Seismic Information Entropy: a new attribute for seismic interpretation

Case Caulfield
Vermilion Energy Corporation
Josh Curtis
Earth Signal Processing Ltd

Summary

This paper proposes new seismic attributes adapted from the concept of Information Entropy. Information Entropy, as developed by Claude Shannon in 1948, is a measure of the probability distribution of an underlying quantity. The authors propose that properly implemented, it provides a new and unique method for the detection of stratigraphic, structural and processing changes in seismic data. Examples of subtle stratigraphic and structural mapping are provided, demonstrating the potential of the technique.

Introduction

Shannon developed the concept of Information Entropy in his monograph (and subsequent book), “A Mathematical Theory of Communication”. (Shannon, 1948). In many ways it ushered the digital age. Nevertheless, the use of Entropy in seismic interpretation has been limited, with most of the previous work being related to image analysis (Tsai, 2008) or seismic texture analysis (Eichkitz, 2014) as implemented in OpendTect. Maximum Entropy methods have also been used extensively in Inversion (Bassrei, 2001) and Deconvolution (Lines, 1977). Hao, et., al., (Hao, 2010) used Information Entropy indirectly to aid in Carbonate Reservoir Characterization.

Crucial to the method’s usefulness is that Entropy is a measure of the probability distribution of a zone (normally a cube in 3d data) and is not directly dependant on instantaneous amplitudes or abrupt contrasts in the data. Probability distributions and associated changes become a mappable product rather than amplitudes or other seismic attributes.

Applications include the detection of subtle stratigraphic trends, such as channels and shoreline sand bodies, as well as faults, and fractured zones. An additional application is that the method reveals residual seismic processing effects that may not be readily apparent on amplitude maps, such as edge effects or 3D merge zones.

Processing results can sometimes be highly non-intuitive, with obvious edges on traditional data providing low entropy values, while highly subtle edges sometimes produce clear, high entropy events. In addition, it is sometimes the continuity of low entropy areas that is important for the interpretation process.

Challenges with the method include the difficulty in forward modelling the expected results and the problem of distinguishing between types of geologic events that produce an Entropy anomaly – for instance, between a fault and a channel edge.

Theory and/or Method

The method will be presented here as applied to seismic volumes after stacking or migration, but extensions to the pre-stack domain can easily be imagined. For the purposes of the attribute, the formula for entropy is

$$S = -\sum_{i} p_i \ln p_i$$

where S is the entropy, p_i is probability of a given state being occupied, and the sum is carried out over all samples in a working box surrounding the target sample. This formula is similar to the form of Entropy found in the field of statistical mechanics, except that the Boltzmann constant has been left out (or rather, assigned the value of 1), since it is irrelevant for relative entropy values. In this context, the word "state" is taken to mean an amplitude value of some type in the seismic section. The types of amplitude typically considered are absolute value of seismic amplitude, instantaneous amplitude, and instantaneous phase. The latter is often the most robust and effective at edge detection, though if parametrized carefully, instantaneous amplitude can also yield valuable results.

In order to get meaningful results, the main issue that must be addressed is how to define the amplitude states. For example, along a given event, the amplitudes (of the types mentioned above) are all slightly different, so calling each amplitude a different state is meaningless and will result in the same values for entropy everywhere. Therefore, an amplitude binning must be specified that bins amplitudes that mean the same thing into the same bin, and those that indicate some geologic change into other bins. For this reason, the calculation is best performed along a horizon, because the amplitude stays relatively constant, except when there is a discontinuity of some kind. The binning chosen can be tailored to this horizon, and separate horizons in the volume likely deserve their own binning. Once the states have been defined, the other important aspect of the calculation is accurately defining the probabilities that each state has of being occupied.

Examples

As mentioned above, the version of the Entropy calculation performed on the Instantaneous Phase can be particularly effective at detecting edges. In Figure 1, a comparison of the conventional seismic with the Instantaneous Phase Entropy illustrates how an extremely subtle seismic edge, in this case a Mannville Channel in Central Alberta, can be effectively revealed with the entropy technique.

