Towards characterization of intrinsic and stratigraphic Q in VSP data with information measures

Siming Lv and Kris Innanen

CREWES, University of Calgary

Summary

The problem of distinguishing between intrinsic Q and stratigraphic filtering is a classical example of non-uniqueness in seismic data analysis. Two very different mechanisms affecting propagating waves – reverberations between thin layers and transformation of mechanical energy to heat – produce almost identical effects. A version of the Shannon entropy, defined on snapshots of a VSP wave field, has been proposed to discuss these two influences. In this project the entropy calculation is applied in time domain and also in frequency domain, aiming to locate what can be separated between these two effects. Conditional probabilities in which correlation of wave field values with neighbouring values is incorporated, rather than a statistical PDF histograms of single instances of particular wave field values. 1D VSP modelling codes and a range of well logs are used to investigate the separability of intrinsic/extrinsic sources of attenuation and dispersion. Progress of this kind will have significant impact on reservoir characterization where viscosity changes are expected: such changes can be tied to intrinsic Q but not extrinsic Q. The results, in which the various processes produce noticeable differences in entropy, indicate that this is a promising line of inquiry. Parameters like bin size have a large effect on the entropy, especially at late times, so that the footprint of bin size is studied in detail.

Introduction

Stratigraphic filtering is the special term used to describe apparent amplitude dissipation caused by reflections, especially internal multiples, in contrast with dissipation caused by the absorption factor Q (Aki and Richards, 1980). Verified by many experiments and observations, the scattered multiples have attenuating effects on the transmitted wave which highly resemble those caused by absorption: decaying and spreading waveform, reducing the high-frequency content of the initial disturbance and appends incoherent coda to the signal. Since its mechanisms have origins not based on intrinsic rock properties, it can be regarded as an extrinsic Q factor in contrast with intrinsic Q.

Ever since O'Doherty and Anstey (1971) pointed out the equivalent importance between stratigraphic and absorptive attenuation in periodic layering section, significant effort has been expended in developing methods which attempt to distinguish between intrinsic and extrinsic Q (Hauge, 1981; Spencer, 1977, 1982; Stewart, 1984; Walden and Hosken, 1985).

Estimation of intrinsic Q free from effects of extrinsic Q is valuable for quantitative interpretation. For example, Vasheghani and Lines (2009) showed that the viscosity of a cross-well section can be derived from the intrinsic Q measurement by Biot-Squirt theory (Lines, Vasheghani and Bording, 2013). And a clear understanding of the viscosity in unconventional heavy oil reservoirs is crucial to help designing production schemes, enhancing recovery and so on.

Theory and/or Method

The Initial Algorithm

We use Shannon entropy, which represents the exact value of the information in a message, to characterize the distributions of amplitudes in seismic wave fields. Shannon Entropy deals with uncertainty of the message. For a discrete random variable X with possible values $\{x_1, x_2, \ldots, x_n\}$ and their corresponding probability distribution $\{P(x_1), P(x_2), \ldots, P(x_n)\}$, Shannon defined entropy H about variable X as:

$$H(X) = \sum_{i=1}^{n} P(x_i) I(x_i) = -\sum_{i=1}^{n} P(x_i) \log_b P(x_i) \qquad (1)$$

We generally take the base b=2, with corresponding unit of entropy H being "bit".

In this research, we define the initial entropy on snapshots of a seismic wave field, that is, distributions of displacement values in space at a fixed instant of time. According to Innanen (2012), if each snapshot consists of N data points (i.e. responses from N receivers), and every datum takes a displacement value u_i from m possible values, by enumerating the number of occurrences of a certain value u_i in the snapshot as $W(u_i)$, we can define probability of its occurrence as:

$$P(u_i) = \frac{W(u_i)}{\sum_{i=1}^{m} W(u_i)} \qquad (2)$$

Then, Shannon entropy is calculated as in equation (1).

A controlled series of Shannon entropy calculations was carried out on four different 1D VSP wave fields generated from the well logs: a) with only primaries; b) with primaries and internal multiples, c) with primaries and absorption and d) with primaries, internal multiples and absorption.

A "fake Q" model (Margrave, 2013) is created for the well log data. The four VSP data sets are then calculated. Using the amplitude binning strategy and equation (2), PDFs representing the probability of picking a particular wave value (i.e., particle displacement) at random from a snapshot of the VSP wave field are derived. Then, with the above strategy, the entropy H of any desired time point in the wave field can be calculated. As we assume the wave field is "zero order", the total entropy value of the snapshot can be obtained by multiplying H by N times. Finally, the entropy variation with traveltime advancement of all wave fields is compared and analyzed.

