Seismic Spectral Attributes of Apparent Attenuation

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Summary

Seismic attenuation estimation is extremely useful for reservoir characterization, subtle geological structure identification, and seismic signal compensation. However, seismic attenuation effect not only distorts their amplitudes but also disperses seismic waves, which gives rise to a number of issues and renders the accurate attenuation estimation challenging. As the measurement of attenuation, the relative value of quality factor Q is more important in seismic interpretation. Instead of struggling to characterize the accurate seismic attenuation value, we propose a package of seismic spectrum characterization based attenuation attributes to evaluate apparent attenuation effects. The proposed attributes assume the seismic wave is propagating through the earth as a Ricker wavelet. Based on this, the attributes' validities are proved analytically in this paper (Part 1: Methodology). Using field data results (presented in the following paper, see Part 2), it is shown that the proposed seismic attenuation attributes are effective and robust for seismic interpretation compared to previous seismic attenuation estimation results.

Apparent Attenuation

Apparent seismic attenuation includes the intrinsic attenuation, as well as the interaction among multiple receivers, geometric spreading, scattering, frequency-independent transmission loss or gain, and frequency-dependent thin layer interfaces. For the reflection seismic data, geometric spreading can be compensated during migration; Thin layer interferences can be corrected based on well logs (Li et al., 2015a). The intrinsic losses due to conversion from mechanical to heat energy, and scattering attenuation due to fractures heterogeneities and rugose surfaces are the two important factors related to conventional and unconventional reservoirs, respectively, so the characterization of apparent attenuation can be beneficial for both kinds of reservoirs.

$$A_{apprt} = A_{intrinsic} + A_{scattering} + A_{spreading} + A_{tuning}$$

Assumptions & Motivations

- Geometric spreading attenuation can be compensated by surface consistent amplitude processing and migration.
- Spectral response to layering can be compensated by computing reflectivity spectra from impedance inversion.
- Reflectivity is white within certain analysis window across the entire survey, while can also be blue with well control.
- Spectral balancing (or bluing) removes the time variant phenomenon of the source wavelet and the absorption effects from the overburden.
- The pre-processing steps leave intrinsic and scattering seismic attenuation effects in the target area.
- Ricker wavelet spectrum assumption may not be the case in the field application, then Ormsby wavelet spectrum assumption is used.
- Measuring the apparent attenuation can highlight the conventional and unconventional reservoirs.

