SENRA Academic Publishers, Burnaby, British Columbia
Vol. 6, No. 2, pp. 1981-1990, June 2012
Online ISSN: 1920-3853; Print ISSN: 1715-9997

Canadian Journal of pure & applied sciences

SPECTRAL DECOMPOSITION IN ILLUMINATING THIN SAND CHANNEL RESERVOIR, ALBERTA, CANADA

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ABSTRACT

In this study, we analyzed 3-D seismic and well-log data from the Blackfoot Field, Strathmore, Alberta, Canada, using seismic inversion and spectral decomposition to resolve the channel-fill Glauconitic sand. The Glauconitic sand is of Early Cretaceous age and forms the oil-bearing reservoir in this field. The sandy channel fill basically is characterized by low acoustic impedance whereas shale plugged channels are characterized by high acoustic impedance. However, the presence of non producing shale zones with low impedance similar to that of the oil sand made the acoustic impedance not an unambiguous diagnostic of hydrocarbon bearing sand. Additionally, regional geology wells producing from shallower zone show also a similar response to that of the sandy channel, thus, the need for another indicator to remove this ambiguity became a necessity. Spectral decomposition has been selected to play this role. To achieve this objective we relied on the fact that this attribute has proven to have the potential to selectively illuminate formations at their tuning frequency which can be different for hydrocarbon and non hydrocarbon saturated rocks. Interestingly, Short Window Fourier Transform workflow could successfully image the channel's stratigraphic features and differentiate shale from sand. Furthermore, the attribute could discriminate the regional geology from oil sand-fill channel in dry wells located in relatively low impedance area where the differentiation using P-impedance was ambiguous.

Keywords: Glauconitic channel, spectral decomposition, short time widow Fourier transform.

INTRODUCTION

Unlike faults, depositional channels and other stratigraphic features usually are confined to a given stratigraphic horizon. Ideally, one would pick that horizon and slice through the appropriate attribute volume to display the channel as it might have looked at a given point in geologic time. Within this horizon the seismic polarity of the channel reflection depends not only on the impedance of the channel fill which changes within the channel system but also on the impedance of the lithologies that underlie and overlie the channel fill (Chopra and Marfurt, 2007). Taking all these characters into account and aiming to better image these geologic interesting events and overcome difficulties regarding mapping their extensions, different approaches and techniques have been developed over the years. Inverting seismic data for different impedances and spectrally decomposing data into sub frequencies are good examples in this regard.

In this study, after using seismic inversion results to define the channel location, we used Fourier spectral analysis to study the spectral-decomposition response to stratigraphic features of Glauconitic oil sand reservoir of Early Cretaceous age from Alberta, Canada.

Acoustic impedance and spectral decomposition in reservoir studies

The original use of seismic data, and still the main use today, has been to identify the geometry of reflections and ascertain their depths. This is possible because seismic waves reflect at interfaces between materials of different acoustic properties. However seismic data contain information beyond reflector location. That is every reflection changes the amplitude of the returned wave. The controlling property in this change at the interface is the contrast in impedance which is the main objective of variety of seismic inversion techniques.

Seismic inversion is simply the transformation of seismic data into pseudo acoustic impedance logs at every trace. This fact provides an acoustic impedance model contains more information than seismic data. Indeed, it contains all the information in the seismic data without the complicating factors caused by wavelets and adds essential information from the log data (Latimer *et al*., 2000).

It is noted that over the last decades inverting seismic data into acoustic impedance has become a rapidly growing field due to many advantages that acoustic impedance has over seismic. As a result, many types of seismic

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*Corresponding author email: m84.farfour@gmail.com inversions are now available and have been widely used in reservoir studies; each has its own advantages and limitations (Lancaster and Whitcombe, 2000; Hampsom and Russell, 1991; Hampson *et al*., 2005; Russell and Hampson, 2006; Francis, 1997, 2005; Cooke and Cant, 2010).

Spectral decomposition is an innovative seismic attribute more recent than seismic inversion. It is used for reservoir imaging and interpretation technology, originally developed and commercialized by BP, Apache Corp. and Landmark (Partyka *et al*., 1999). The technology utilizes a sequence of seismic frequency slices through an area of interest to create a suite of amplitude maps which can be selectively combined to yield much higher resolution images of reservoir boundaries, lithologic heterogeneities and interval thicknesses than the traditional full band seismic displays (Burns and Street, 2005). Note that over the last decade extensive studies have been performed on the effect of thickness and fluid of reservoir on the tuning frequency, and these studies have been published by Marfurt and Kirlin (2001), Laughlin *et al*. (2002), Chopra and Marfurt (2007) and Chen *et al*. (2008). Other studies have discussed how this new attribute can be used to differentiate both lateral and vertical lithologic and pore-fluid changes (Burnett *et al*., 2003; Sinha *et al*., 2003; Goloshubin *et al*., 2006; Suarez *et al*., 2008). It can also delineate stratigraphic traps and identify subtle frequency variations caused by hydrocarbons (Burnet *et al*., 2003; Castagna *et al*., 2003; Goloshubin *et al*., 2006; Miao *et al*., 2007). All these studies among others proved that spectral decomposition can be applied in different areas around the globe, and in a variety of environments.

