Characterizing intrinsic and stratigraphic Q in VSP data with information measures, part II

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Summary

In last year's paper that has the same title as this, a Shannon entropy measure, which is originally designed to measure the amount of information carried by an uncertain message in information theory, was adapted to the time domain synthetic VSP data, with the purpose of distinguishing between absorption (intrinsic Q) and stratigraphic filtering (extrinsic Q) who have similar amplitude attenuation and dispersion effects on seismic waves. As a result, Intrinsic Q and extrinsic Q were found to have seemingly opposite effects on entropy variation with time result of the VSP data sets, for both the first-order entropy and the second-order (conditional) entropy. In this paper, a speculation is made and tested based on the previous result, that, the entropy variation with time result of a VSP data set which is affected by both intrinsic and extrinsic Q can reflect the relative strength of two attenuation mechanisms when they act simultaneously on seismic waves. An experiment valuing the first-order entropy result of synthetic VSP data sets built from seven wells showed that the speculation has merit.

Introduction

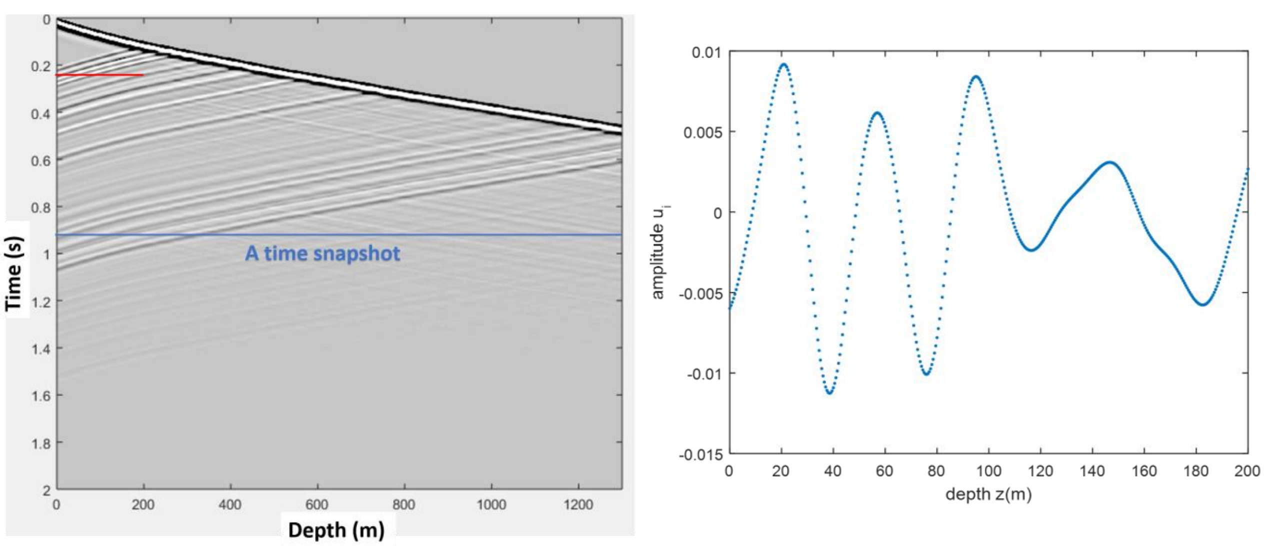

Figure 1. An example of a discrete VSP data set (left) and the amplitude distribution with depth zoomed on to the part covered by the red line (right). The right plot shows that the data points in the wave field are discrete.

For a discrete VSP data set, assume each of its time snapshots to be a "message", and data points with amplitude u_i in the snapshot can be regarded as the "letters" which make up the "message".

Suppose each time snapshot consists of N data points (i.e. responses from N receivers), and every data point takes an amplitude value u_i $(i = 1,2, \dots, m)$. By enumerating the occurrences of a certain u_i in the snapshot as $W(u_i)$, define the probability of its occurrence (Innanen, 2012) as:

$$P(u_i) = W(u_i) / \sum_{i=1}^{m} W(u_i).$$

And the first-order entropy of a single data point is:

$$H' = -\sum_{i=1}^{m} P(u_i) \log_2 P(u_i).$$

The first-order entropy of a snapshot is:

$$H = N * H'.$$

We investigated how entropy change (with time) among different snapshots of synthetic VSP wave fields which contain correspondingly: a) primaries; b) primaries with internal multiples; c) primaries with absorption and d) primaries with both absorption and internal multiples to allow the separate or combined effects of intrinsic Q and extrinsic Q on entropy to be studied. Log data from seven wells:

(a) Two from Blackfoot Oilfield in Alberta, Canada. Located 15km south-east of Strathmore: 1227 and 1409 (Hoffe et. al., 1998);

(b) Three from working area near Hussar, Alberta, Canada: 12-27-025-21, 14-27-025-21 and 14-35-025-21;

(c) Two from Gove and Comanche working area in Kansas, United States: Roemer-Bell No. 1-1 and Kissel A No. 1-8,

were used to built the VSP data sets respectively.

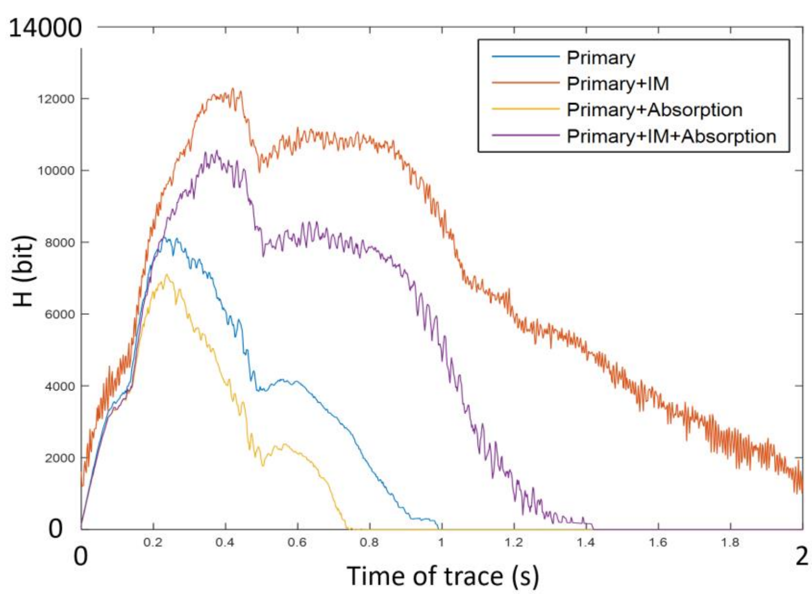

Figure 2. The first-order entropy variation result of synthetic VSP data sets built from well Blackfoot 1227.

Take the first-order entropy variation with time result in figure 2 as an example, the following observations can be made:

(1) For all situations, entropy increases with advancing time, reflecting the increasing disorder in wave field; the entropy decrease is proven to be an artifact;

(2) Wave fields including internal multiples (purple and red curves) contribute to larger peak entropy values than other wave fields (blue and yellow curves);
(3) Entropies measured from wave fields containing absorption exhibit smaller peaks than others (comparing purple and yellow curves to the red and blue ones respectively);
(4) The most disordered wave field contributes to the largest entropy peak (red curve) and vice versa (yellow curve).

Theory and method

Intrinsic Q and extrinsic Q are likely to influence entropy in the opposite sense. Which gives promise in using the entropy behavior as an indicator of the relative strength of stratigraphic Q and absorptive Q, in scenario when their effects on seismic waves are inseparable.

To test that, take the first-order entropy peak increase from wave field (a) (blue curve in figure 2) to wave field (d) (purple curve in figure 2) as a measurement of the entropy behavior. Then, utilize the following relationship (Spencer et al., 1982) to estimate the extrinsic Q in the VSP data sets who gave the entropy results as a reference:

$$\frac{1}{Q_{apparent}} = \frac{1}{Q_{\text{intrinsic}}} + \frac{1}{Q_{extrinsic}}.$$

In which $Q_{intrinsic}$ and $Q_{apparent}$ are calculated respectively from wave field (c) and wave field (d) by the spectral ratio method.

Examples

All seven wells are included in the experiment to ensure that the comparison between entropy peak increase and the extrinsic Q strength relative to total Q reflects the character of the information measure rather than the data.