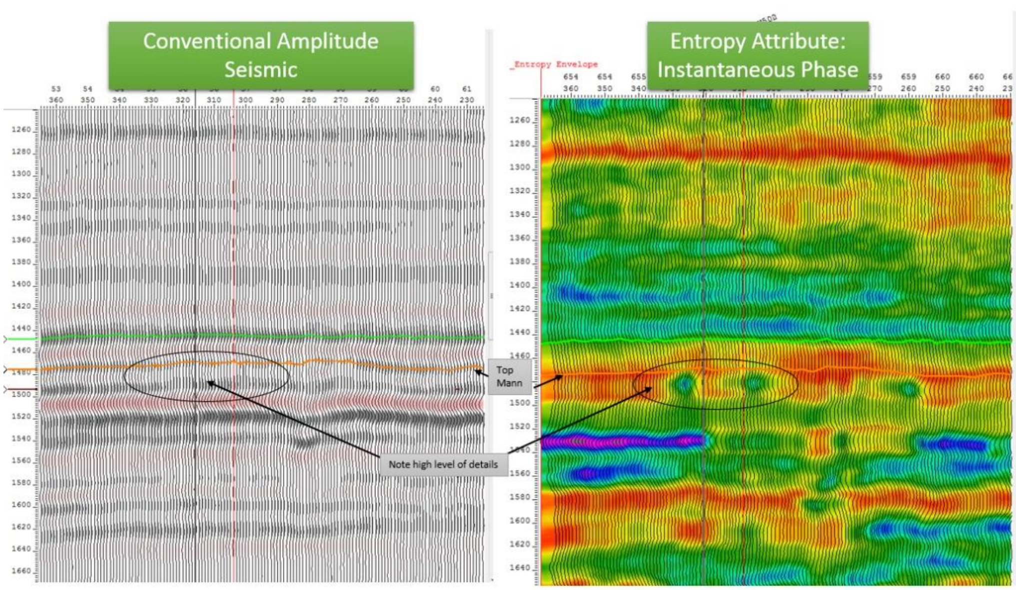

Figure 1. Detection of a Subtle Mannville Channel: Comparison between conventional data and Seismic Entropy of Instantaneous Phase

In Figure 2, in a different area than the above cross section, a time slice through the Amplitude Envelope Entropy shows the edges in a producing channel, and suggests that the pre-existing geologic mapping may need to be updated to match the new information from the Entropy map.

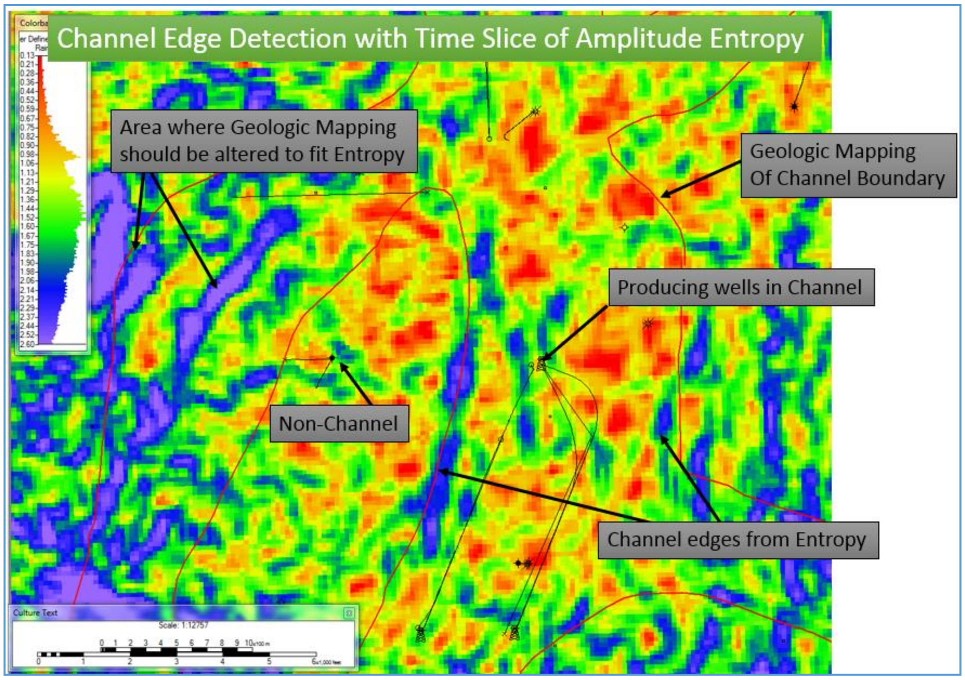

Figure 2. Time Slice at Channel Level showing detection of edges.

Figure 3 shows the comparison of a fault on the Instantaneous Phase Entropy versus a conventional amplitude cross section. Note the areas of high entropy (red) that show possible effects of the fault outside of areas that are evident on the conventional section. These high entropy areas may be related to minor faulting or fractures, although work has not yet been done to confirm this.