Note that although we have used acoustic impedance as indicator, our focus is mainly on the spectral decomposition response to reservoir fluids from glauconitic channel.

In order to decompose the seismic band into its individual frequencies, we used a fixed length analysis window for all frequencies. This allows us to determine which frequency component is dominant within our area of interest and use these frequency components to map our channel stratigraphic features. The decomposition reveals that the amplitude contrast between the oil sand and shale is much higher at individual frequencies than it was in seismic full band imaging.

Geologic setting

The Blackfoot field is located in the south-east of Strathmore, Alberta, Canada (Fig. 1). The 3C-3D seismic

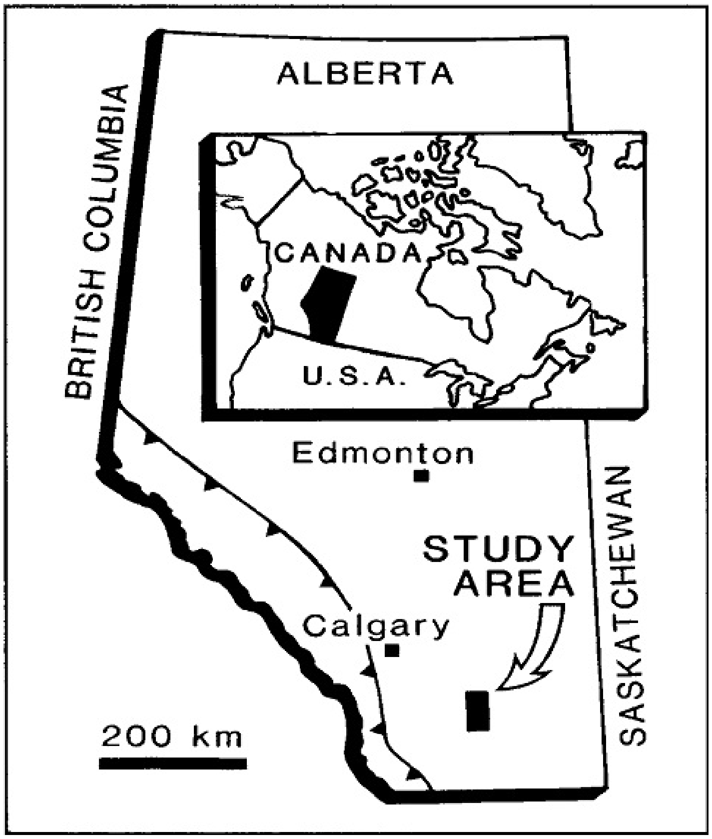

Fig. 1. Index map showing location of study area in the plain of southern Alberta, Canada (Source: Wood and Hopkins, 1992).

survey was acquired over a Lower Cretaceous incised channel filled with sand and plugged shale. The producing formation is cemented channel sand deposited as incised valley fills sediments in clastic sequences which uncomfortably overlie carbonates of Mississippian age. The Glauconitic sandstone is up to 35-m thick and is approximately 1550 m below surface in the Blackfoot area.

The average porosity is near 18% in the producing sandstone and cumulative production throughout southern Alberta exceeds 200 million barrel of oil and 400 billion ft^3 of gas (Margrave *et al*., 1998).

Data set used in the study

The Blackfoot 3C-3D seismic survey was acquired near Strathmore, Alberta, Canada in 1995. The resulting 3-C data were processed for both *P-P* and *P-S* primary reflections to produce two independent 3-D migrated volumes. Final signal bandwidths were 10-80 Hz for *P-P* and 10-40 Hz for *P-S*. The subset we use in this study is consisting of 119 lines and 81 cosslines. The bin size is 30x30 m and offsets ranged from 300 to 1700 m with 11 wells in the covered area. Note, several published work have discussed thoroughly the Blackfoot dataset’s processing, interpretation (Dufour *et al*., 1998, 2002, Margrave *et al*., 1998; Swisi and Morozov, 2009). The studies represent very rich and helpful references for further studies addressing this field.