The Conditional Algorithm

If $H(Y|X = x_i)$ is the conditional entropy of variable Y with prerequisite X taking a certain value $x_i (i = 1,2, \ldots n)$. And the PDF of X is $P(x_i)$, conditional PDF of Y is $P(y_j|x_i)$ (y_j represents every possible value of Y), then conditional entropy is defined as:

$$H(Y|X) = \sum_{x_i} P(x_i) H(Y|X = x_i) = -\sum_{x_i} P(x_i) \sum_{y_j} P(y_j|x_i) \log P(y_j|x_i) \qquad (3)$$

We calculate the new entropy of snapshots in wave field according to the work flow in figure 1.

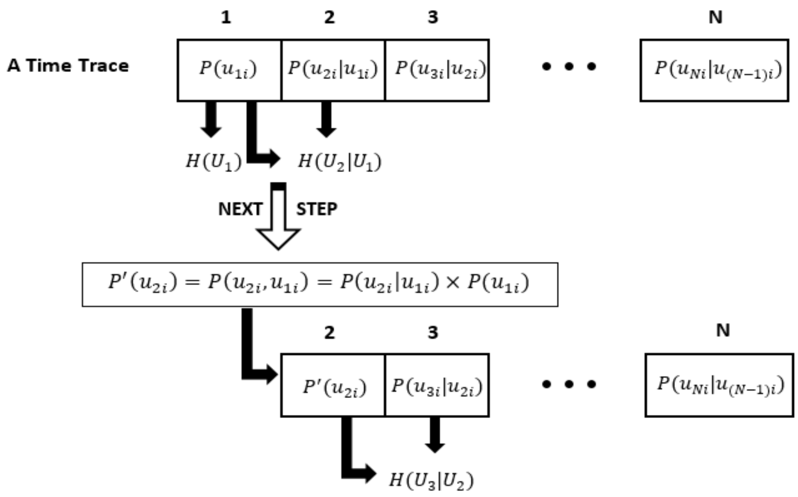

FIG. 1.

Examples

Well log data has been collected from a range of areas to be used in the analysis to minimize the possibility that the results are special to one area. Figure 2 and 3 are the initial entropy comparison and conditional entropy comparison with increasing travel time among seven well logs.

