Bulletin of Earth Sciences of Thailand

Academic article

Seismic Attributes and Their Applications in Seismic Geomorphology

Sanhasuk Koson, Piyaphong Chenrai* and Montri Choowong

Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
*Corresponding author email: piyaphong_c@hotmail.com

ABSTRACT

Seismic attributes are the components of the seismic data, which are obtained by measurement, computation, and other methods from the seismic data. Seismic attribute analysis can extract information from seismic data that is, otherwise, hidden in the data and have been used to identify prospects, ascertain depositional environments. Hence, many new attributes were used in seismic geomorphology study. Most of these attributes are yet to be understood by many geoscientists and interpreters. The main aim of this paper is to review and introduce the most commonly used seismic attributes and their usage as interpretation tool for seismic geomorphology.

Key words: Seismic attributes, Seismic geomorphology, Local structural dip

1. Introduction

Recent development of three-dimensional (3-D) seismic datasets enables geologists to visualize and analyze buried-lands and sea-scapes revealed by subsurface geophysical data in a manner resembling surface geomorphology. Seismic geomorphology is useful technique to interpret seismic patterns for geomorphology of a formation, which is similar to using satellite and aerial photos of the Earth's surface. Seismic geomorphology interpretation is also a primary method in viewing, mapping subsurface geologic features, and making interpretation of structure and stratigraphy possible away from well control in petroleum exploration.

Seismic attributes have been increasingly used in petroleum exploration and production and have been integrated in the seismic interpretation process. Since 1990s, the seismic attributes have been developed into many types of them such as structural attributes and stratigraphic attributes (Chopra and Marfurt, 2005). The fundamental seismic data type is amplitude data, but seismic attributes can reveal characteristics, which are not easily seen in amplitude data themselves. The seismic attribute technique should allow us to increase ability of geological interpretation of a formation, particularly in the thin bed reservoir environments. Seismic attributes typically provide information relating to the amplitude, shape, and position of seismic waveform. Seismic attribute analysis can extract information from seismic data that is otherwise hidden in the data and have been used to identify prospects, ascertain depositional environments (*e.g.*

fluvial or deep water channels, carbonate buildups), detect and enhance faults and fracture sets to unravel structural history, and even provide direct hydrocarbon indicators.

The purpose of this paper is to review and introduce some seismic attributes for seismic geomorphology. It is aimed to provide geoscientists with the minimum required theory of how each attribute is generated and to understand the seismic attribute application at basic stage.

2. Envelope attribute

Envelope attribute or reflection strength displays acoustically strong (bright) events on both negative and positive events and is the most popular trace attribute. It is calculated from the complex trace of seismic signal used to highlights main seismic features. The envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient. The envelope is useful in highlighting discontinuities, changes in lithology, faults, deposition variation, tuning effect, and sequence boundary. Bright spots from this attribute are important as they can indicate gas, especially in relatively young clastic sediments. The advantage of using this attribute instead of the original seismic trace values is that it is independent of the phase or polarity of the seismic data, both of which affect the apparent brightness of a reflection (figure 1). The bright spots probably are corresponded to channel bodies or sand layers due to an acoustic impedance contrast. Faults in the envelope attribute are usually characterized by lateral discontinuous features. However, it is difficult to observe on the seismic attribute (Koson, 2014).

3. Root Mean Square (RMS) Amplitude

RMS amplitude provides a scaled estimate of the trace envelope. It is computed in a sliding tapered window of N samples as the square root of the sum of all the trace values *x* squared where *w* and *n* are the window values as presented in Equation 1.

$$x_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} w_n x_n^2}$$

Equation 1.