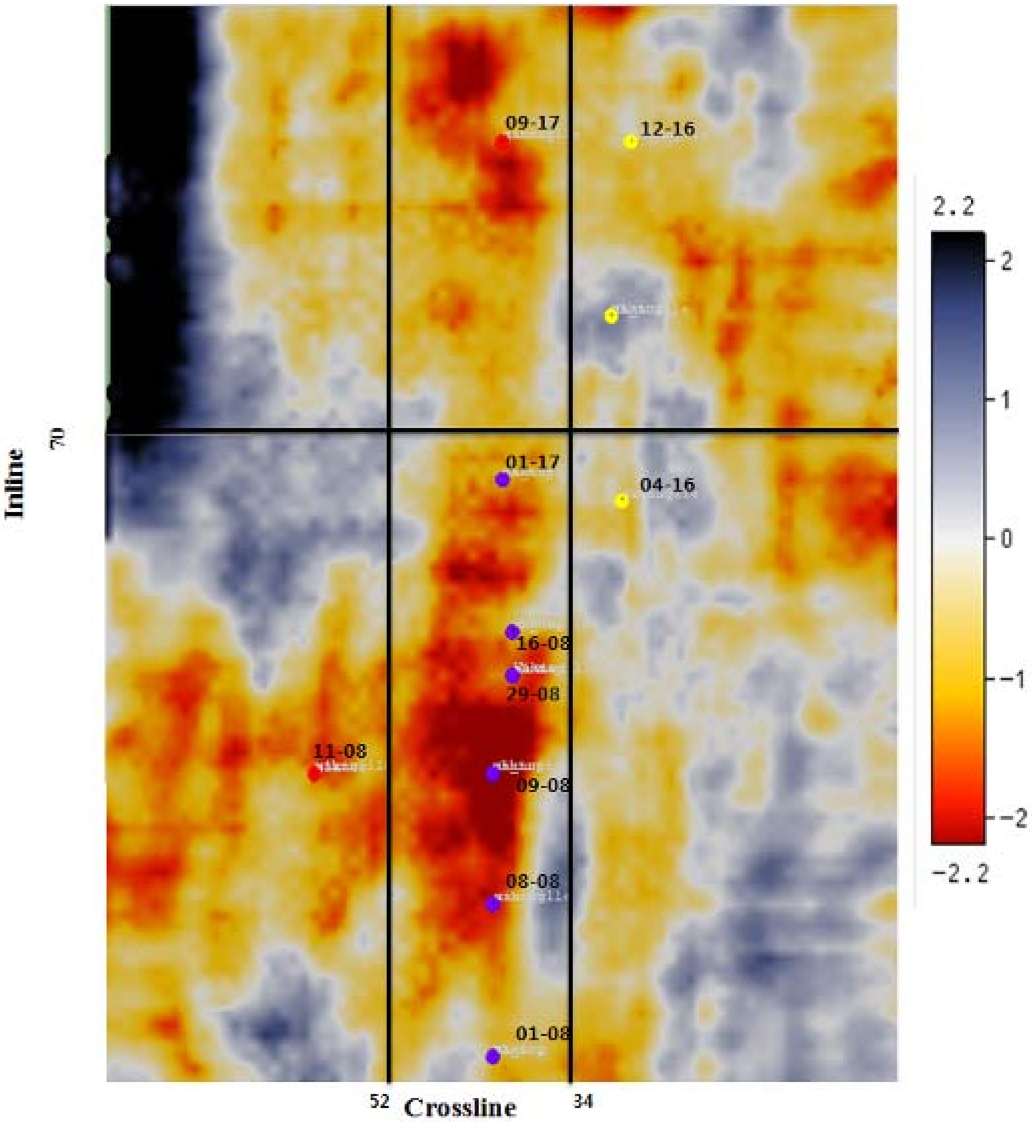

Fig. 2. Seismic broad band amplitude slice through the channel. Although some lateral changes are apparent, the channel remains invisible and difficult to map.

MATERIALS AND METHODS

Methodology

The emphasis in this study is to delineate the channel boundaries and to distinguish sand-fill from shale-fill and regional geology within the channel system. First, seismic inversion was implemented to identify the glauconitic sand channel. Seismic inversion allows us to remove the wavelet effects, thus avoiding its relevant problems such as wavelet side lobes interference and false stratigraphic like effects. In addition, the acoustic impedance data support fast inspection and accurate volume-based interpretation techniques and analyses. According to well data analysis performed at control wells from previous work published by Swisi and Morozov (2009) the channel is thin and exhibit low acoustic impedance compared to its surrounding. We, therefore, expected that decomposing the seismic broadband into its individual components may help image the channel and deliver more information.

