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Dispersion analysis of guided waves observed on microseismic records in an underground mine

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Summary

Seismic guided waves can propagate in low-velocity subsurface formations acting as a waveguide with much less energy loss than body waves. In this study, we observed the presence of dispersive arrivals in microseismic events from a potash mine in Saskatchewan, Canada. These records were acquired by a network of in-mine broadband seismometers. Theoretical dispersion curves were generated using a 1D velocity model of the mining region; it is suspected that the low-velocity evaporites are acting as waveguides. We use the multiwavelet method to compute dispersion curves from the observed seismograms. This method is also applied to the synthetic seismograms generated from microseismic events and receiver locations with the given 1D velocity model. A comparison of the dispersion curves for the synthetic and observed seismograms suggests that lateral heterogeneity may be present in the medium. These guided waves have the potential for imaging the waveguide.

Theory

Guided waves are obtained by solving the wave equation under specific boundary conditions at the waveguide interface. Several matrix formulations have been developed for modeling wave propagation through 1D horizontally layered media. We use the global matrix method of Knopoff (1964) as described in Lowe (1993) for modeling the theoretical dispersion curves for the guided waves. A 1D velocity model shown in Figure 1a is used to model the theoretical dispersion curves. The group velocity can be subsequently computed from the phase velocities (Bensen et al., 2007).

We use the multiwavelet method (Poppeliers and Preston, 2019) to compute the group velocities from the observed seismograms. This method uses a series of complex-valued, mutually orthogonal Slepian wavelets (Lilly and Park, 1995) which are convolved with the seismogram. These wavelets are band-limited and their center frequencies are adjusted by rescaling the wavelet. When the wavelets are convolved with the seismogram, they reject the Fourier components of the seismogram outside the band of the wavelet. Thus, convolving the wavelets for a range of scales yields a series of narrowband decompositions of the seismograms. Moreover, this method can provide estimates of the uncertainty of surface wave group velocity (Poppeliers and Preston, 2019).

Results

Figure 1a displays a 1D velocity model showing the major lithologies present in the mining region and has been obtained from averaging well logs from a neighboring mine (Prugger & Gendzwill, 1988). The theoretical dispersion curves (Figure 1b) display phase and group velocities as a function of frequencies. Several possible modes of propagation are excited with the P-SV normal modes shown by the blue color in Figure 1b. The P-SV normal modes are dispersive with the low frequencies having the highest velocities close to the shear velocity of the top Carbonate layer above the low-velocity layer. The leaky modes shown in red color have phase velocities bounded by the P-wave velocity of the evaporite (4.3 km/s) and the overlying carbonate rock (4.8 km/s). The green curve shows the group velocity computed from the phase velocity of the fundamental normal mode.

Figure 2a shows a good quality microseismic event recorded at the 12 underground receivers. We have picked arrival times of dispersive phases that are coherent across the network shown by green and magenta-filled circles for early and late arriving phases (Figure 2a). Barthwal et al., 2022 studied these microseismic data recorded between April 1, 2021, and May 31, 2021, and performed event locations and moment tensor inversion. Figure 2b-c shows the application of the multiwavelet method for computing the group velocities from the vertical component seismograms recorded at receivers 5 and 12 respectively. The colormaps correspond to the magnitude of wavelet coefficients obtained when convolved with the seismograms and their peak values at each frequency are located (shown with red crosses) to obtain group velocity dispersion curves. Using event locations obtained by Barthwal et al., 2022 and the 1D velocity model shown in Figure 1a, we compute the synthetic seismogram with the Computer Programs in Seismology package (Herrmann, 2013). We apply the multiwavelet method to the vertical component synthetic seismograms to obtain dispersion curves and compare them with those obtained from observed seismograms in Figure 2d-e. The observed group velocities decrease with increasing frequency at receiver 5 similar to that obtained for the synthetic seismograms computed with the 1D velocity model. However, at receiver 12, the lower frequencies have lower group velocities whereas higher frequencies propagate at higher velocities, unlike the dispersion curve for synthetic seismogram.

Conclusions

We study microseismic data recorded by in-mine seismometers in a potash mine. The seismograms are dominated by dispersive phase arrivals. We compute theoretical dispersion curves using a 1D velocity model of the study region. The dispersion curves exhibit normal behavior with phase and group velocities decreasing with increasing frequency. The dispersion curves obtained for the observed seismograms of an event at different receivers show both increasing and decreasing group velocities with frequency. The synthetic seismograms computed with the 1D velocity model show normal dispersion curves. Thus, the 1D velocity model cannot explain the increasing velocity with frequency thereby suggesting a more complex, laterally varying medium.