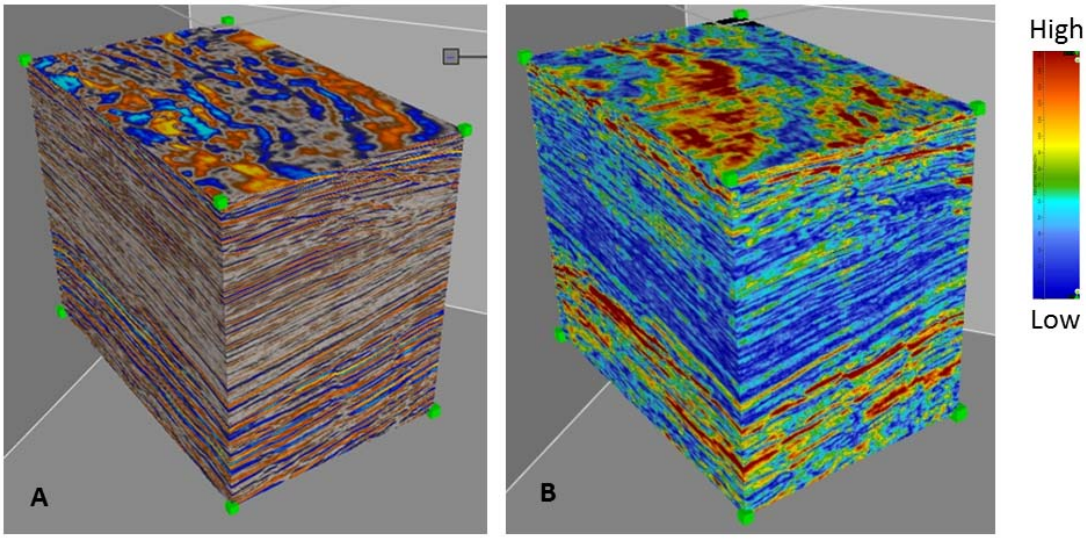

Figure 1. Examples of original volume (A) and resultant envelope attribute volume (B). The attribute values range from 0 (blue) to 152.4 (red) as shown on the color bar (http://esd.halliburton.com).

RMS amplitude resembles a smoother version of reflection strength. It is applied in the same way as reflection strength to reveal bright spots and amplitude anomalies in the seismic data (figure 2). In contrast with reflection strength, the resolution can be set by changing the window length, longer windows produce a smoother amplitude estimation, which is sometimes useful. This attribute is useful to highlight coarser-grained facies, compaction related effects (*e.g.* in marl and limestone) and unconformities.

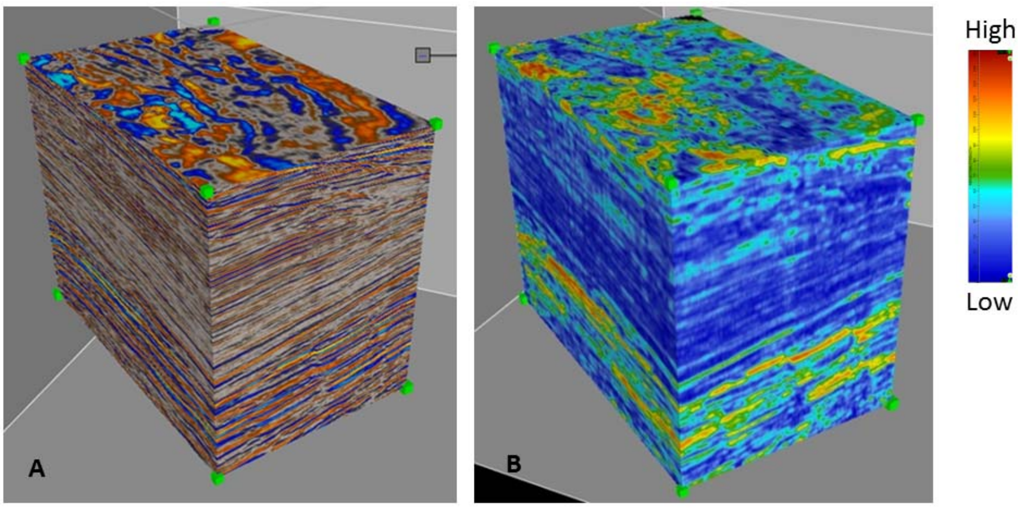

Figure 2. Examples of original volume (A) and resultant RMS amplitude attribute volume (B). The attribute values range from 0 (blue) to 127 (red) as shown in the default color bar (http://esd.halliburton.com).

4. Local Structural Dip

Structural dip or dip deviation attribute is an edge detection method which designates rapid changes in local dip, *e.g*. such as fractures and channel margins. Structural dip attribute has a good ability for detecting features from dip of reflections such as channel edges and faults (figure 3). The dip deviation attribute does indicate disruptions in reflectors but in the figure 3 only roughly indicates the position of the channels owing to the depositional variability indicated by the shallow reflectors (Pigott *et al*., 2013). Vertical seismic profiles can be used to discontinuity features, which are interpreted as faults and channel bodies. Hence, this attribute can be used to outline channel geometry and channel edge in seismic geomorphology interpretation. In addition, combination of structural dip attribute with other attributes can enhance interpretation of seismic geomorphology.