On the other hand, minimizing uncertainty and errors that might be generated from tracking which certainly will affect all further processes pose a new challenge for us. For this purpose, we first, selected a geophysically recognizable horizon based on well ties and calibration to well data. Then, for such careful tracking we have invoked Horizoncube. Horizoncube is new commercial

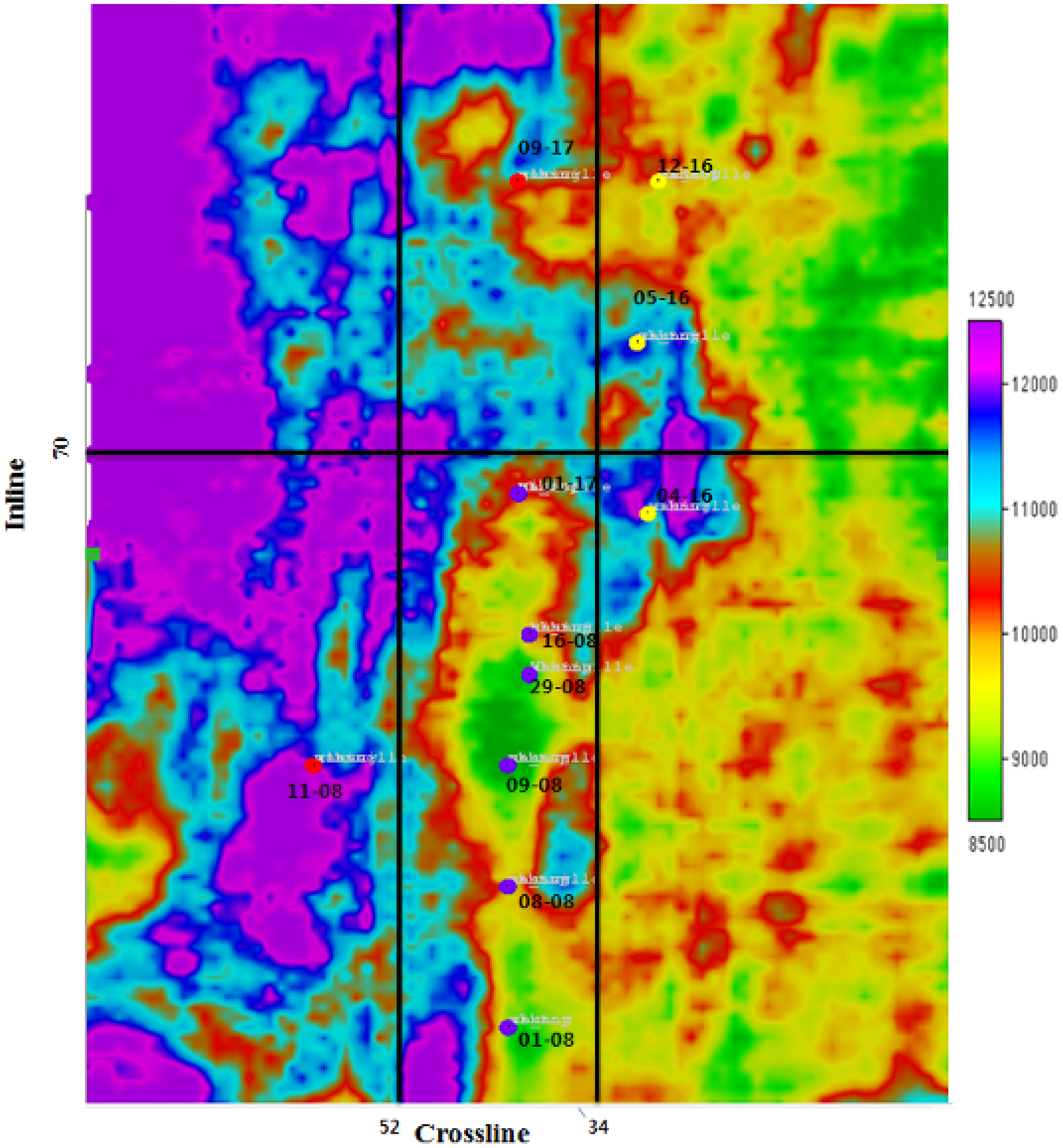

Fig. 3. Acoustic impedance slice through the channel interval shows low impedance along the oil sand channel.