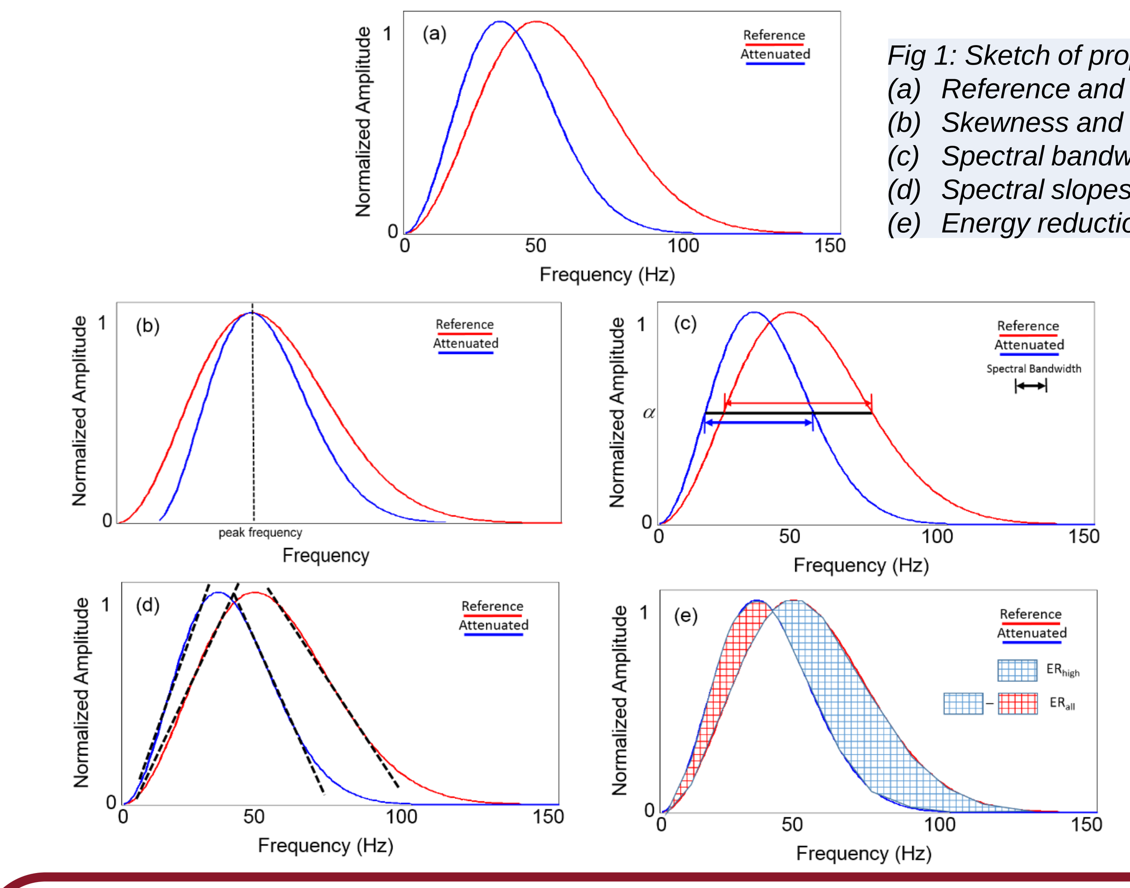


Fig 1: Sketch of proposed attributes:
(a) Reference and attenuated spectra;
(b) Skewness and Kurtosis;
(c) Spectral bandwidth;
(d) Spectral slopes;
(e) Energy reduction.

Synthetic Example

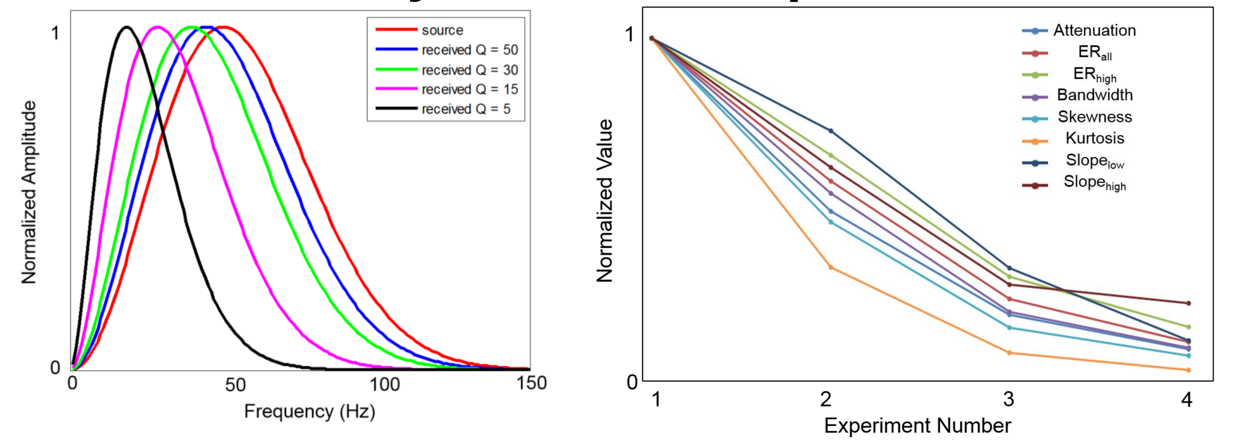


Fig 2: Ricker wavelet spectra with different attenuation, and normalized values of seismic attenuation attributes.

Figure 2 shows the normalized spectra of reference and attenuated signal. Note that when attenuation is stronger, the peak frequency is smaller, and more high frequency energy attenuated. Results of attenuation attributes associated with different Q values are also displayed. Because we want to know the relative attenuation relationship, all values are shown in the normalized way. It is clear that every attributes has a good correspondence with the attenuation factor.