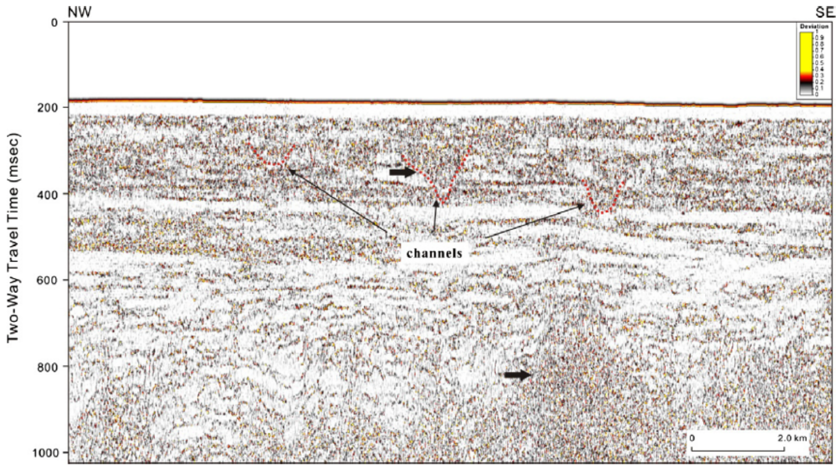

Figure 3. Structural dip attribute shows interpreted channels from seismic cross section. The black arrows highlight the reflector discontinuity (Pigott *et al*., 2013).

5. Sweetness

Sweetness (instantaneous amplitude divided by the square-root of instantaneous frequency) is defined as the trace envelope a(t) divided by the square root of the average frequency $f_a(t)$ as presented in Equation 2.

$$s(t) = \frac{a(t)}{\sqrt{f_a(t)}}$$

Equation 2.

Sweetness is an attribute designed to identify "sweet spots" places that are oil and gas prone and improves the imaging of relatively coarse-grained (sand) intervals or bodies. The definition of sweetness is motivated by the observation that, in young clastic sedimentary basins, sweet spots imaged on seismic data tend to have high amplitudes and low frequencies. Hence, high sweetness values are those that most likely indicate oil and gas (Radovich and Oliveros, 1998). Sweetness anomalies of interest are, therefore, corresponded to reflection strength anomalies. Hart (2008) suggests that sweetness is particularly useful for channel detection. The anomalies from this attribute are, sometime, located in similar location to RMS amplitude and envelope attributes due to their physical properties. The example of sweetness attribute is presented in figure 4. In addition, plan view image of sweetness attribute has been proven that it shows a great detail on geomorphic feature such as sand bodies from point bars and distributary channels (Koson, 2014). Although, sweetness attribute can improve channel features, faults/fractures are difficult to identify from horizontal map possibly due to little to no lateral lithology contrasts along fault planes.

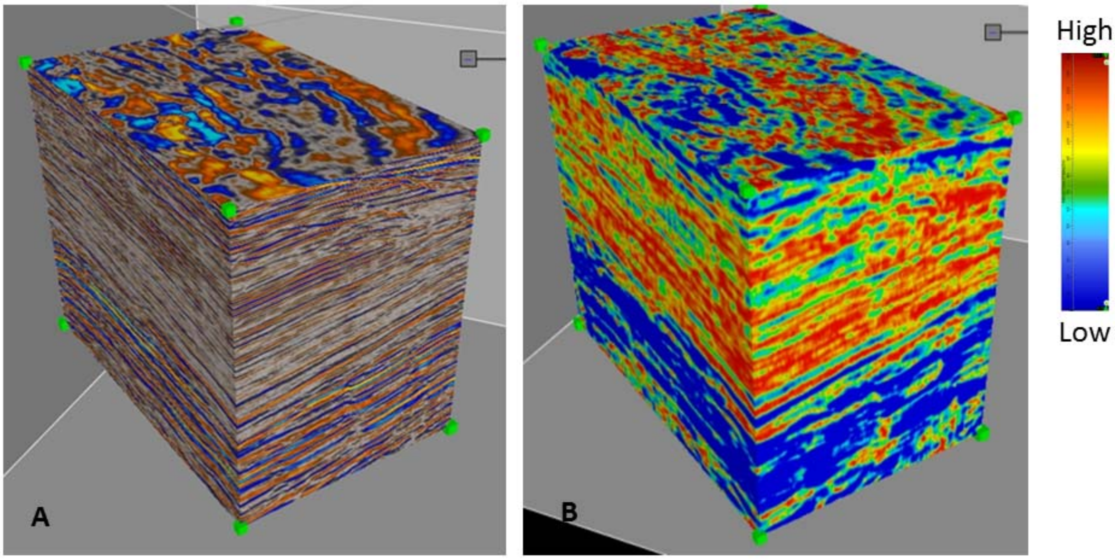

Figure 4. Examples of original volume (A) and resultant sweetness attribute volume (B). The attribute values range from 0 (red) to 19.05 as blue color (http://esd.halliburton.com).