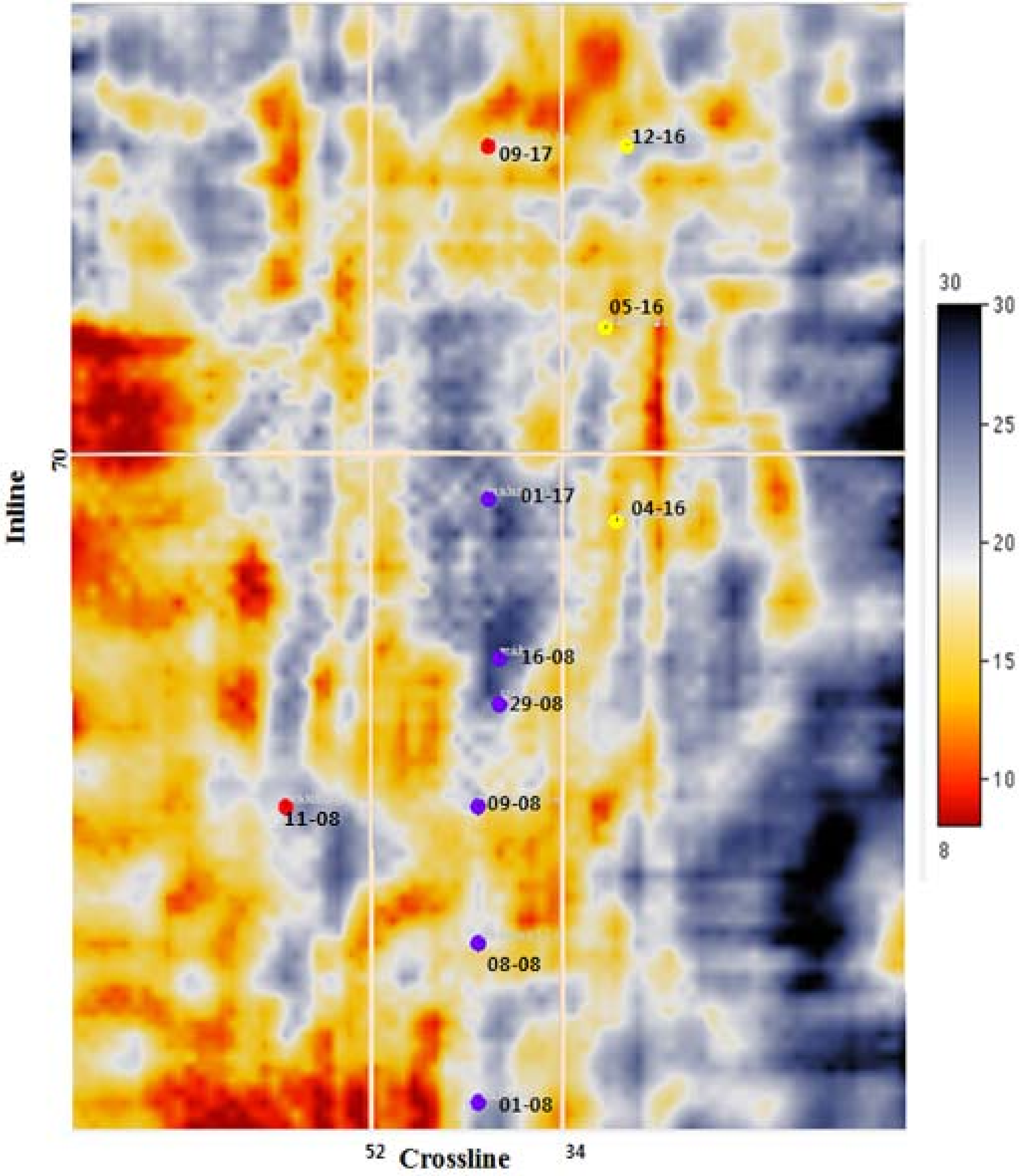

Fig. 4. Spectral amplitude at 15 Hz showing some details of the channel.

plugin in opendtect software (De Grout *et al*., 2010). The approach currently being adopted for generating the horizon cube involves two main steps. First, a dip “steering cube” is generated which calculates local dip azimuth values of coherent features within the seismic. The steering cube is subsequently used to generate the horizon cube. A special autotracker tracks the dip/azimuth field to generate horizons that are typically separated by one sample at the starting position. This densely tracked horizons mapping enables us to extract more information with very complex structures. We then calculated our attributes and performed our analysis at the time that a reservoir interval occurred. After that we studied carefully the spectral-decomposition response to the different channel fills for different frequencies. Each frequency component was expected to help understand and interpret subtle details of the stratigraphic framework of the oil reservoir.

RESULTS AND DISCUSSION

Starting by seismic broadband amplitude analysis, seismic time slice was taken across the channel. The slice shows that some lateral changes are present in the channel location; however channel’s seismic expressions are still difficult to discern (Fig. 2). Results obtained from seismic inversion indicate that the channel like structure is clearly pronounced between crosslines 34 and 52, with low acoustic impedance relative to the surrounding formations (Fig. 3). As shown in figure 3, a total of 11 wells were