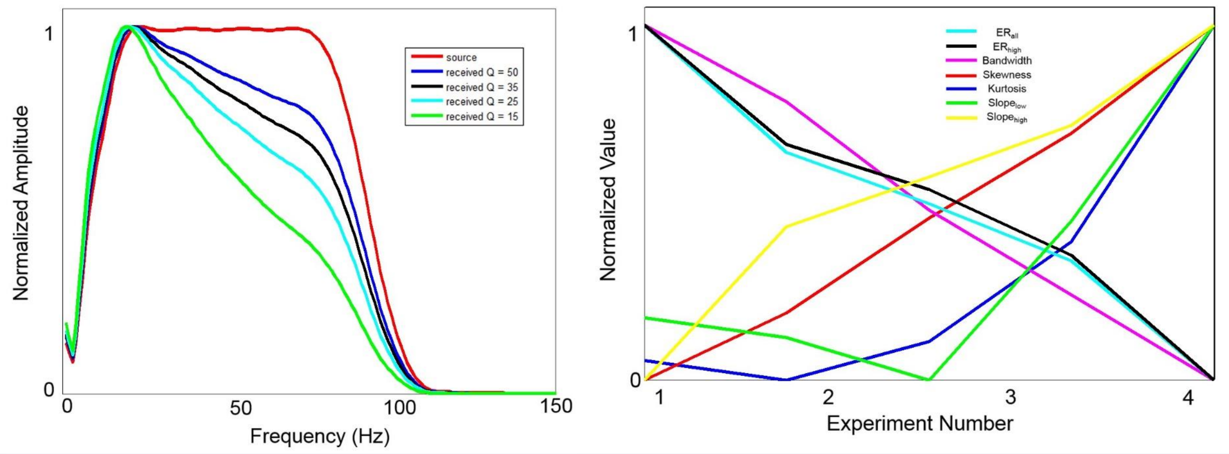


Fig 3: Ormsby spectra with different attenuation, and normalized values of seismic attenuation attributes.

In the field, the wavelet may not always be the Ricker wavelet. After spectral balancing (bluing), the flat spectrum is usually expected. Fig 3 shows a synthetic example using Ormsby wavelet with corner frequency 10-20-80-100 Hz. The results show that most of the attributes still work.

Field Application

The study area is in the eastern part of the Anadarko Basin, Oklahoma (Fig 4). Pennsylvanian rocks throughout most of the Anadarko Basin are dominated by shallow-shelf marine clastics. The target is the Red Fork Sand of the middle Pennsylvanian age, composed of clastic facies deposited in a deep-marine (shale/silt) to shallow-water fluvial-dominated environment. The Red Fork Sandstone is sandwiched between two limestone layers, with the Pink Limestone on top and the Inola Limestone on the bottom. The Oswego Limestone that lies above the Pink Limestone and the Novi Limestone that lies below the Inola Limestone are prominent reflectors that can be mapped easily on seismic-amplitude data, providing an approximation to a fixed geologic time. The Upper Red Fork incised-valley system consists of multiple stages of incision and fill, resulting in a stratigraphically complex internal architecture.