6. Variance Attribute

Variance attribute, which is an edge method measures the similarity of waveforms or traces adjacent over given lateral and/or vertical windows. Therefore, it can image discontinuity of seismic data related faulting or stratigraphy. Variance attribute is a very effective tool for delineation faults and channel edges on both horizon slices and vertical seismic profile. Variance attribute is proved to help imaging of channels and faults (Pigott *et al*., 2013) and is also used to display directly the major fault zones, fractures, unconformities and the major sequence boundaries (figure 5).

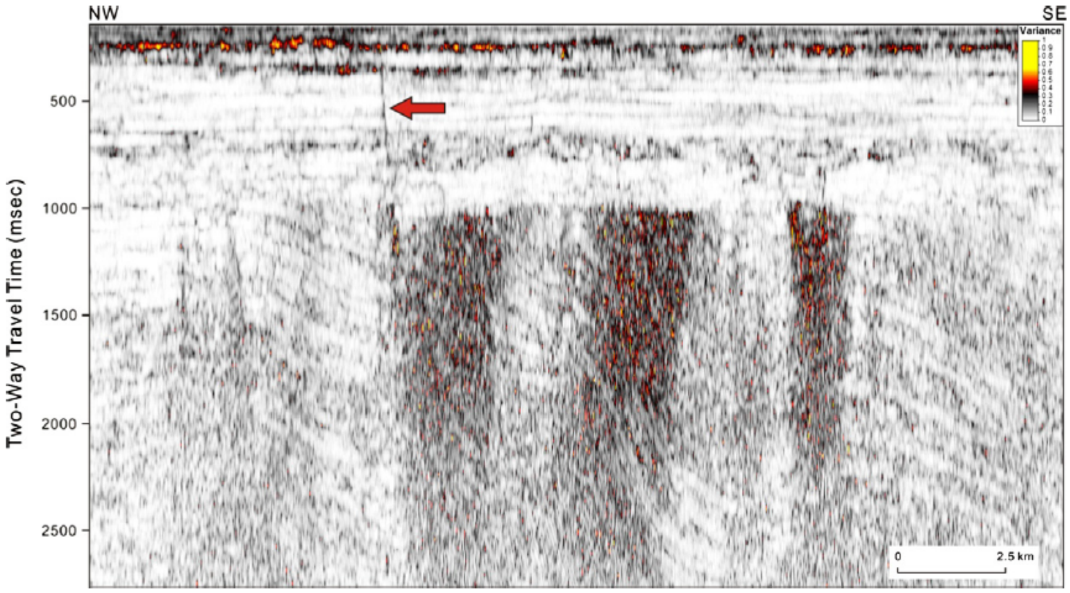

Figure 5. Example of the variance attribute showing fault highlighted by red arrow. The darkest regions, which make vertical strips, might suggest fracture zones (Pigott *et al*., 2013).

7. Chaos Attribute

Chaos attribute is defined as measure of the "lack of organization" in the dip and azimuth estimation method. In another word, chaos attribute can detect chaotic textures within seismic data, which can highlight directly positions of reflector disruption. Due to the discontinuous character of coarse-grained sediments within channel infills, this can give the chaotic signal pattern contained within seismic data. Hence, chaos attribute can be used to distinguish different sediment facies in lithology variation environments (*e.g*. sand and shale). Zones of maximum chaoticness indicate zones of reflector discontinuities such as fault zones, angular unconformities, channel sand bodies and possible zones of fractures. From figure 6, the uncolored values indicate minimum chaoticness and correspond to inferred bed continuity (Pigott *et al*., 2013). Point bars and channels can be observed on both seismic profile and horizon time slice of chaos attributes (Koson, 2014).