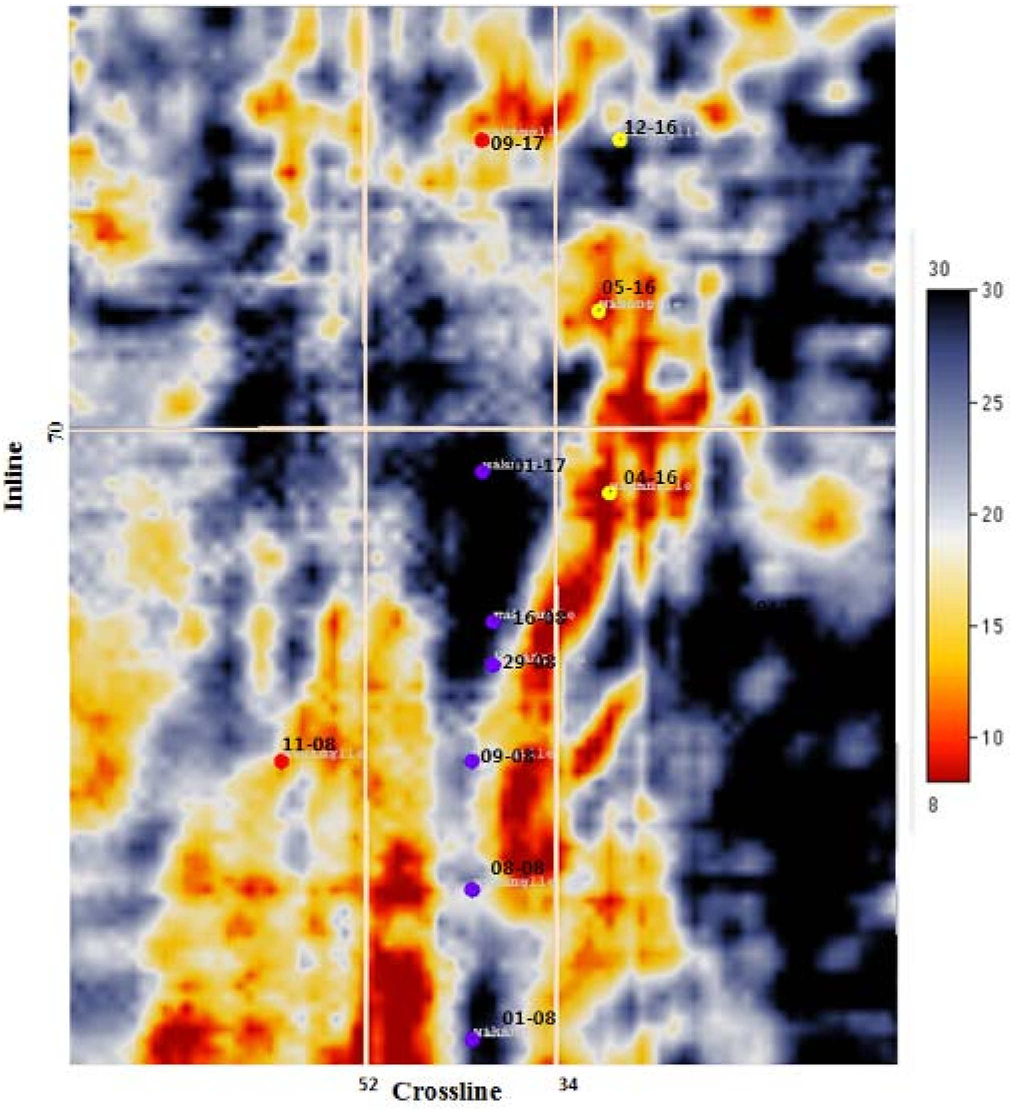

Fig. 5. Spectral amplitude at 30 Hz showing the channel's like structure. Note that oil wells (purple) are along the channel area with high amplitude, while dry wells (yellow) are beyond the channel with low amplitude.

used in the study are displayed. Wells at 01-08, 08-08, 09-08, 16-08 and 29-08 (purple) all encountered sandstone at the upper valley level, whereas 04-16, 05-16, and 12-16 (yellow) have only the upper valley shale fill; wells at 09-17and 11-08 (red) are regional wells with gas production from shallower zones (Dufour *et al*., 2002; Todorov, 2000). Note that all the producing oil wells at 01-08, 08-08, 09-08, 16-08 and 29-08 (purple), positioned within the sand-fill channel, correlate with a low-impedance anomaly; while, the dry wells 04-16, 05-16, (yellow) in the shale-plugged channel fall into high-impedance zone. Consequently, the inversion result can be used to discriminate the sand-fill from the shale-fill channel. However, one dry well (12-16) and the regional geology well 09-17 were found being located in relatively low-impedance area making the differentiation between the sand-fill channel and the regional geology ambiguous (Todorov, 2000). Nevertheless, the acoustic impedance pointed out also high impedance zones separating these wells from the producing wells. The zones are most likely to be associated to lithology change occurred between producing and non-producing wells. Thus, the need for another indicator to confirm this assumption and distinguish oil sand fill over shale fill and regional geology and remove the ambiguity is unavoidable. Spectral decomposition was the key seismic attribute to achieve this goal. Several frequencies were computed for a single horizon. The seismic horizon and its corresponding frequency components at 15 and 30 Hz are displayed in figure 4 and 5. At 15 Hz the channel is