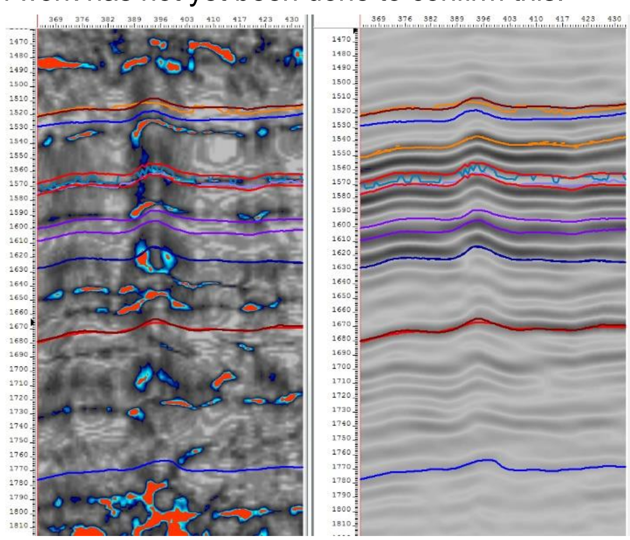

Figure 3. Comparison of effects of a faulted region on Instantaneous Phase Entropy (left) versus conventional seismic (right). Note how regions of high entropy, shown in red, are associated with the fault.

Seismic Entropy can also reveal non-geologic aspects of the data. In the image shown in Figure 4, a time slice through the Instantaneous Amplitude Entropy shows an apparent edge effect, while the conventional amplitude fails to show the edge effect. Presumably, the Seismic Entropy could be used to study Signal-to-noise levels, as well as weighting regressions to aid in predicting geologic attributes such as porosity, thickness and fracture density.

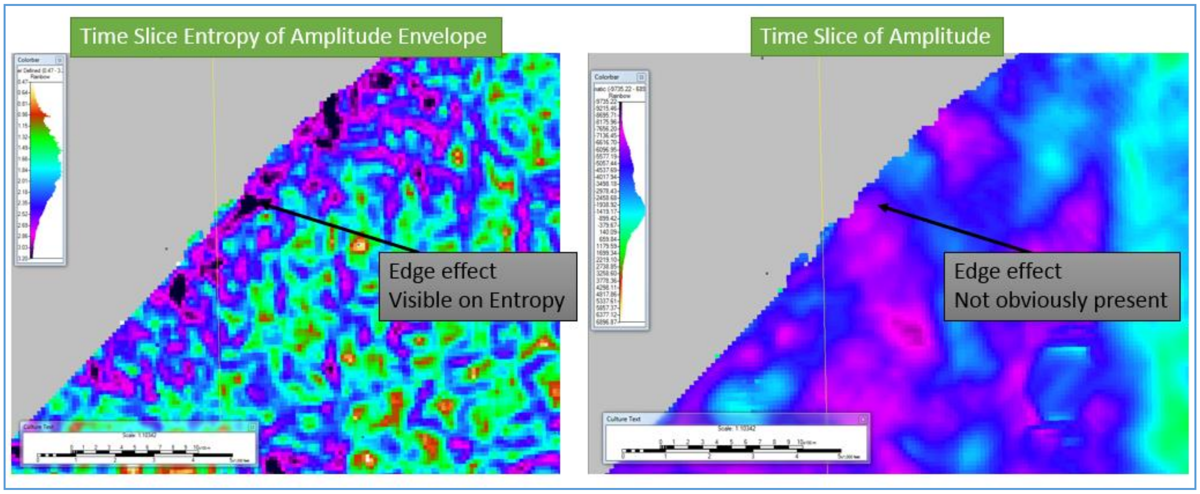

Figure 4. Comparison of edge effects on Time Slices of Entropy and conventional Amplitude.

Conclusions

Seismic Information Entropy shows promise as an innovative method for revealing important aspects of seismic data that remain suppressed in conventional data. This ability is related to the underlying definition of Information Entropy as a measure of the nature of the probability distribution. Calculation of the probability distribution and Entropy requires a careful implementation to avoid spurious results. The method has been shown to detect a variety of stratigraphic, structural and non-geologic features.

Acknowledgements

The authors would like to thank Vermilion Energy.

References

Bassrei, A., Quezada, J., 2001, Inversion of seismic data by a generalized maximum entropy method. SEG Technical Program Expanded Abstracts 2001: pp. 744-747,

Eichkitz, C. G., Groot, P., Brouwer, F., 2014, Visualizing Anisotropy in Seismic Facies using Stratigraphically Constrained, Multi-directional Texture Attribute Analysis. Search and Discovery Article #120163.

Hao, Y., Xiaodong, Z., Shufang, M., Xingfang, L., Jinsong, L., 2010, Seismic Attribute Analysis based on Information Entropy for Carbonate Reservoir Characterization.

Lines, L., Ulrych, T., 1977, The Old and the New in Seismic Deconvolution and Wavelet Estimation. Geophysical Prospecting 25, 512-540.

Tsai, D., Lee, Y., Matsuyama, E., 2008, Information Entropy Measure for Evaluation of Image Quality, Journal of Digital Imaging, 2008 Sept ; 21(3).

Shannon, C. E., 1948, A Mathematical Theory of Communication, University of Illinois Press.