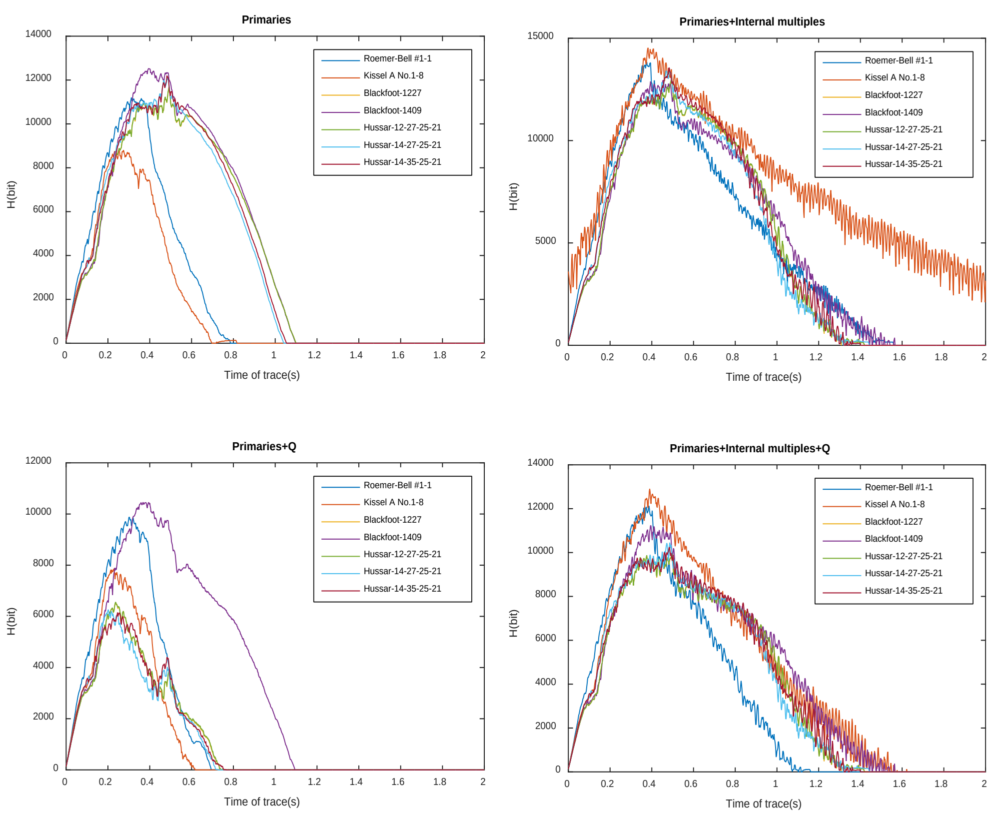

FIG. 2.

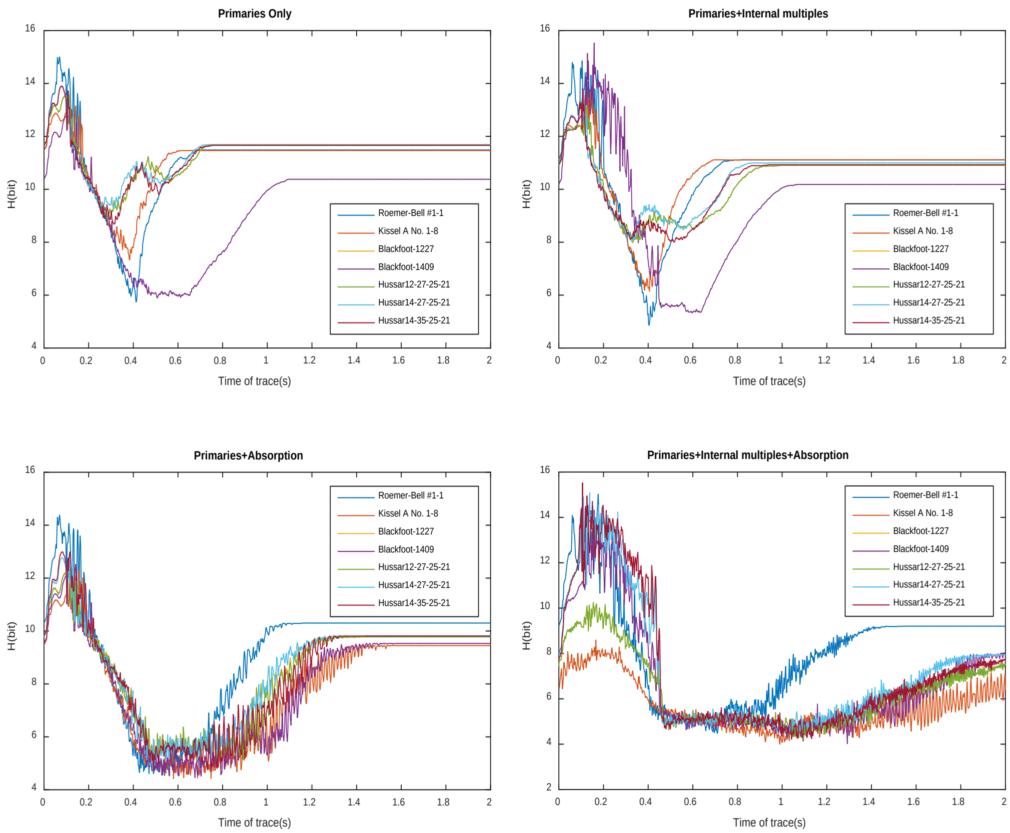

FIG. 3.

Conclusions

We realized the physical process differences of stratigraphic filtering and absorption is the key to distinguish them in practice. Absorption transforms part of the wave energy into heats in an irreversible way while reverberations scatter energy to prevent them from completely transmitting through layers but leaving the overall energy intact. Shannon entropy investigates into the wave field to monitor the functioning of the two mechanisms, serves as a magnifier that enhances these process differences, and translates them into a visible and measurable form.

Two entropy algorithms we used show very different results but analysis proves they are all reasonable. More importantly, reverberations and absorption always influence entropy variation in the opposite way in experiment, which is a promising start point to better evaluate the relative strength of stratigraphic dispersion and absorptive dispersion in a mixing effect scenario.

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