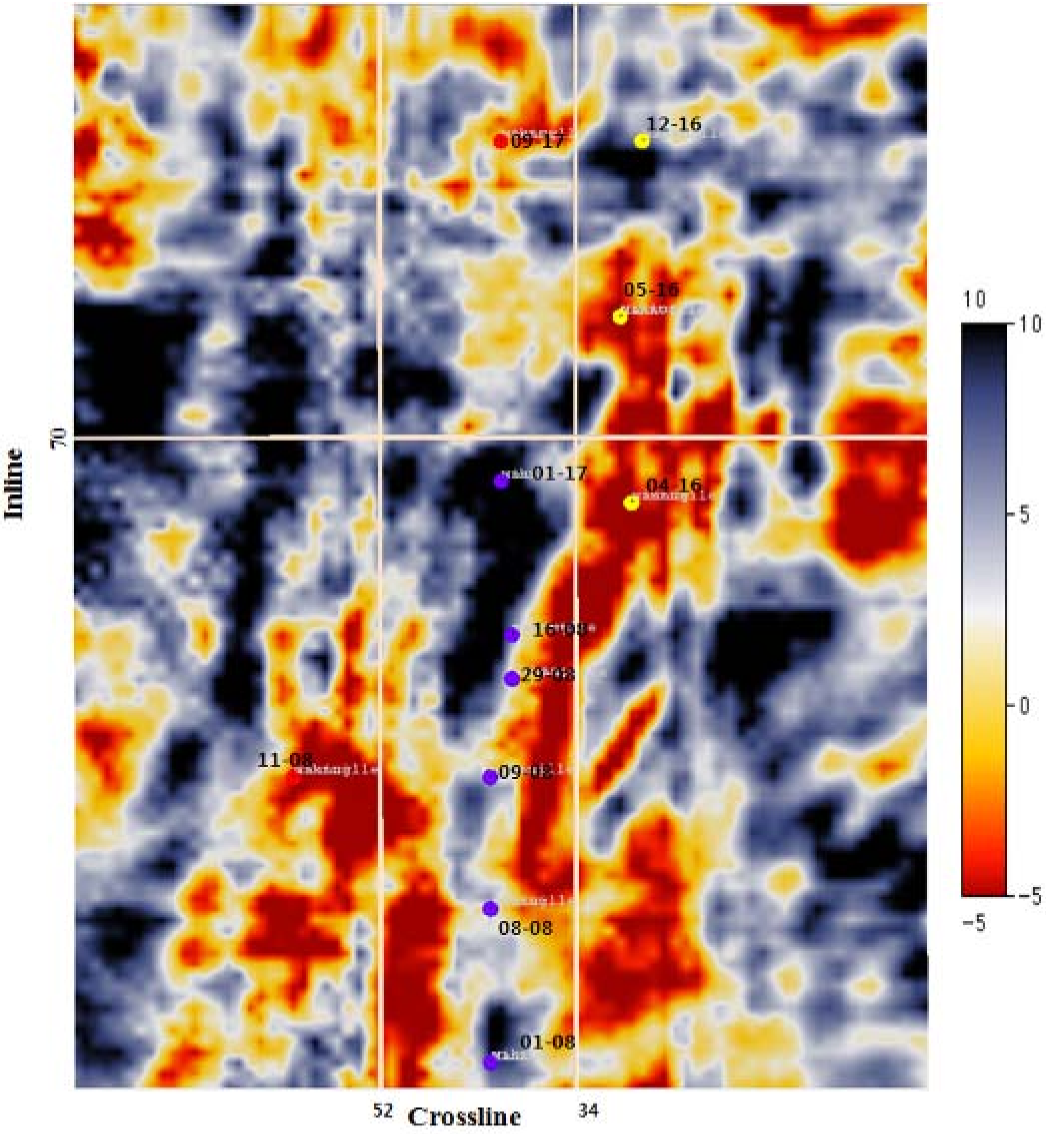

Fig. 6. The difference between 30 Hz and 15 Hz. The channel is clearly visible showing higher frequency amplitude contrast relative to the surrounding rocks along the channel.

poorly imaged but is clearly visible on 30-Hz spectral component, ensuring that 30 Hz is closer to the tuning frequency than 15 Hz is. Thus, the anomalous amplitude present along the channel between crossline coordinates 34 and 52 and ends around 70 inline in figure 5 can be attributed to the result of both thin bed tuning and hydrocarbon charge which is observed only in oil producing wells zone. In fact, the oil presence makes the reservoir reflectivity coefficients larger than those in the adjacent non hydrocarbon filled areas. The thin bed tuning effect of those large reflection coefficients preferentially reflects higher frequencies, then, making the sand channel brighter and clearer at 30 Hz than at other frequencies. In addition, the frequency maps show different distributions of frequency amplitude within the reservoir. A possible reason for this might be due to change in thickness of the reservoir.