Acknowledgments

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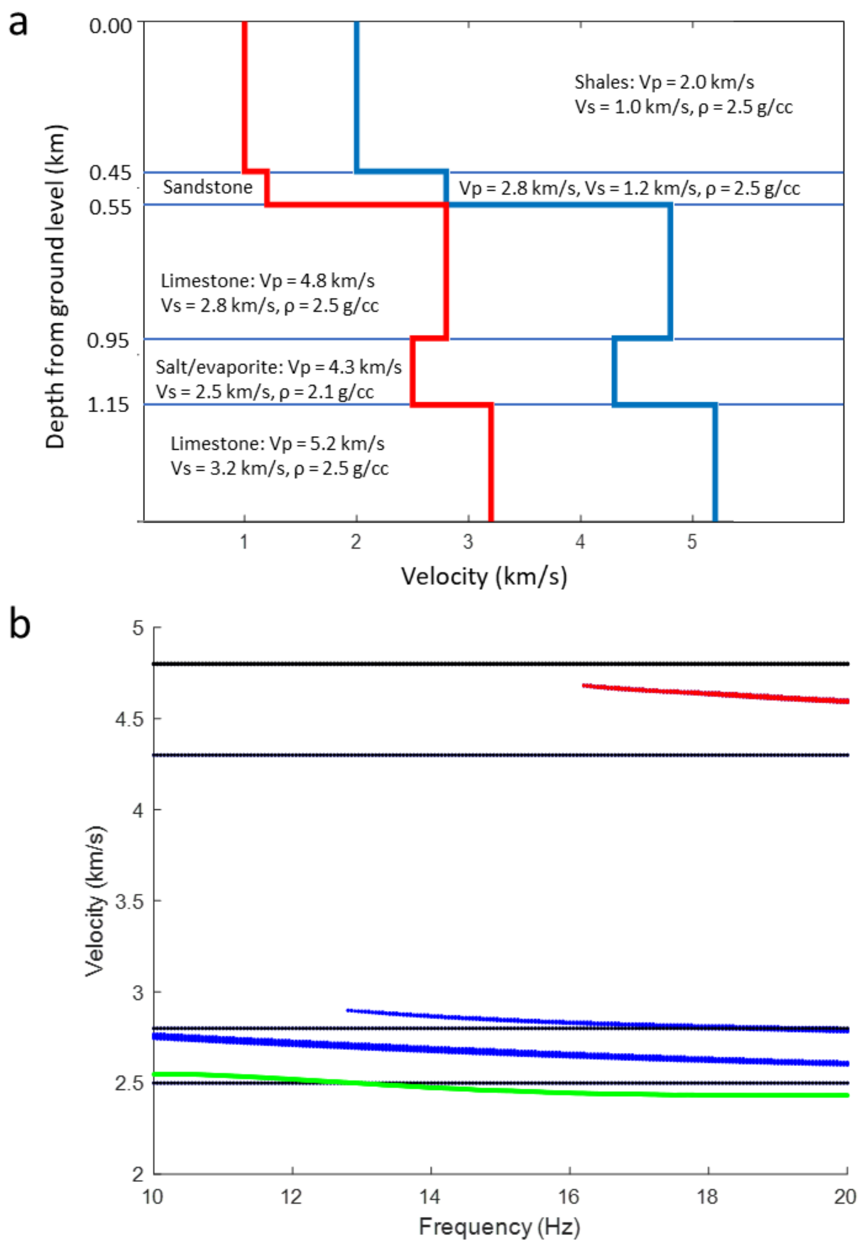

Figure 1. (a) 1D P- and S-wave velocity models shown by blue and red colors respectively. The lithologies and corresponding densities are also given. (b) The theoretical dispersion curves computed for the velocity models shown in Figure 1a. The leaky modes, P-SV normal modes, and phase velocity boundaries are shown in red, blue, and black colors respectively. The green color shows the group velocity derived from the phase velocity of the fundamental normal mode.