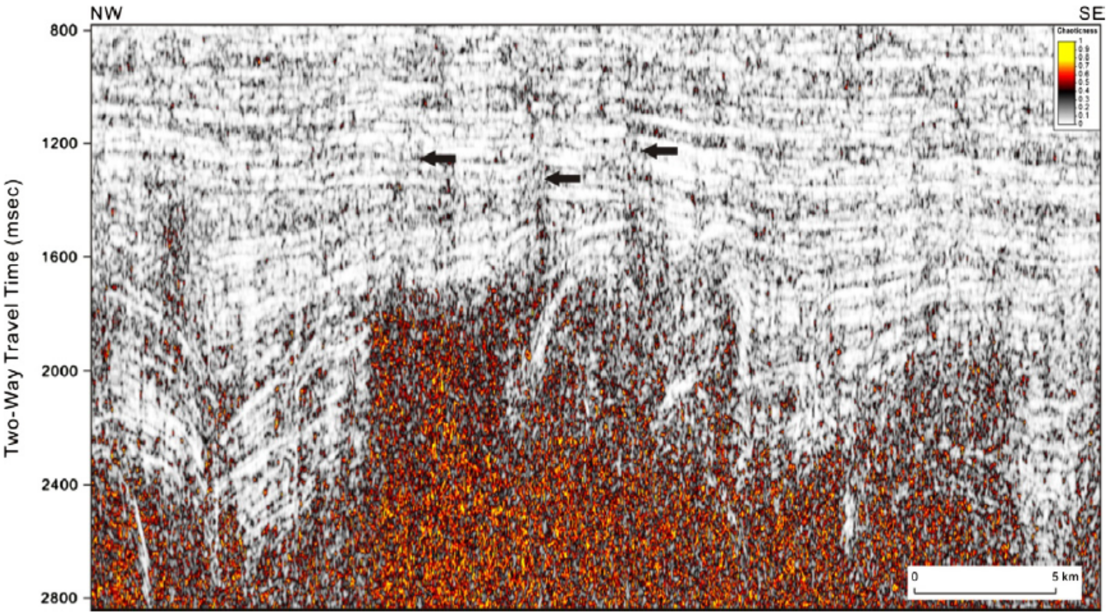

Figure 6. Chaos attribute displays the fault zone and the black arrows point to some of these faults which well-revealed (Pigott *et al*., 2013).

8. Spectral Decomposition

The concept of this attribute comes from the seismic data which response each frequency in different ways (higher frequency, shorter wavelength, detecting thin channel). Since the data were previously spectrally whitened during the seismic processing stage, the spectral components exhibit the effects of the geology with different channel thicknesses and infill exhibiting different spectral responses (Del Moro, 2012). At a specific frequency band, certain size structures are more visible due to tuning effects, *etc*. This means that for example instead of looking at one phase volume for a cube of stacked data, interpreters are able to view several of them and see if any single one shows a structure or geomorphological information better (Subrahmanyam and Rao, 2008). This attribute is very useful for solving problem of thin-bed sand layer. In general, thinner beds will be better displayed with higher frequency components and thicker beds with lower frequency (figure 7). The example of the spectral decomposition method is presented in figure 8.

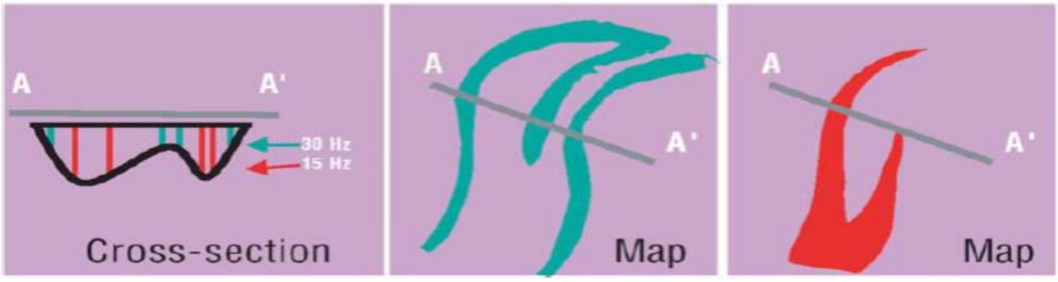

Figure 7. The effect of thin bed tuning in different frequencies (Laughlin *et al*., 2002).