Table 1. Q information in seven wells' positions (I)

	Roemer Bell No. 1-1	Kissel A No. 1-8	Blackfoot 1227	Blackfoot 1409
Intrinsic Q	68.6	68.6	68.7	68.5
Apparent Q	29.2	54.2	47.9	35.8
Percentage of extrinsic Q in total Q (%)	57	21	30	48

Table 2. Q information in seven wells' positions (II)

	Hussar 12-27-25-21	Hussar 14-27-25-21	Hussar 14-35-25-21
Intrinsic Q	68.6	68.6	68.7
Apparent Q	47.9	34.1	42.0
Percentage of extrinsic Q in total Q (%)	30	50	39

The last row of table 1 and 2 lists how much of the total Q is contributed by the extrinsic Q in seven well positions. We compared the extrinsic Q strength with the entropy peak increase from wave field (a) to (d) for different wells. A positive entropy peak increase indicates that wave field (d) contributes to a larger entropy peak value than (a) and a negative number indicates a smaller entropy peak value of wave field

(d) than (a). Also, the larger the number, the more the entropy peak increases from (a) to (d). The comparison result is displayed in figure 3.

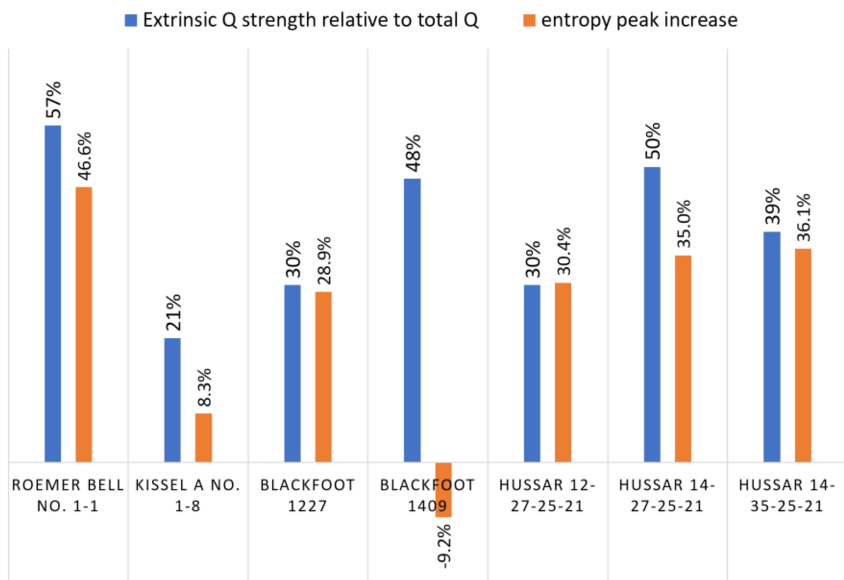

Figure 3. Comparison between extrinsic Q strength relative to total Q and the entropy peak increase from wave field (a) to wave field (d) of seven wells.

Basing on existing knowledge of time domain first-order entropy, we speculate that the stronger the strength of extrinsic Q in total Q is, the larger the entropy peak increase will be. This speculation is somehow supported by figure 3. Roemer Bell No. 1-1, the one having the strongest extrinsic Q of all wells, also has the largest entropy peak increase of all; in contrast, Kissel A No. 1-8 appears to have the weakest extrinsic Q and the smallest positive entropy peak increase. A similar positive relationship between extrinsic Q strength and the entropy peak increase is observed on well Blackfoot 1227 and three wells from Hussar working area. However, well Blackfoot 1409 does not share the relationship. We found that its well logs have a narrower frequency band than well logs of other six wells, which would almost certainly have affected the outcome of spectral ratio method.

Conclusions

The experiment in this paper showed promise for utilizing an information measure on the wave fields for estimating the relative strength of intrinsic Q and extrinsic Q when they both affect the seismic wave. Among seven wells that were tested, six exhibited good agreement with the hypothesized relationship of extrinsic Q strength relative to total Q and the entropy peak increase from wave field (a) to wave field (d) built from the wells. Specifically, the stronger extrinsic Q is relative to total Q, the larger the entropy peak increase would be. In figure 3, all wells except Blackfoot 1409 appear to have positive entropy peak increase, when extrinsic Q strength in their positions ranges from 20% to 60%. It indicates that the impact of extrinsic Q on entropy is more influential than that of intrinsic Q. Therefore, it is provisionally concluded that whenever the entropy peak increase is negative, it could mean that the extrinsic Q strength over the depth interval of interest is considerably weak, likely to take less than 20% of total attenuation.

Acknowledgements

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