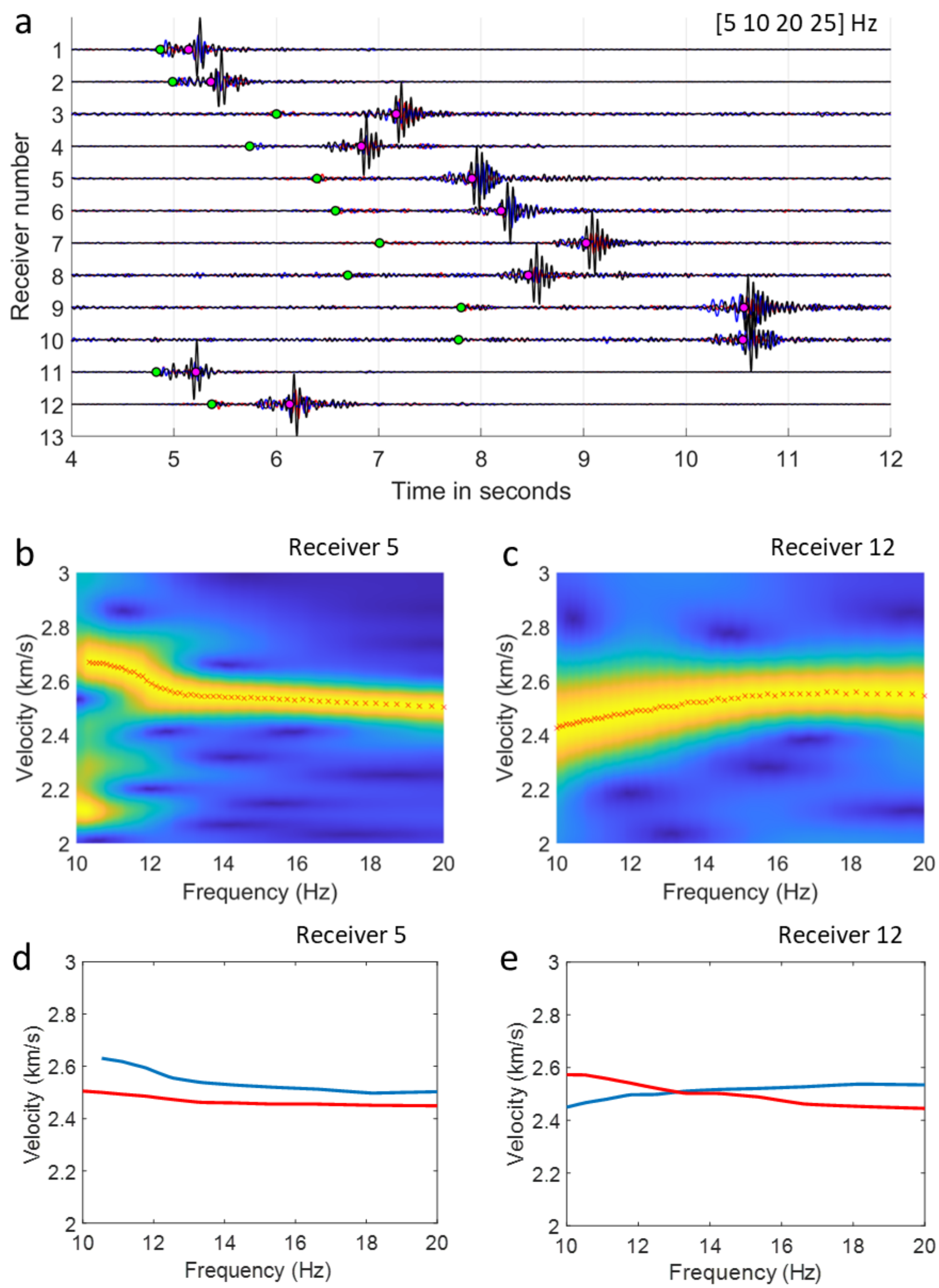

Figure 2. (a) A microseismic event recorded at 12 underground receivers. The green and magenta-filled circles correspond to the arrival time picks of the high-energy phases coherent across the recording network. A trapezoidal filter [5 10 20 25] Hz has been applied to the waveforms. (b) and (c) show the colormap corresponding to the magnitude of the wavelet coefficients obtained by convolution with the vertical component seismograms at receivers 5 and 12, respectively. The red crosses are the estimated group velocities from the peak magnitudes of the wavelet coefficients. (d) and (e) show the estimated group velocity dispersion curves at receivers 5 and 12, respectively. The blue and red curves are obtained for the observed and synthetic vertical component seismograms, respectively.

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