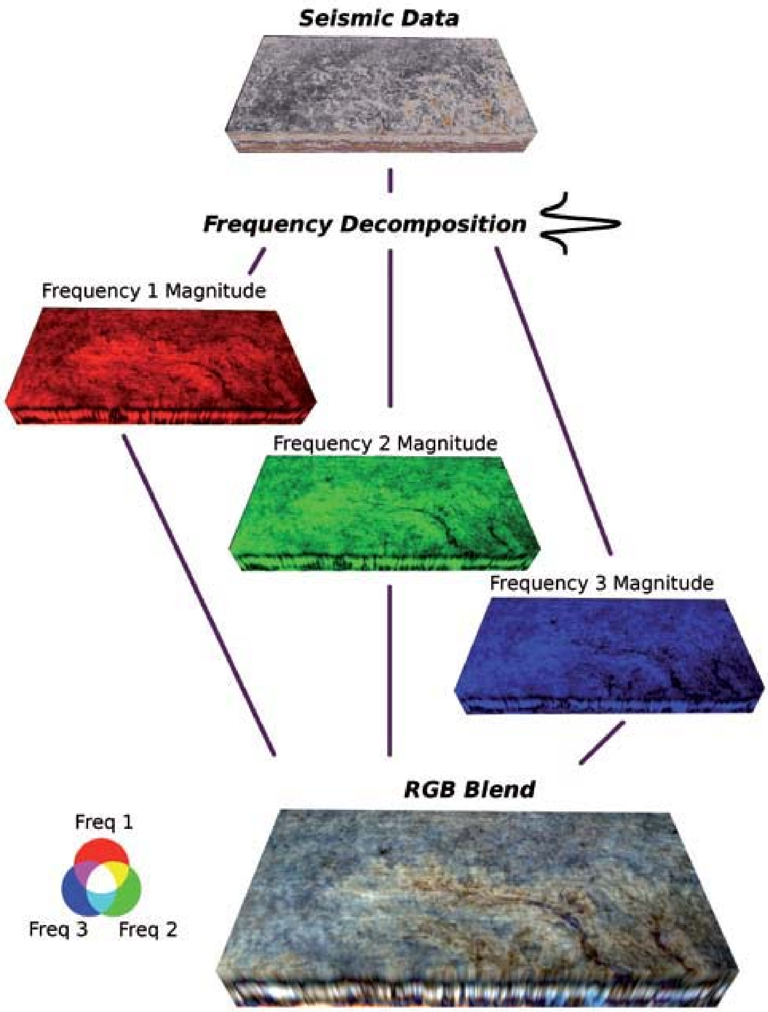

Figure 8. The example of frequency decomposition and RGB colour blending workflow, whereby three different frequency magnitude responses are assigned red, green and blue colour schemes and blended together with the result highlighting variation in frequency and amplitude as variation in colour and intensity (McArdle and Ackers, 2012).

9. Conclusion

Seismic attribute can help the interpreter to extract more information from conventional seismic data, which can support the geomorphology and also paleo-environments interpretation. The main types of fluvial system elements are major channels are well displayed with envelope, rms amplitude, sweetness, chaos attribute and spectral decomposition. Structure such as faults and fractures are displayed well with structural dip and variance attribute.

10. Acknowledgement

This research has been supported to M.C. by National Research University Project, Office of Higher Education Commission (WCU-045-CC-57).

11. References

Chopra, S. and Marfurt, K.J., 2005. Seismic attributes for prospect identification and reservoir characterization: *SEG Geophysical Development Series No. 11*, 464 p.

Del Moro, Y., 2012. *An integrated seismic, geologic and petrophysical approach to characterize the Red Fork incise valley fill system in the Anadarko Basin, Oklahoma*. M.Sc Thesis, University of Oklahoma, USA, 121 p.

Halliburton, 2014. *Seismic Attribute*, http://esd.halliburton.com, 16 February

Hart, B.S., 2008. Channel detection in 3-D seismic data using sweetness: *AAPG Bulletin*, v.92, 733-742

Koson, S., 2014. *Enhancing Geological Interpretation with Seismic Attributes in Gulf of Thailand*. B.Sc. report, Chulalongkorn Uni., Thailand, 42 p.

Laughlin, K., Garossino, P. and Partyka, G., 2002. Spectral decomp applied to 3D: *AAPG Explorer*, v.23, No. 5, 28-31

McArdle, N.J. and Ackers, M.A., 2012. Understanding seismic-thin bed responses using frequency decomposition and RGB blending. *First Break*, v.30, 57-65

Pigott, J.D., Kang, M.H., and Han, H.C., 2013. First order seismic attributes for clasticseismic facies interpretation: Examples from the East China Sea. *Journal of Asian Earth Sciences*, v.66, 34-54

Radovich, B.J., and Oliveros, R.B., 1998. 3D sequence interpretation of seismic instantaneous attributes from the Gorgon Field. *The Leading Edge*, v.17, 1286-1293

Subrahmanyam, D. and Rao, P.H., 2008. Seismic Attributes - A Review. *Hyderabad International Conference and Exposition on Petroleum Geology*, 398-403