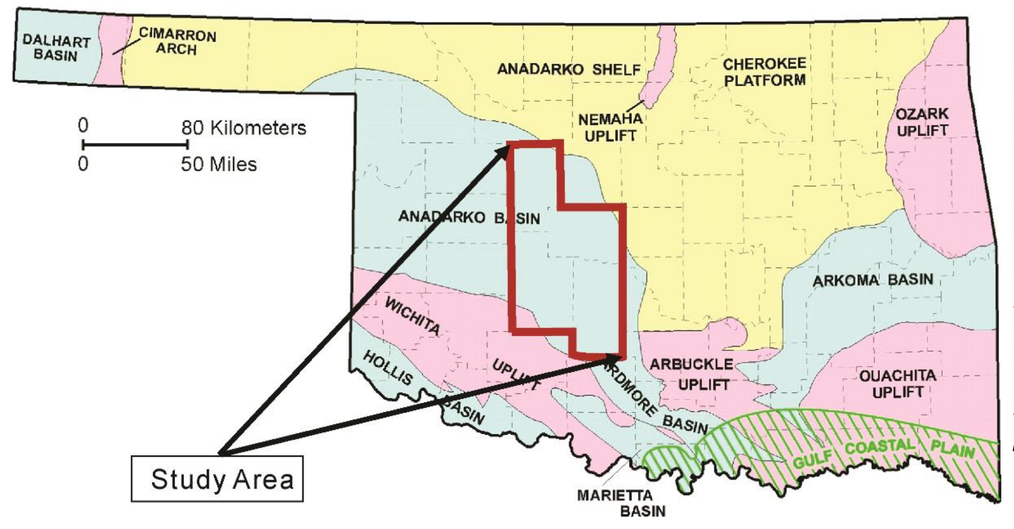
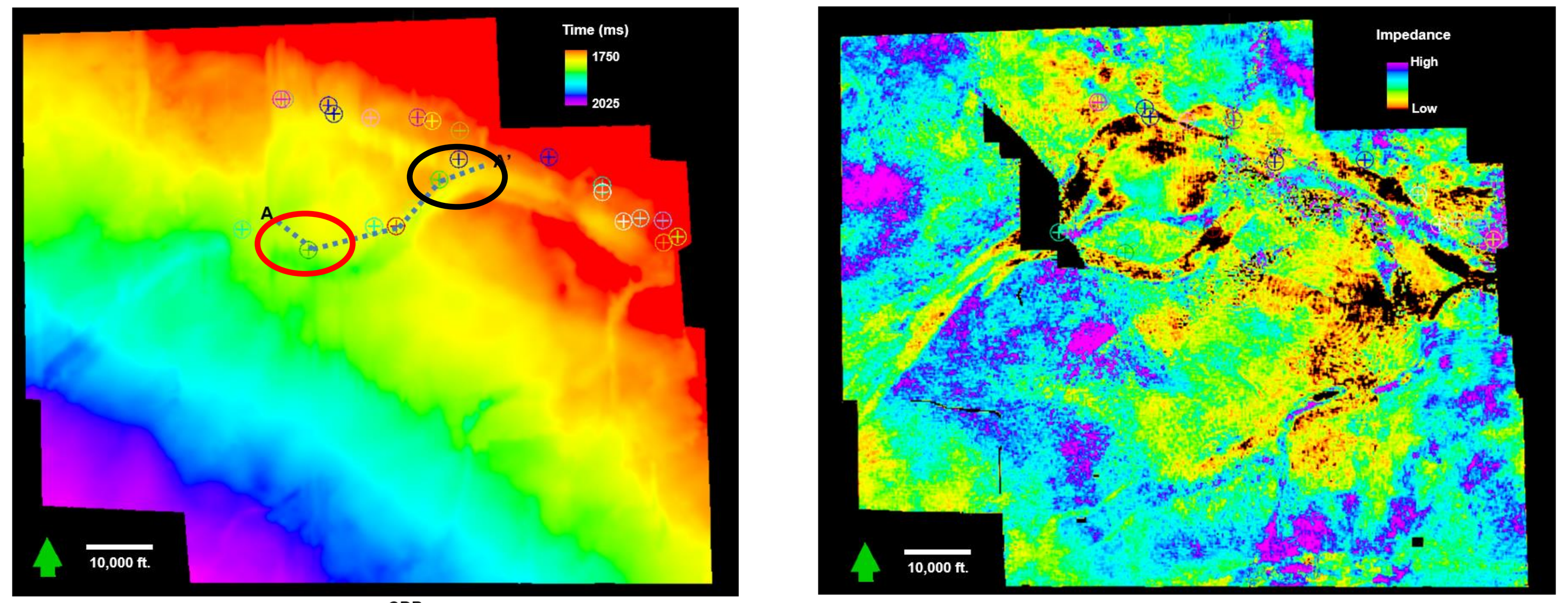


Fig 4: Location map of the Anadarko Basin area on a map of Oklahoma. The study area lies inside the red boundary. (After Del Moro et al., 2013).

