velocity drop; this results in a large Vp/Vs of 10.7 below the water table for group 2. These results are corroborated by a refraction survey (Lawton, 1990).

**Conclusions and Recommendations**

The converted waves are already substantially attenuated at a depth of 18m, and additional attenuation was not detected data. In all groups the P-P reflections have a between 18m and the surface. Refraction static models of the 2-D line indicate that the low-velocity layer is in excess of 50m thick in places, which explains the high degree of shear-wave attenuation observed. This experiment would probably have better success at detecting attenuation in the low-velocity layer if the geophones are buried deeper and separated by larger intervals. Alternatively, this experiment could be repeated in an area that has a thinner overburden layer. Fitting the geophones with high-strength cable is recommended to make recovery of these expensive phones possible.

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**References**


**Figure 1.** Uphole interval velocities for all groups, and Vp/Vs for intervals where both Vp and Vs could be determined.
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Figure 2. Group 1 receiver gathers, all channels. Data have been filtered to suppress ground roll and gained with a 500ms AGC. Trace windows represent data analysis locations (see text for details). V = vertical channel; R = radial channel; T = transverse channel.
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Figure 3. Frequency spectra of f-k filtered P-P and P-S reflections, for all groups.