As shown in figure 5 and 6, all the oil producing wells (in blue) found to be inside the mapped channel, while dry wells lie outside the channel with low amplitude, except one well (12-16) exhibiting high anomaly quite similar to the oil wells. The frequency map does indicate also a possible reason for this dry well anomaly which is most likely to be associated with tuning effect. A low amplitude barrier separating this well from the oil channel appear clearly in figure 5 can be interpreted as indicator of depositional variation explaining why the well does not encounter oil bearing sandstone. However, it is important to say that high spectrum amplitude alone is not diagnostic of hydrocarbon charged sand. Indeed, it is with the help of the other data (well logs, production history) that the anomalously high amplitude along the channel thought to be related to hydrocarbon presence. The difference between the two frequencies components was also calculated (Fig. 6). The frequency difference horizon slice shows that the significant frequency contrast is mainly distributed along the channel, ensuring the effect of the hydrocarbon presence on the frequency behaviour of the channel. It also outlines the channel and indicates much better the presence of the amplitude barrier between the dry wells and the oil sand. It is important to notice that all these interpretations, derived from spectral decomposition, are consistent with inversion results and well information.

We saw that oil sand frequency behaviour was noticeably different than the non producing shale; thus, the wells 09-17 and 12-16 that could not be differentiated form producing wells in the inversion images could be easily distinguished in spectral decomposition maps. Interestingly, the study correlate also with several AVO analyses and inversion studies published by Margave *et al*. (1998), Dufour *et al*. (1999, 2002) and Swissi and Morozov (2009); thus representing an additional source in the direction of characterizing the glauconitic sand in Alberta, South Canada.

Note that the inversion results are the result of incorporating sonic and density well logs from different wells with seismic to predict pseudo well logs in every single trace location. In other words, the acoustic impedance volume is dictated basically by well logs from control wells and constrained by the seismic. On the other hand, spectral decomposition images are fully extracted from decomposing the broad band of the seismic into its individual frequency components without any assistance from well logs. However, the latter could successfully confirm information that the seismic inversion has revealed. Indeed, this study demonstrates that spectral decomposition can work well in somewhat seismically difficult environment where targets are not easy to resolve and exhibiting acoustic impedance that is not enough to discriminate sand from non producing shale.

Throughout this work it might have been noticed that the technique has several advantages over the seismic inversion process in that it is simple to use and to interpret. Furthermore, the fact that it has no relationship with seismic wavelet extraction and well ties and correlations, that seismic inversion depends heavily on, makes this attribute free of several sources of risk and errors. This makes its released information considered as an independent source of data that confirm and increase accuracy and confidence in other sources or even supply new information about the targets. However, it is worth emphasizing that without the assistance of prior reconnaissance and information (geology, reservoir engineering, inversion, etc), that provide some prior knowledge about the target the technique might have a limited success in addressing some seismic targets. This is due to the fact that strata of different lithology and thickness display different spectrum features in the frequency domain, in addition to various factors that may affect the frequency spectrum recorded. Thus, this can generate some difficulties in tuning the optimum frequencies that have the potential to image the desired target through only the repeated experiments and experience rule. However, there are other techniques, more complex, developed mainly to overcome these limitations and to deal with more complex situations and to target reservoirs when there is few or no prior information available (Maoshan *et al*., 2010; Zhang *et al*., 2009).

CONCLUSION

Spectral decomposition did reveal successfully stratigraphic information that could not be derived from broadband seismic. In addition to its routine use in delineating reservoirs extension and highlighting hydrocarbon attenuation effect, spectral decomposition could discriminate sand filled channel from shale filled channel and regional geology where differentiation based on P impedance was ambiguous.

Note that although spectral decomposition is a frequency dependent attribute that doesn’t have any relationship with well logs information, it could confirm results that were obtained from seismic inversion where acoustic impedance is amplitude related attribute that relies significantly on well correlations and wavelets.

This study presents an example among many other successful applications of spectral decomposition for delineating channels older and less porous than rocks in tertiary basins such as the Gulf of Mexico and West Africa over which spectral decomposition was first successfully applied.

ACKNOWLEDGMENT

We would like to thank dGB Earth Sciences Company and the people from opendtect.org for providing the software (Opendtect), and Hampson-Russell for providing the software (Strata). Our thanks also go to Korean Gas Corporation (KOGAS) for their support.

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Received: March 13, 2012; Revised: April 25, 2012;
Accepted: April 26, 2012