Fig 5: (a) Time structure map of the base of the incised channels in the Red Fork channels showing dip to the SW. (b) Horizon slice along base of Red Fork through seismic impedance. Note that the sandstone in the channel shows low impedance in yellow, red and black, while the surrounding matrix shows higher impedance in green, blue, and magenta. The cross circles denote the positions of 19 productive wells.



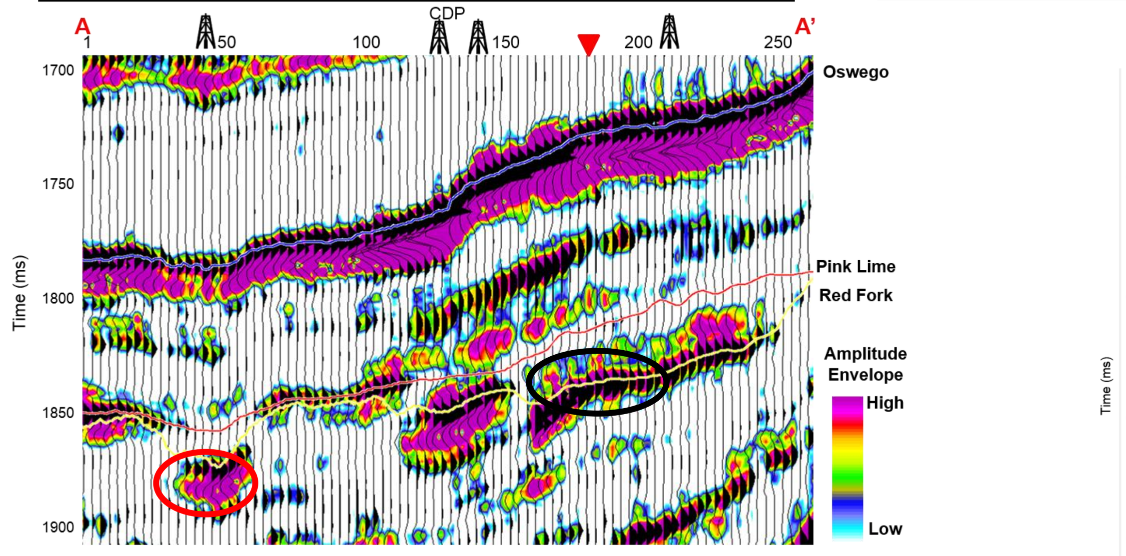


Fig 6: Vertical slice along line AA' shown in Fig 5a through amplitude wiggles overlain by instantaneous envelope. The Oswego Lime (blue pick) and Pink Lime (red pick) form regional markers.

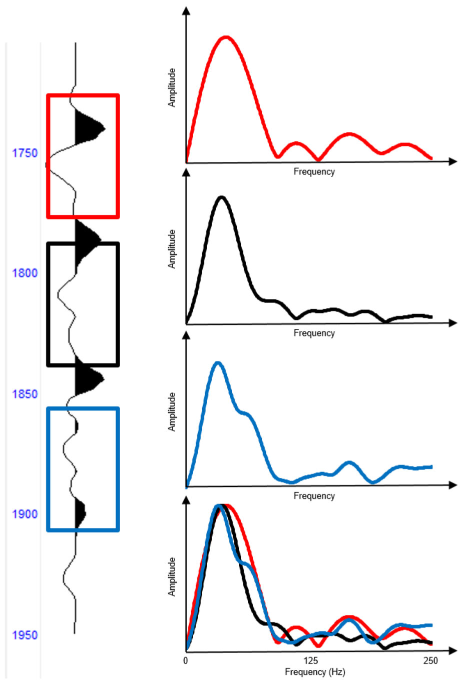


Fig 7: Single trace example (extracted from CDP 170, denoted as a red triangle in Fig 6) of seismic spectral changes with increasing depth.

Fig 5a shows the time structure map of the base of the channels in the Red Fork, where the channels are clearly visible. Fig 5b shows a horizon along the Red Fork through inverted seismic impedance, where the sandstone deposited in the channels exhibits impedance, and the surrounding matrix shows high impedance. Fig 6 shows the vertical seismic section of the dashed line AA' in Fig 5a. The seismic traces are drawn in wiggles overlain by seismic instantaneous envelope in color. We extract seismic trace at CDP 170 denoted by red triangle along the arbitrary line AA' in Fig 5a and analyze its spectrum in a sliding window. Fig 8 shows the seismic attenuation attribute values between the top Pink Lime and bottom of the incised Red Fork formation in Fig 6.

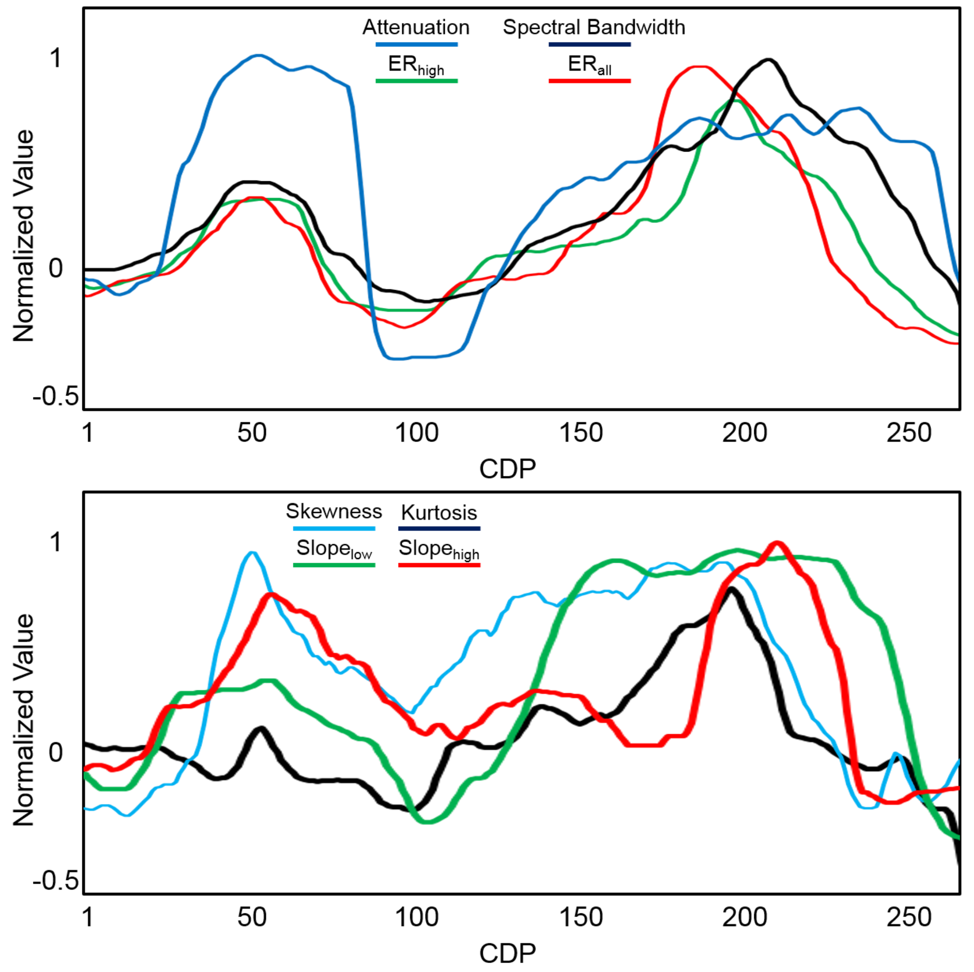


Fig 8: Seismic attenuation attributes between the pink and yellow horizon shown in Fig 6. Attenuation estimation using the central frequency shift (CFS) method, spectral bandwidth, energy reduction in full bands and high frequency bands, spectral slopes of low and high frequencies, skewness and kurtosis.

Conclusions

We propose a package of seismic attenuation attributes based on spectral shape changes to characterize apparent seismic attenuation. All these changes are associated with seismic attenuation non-linearly, but they are promising indicators for relative attenuation changes which are useful for seismic interpreters.

Acknowledgment

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