# DIFFERENCIATING OIL, GAS AND WATER IN SEISMIC SECTION USING SPECTRAL DECOMPOSITION*)

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**ABSTRAK**

Minyak, air dan gas yang ada di dalam pori-pori batuan seharusnya memberikan tanggapan yang berbeda terhadap gelombang seismik dan ini direkam di dalam trace seismik. Menurut ilmu fisika minyak cukup dapat dikompresi, gas sangat mudah di kompresi sedang air tidak dapat dikompresi, oleh sebab itu secara prinsip mereka harus memberikan respons yang bebeda di dalam rekaman seismik. Karena respons dalam domain waktu kadang-kadang amat rumit, maka suatu usaha telah dilakukan untuk mengurai masalah ini dalam domain frekuensi. Sebuah konsep yang cukup mutakhir yang disebut dekomposisi spectral dicoba diterapkan untuk membedakan minyak, gas dan air di dalam penampang seismik. Formulasi yang dipakai untuk ini adalah CWT (*Continuous Wavelet Transform*) dan diterapkan pada data seismik di bagian laut dalam dari Selat Makasar dan hasilnya cukup menjanjikan. Dalam hal ini minyak air dan gas dapat terlihat secara terpisah di dalam spetrum CWT.

**Kata Kunci:** minyak, air, gas, *spectral decomposition,* cwt, laut dalam

***ABSTRACT***

*Oil, gas and water contained in the pore spaces should give different response in the seismic trace, but this is not an easy problem. However, from the physical point of view oil is quite compressible, gas is very compressible and water is incompressible, so in principle they should give different response in seismic record. Since the response in the time domain is sometimes complicated in nature, an effort has been carried out to remedy the problem in the frequency domain. A recent advance in signal analysis which is referred to as the spectral decomposition has been used to differentiate oil, gas and water in seismic section. In this case a specific method in spectral decomposition called as the Continuous Wavelet Transform (CWT) was utilized for this purpose. The result demonstrates that oil, gas and water can be differentiated clearly in the CWT spectrum using the data from the deep water part in the Makassar Strait. The results are encouraging.*

***Keywords:*** *oil, water, gas, spectral decomposition, CWT, deep sea*

## I. INTRODUCTION

Deep sea prospect has gained more and more attention over the last decades as a place where significant oil and gas reserves accumulated. The discovery of several oil and gas fields in the deepwater part of the Kutei basin has proven its potential. Reports around the world also mentioned that the deepwater prospects have also been exploited by several multinational companies.

The success of finding oil in the deep sea area is mainly depends on the quality of seismic section**.** This is because the reservoir is commonly found hundreds meter below the sea bottom, with water depth more that 1000m. However, the interpretation of the seismic section is limited by the following factors:

1. Destructive interference as well as high-amplitude reflectors generated by water bottom multiples.

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2. Amplitude attenuation due to small shallow gas deposit above the deep target.
3. The low frequency content of the seismic data which causes the detail stratigraphy such as channel-fed lobes, stacked canalized lobe, thin-bedded turbidites, etc. cannot be investigated using ordinary seismic section.

Although the limitations mentioned above are not simple to solve, geoscientists are forced to exploit the seismic data in order to image the prospect. This means that anything related to the deepwater reservoirs such as its thickness, its lateral extension, its porosity, etc. are deduced from seismic data. Among many interesting seismic signatures which represent gas deposit, the bright spot is the most popular one. Bright spot has been used as a diagnostic basic for gas indicator since 1970-ies. Over the last few decades bright spot has also been analyzed intensively using sophisticated method in AVO analysis.

This paper deals with more detail investigation on bright spot. A specific approach which is referred to as the spectral decomposition is used with an example from deepwater seismic data from Indonesia. Spectral decomposition enables the resolution of seismic data to be improved significantly yielding a new possibility to map thin layers such as channel sand, point bar and any other stratigraphic features. The spectral decomposition of seismic traces into frequency domain is an established and popular technique for stratigraphic analysis from seismic reflection data (Kishore *et al*, 2006).

## II. SPECTRAL DECOMPOSITION

### Frequency and layer thickness

By definition spectral decomposition refers to any method which produces a continuous time-frequency analysis from a single seismic trace. Nowadays, it becomes one of the central attentions for solving thin layered problems encountered in oil and gas exploration (Suprajitno and Humbang, 2009). Spectral decomposition reveals geological hidden features in the amplitude maps from a deep water reservoir in the Campos basin (Johann, P., and Spinola, M, (2003). Hall and Trouillot (2004) used spectral decomposition for predicting stratigraphy.

The spectral decomposition originates from optics. Newton (142-1727) has found that white light can be decomposed into seven different colors each having its own frequency (see Figure 1.a). By making analogy that the white light is similar to a broad band seismic wavelet, a seismically detectable geological object can also be decomposed into several different frequencies (tuning frequencies) which represent subsurface strata each having certain thickness (Figure 1.b).

The above statement can be clearly understood using a schematic diagram as illustrated in Figure 2 which demonstrates the relationship between layer's thickness and tuning frequency (Laughlin, 2003).

The feature demonstrated in Figure 2 is nothing special. It was already known that low frequency signal (15 Hz) detects thick layer (represented by red color), while high frequency signal (30 Hz) detects thin layer (represented by green color). But although it is obvious, it forms the basic concept in spectral decomposition of seismic data. It can be expanded to handle multi layers strata with different thicknesses or different absorption properties based on tuning frequencies. Besides, the tuning thickness normally found in thin layer reservoir can be better resolved using the spectral decomposition. With this method the 3D seismic data volume which is normally sampled in time (msec) can be resampled in frequency interval (Hz).which has much more better resolution. In addition, the tuning frequency extracted from spectral decomposition is inversely proportional to the reservoir thickness. Partyka *et al,* (1999) have shown that the thin bed reflection tuning signal which cannot be separated in the time domain can be resolved clearly in the frequency domain (Figure 3). It can be seen that there are two notches in the Amplitude spectrum of thin bed reflection. The distance between these notches is inversely proportional to the thickness of the thin bed.

In the left hand side of Figure 3 we can see that the amplitude spectrum of the source wavelet is flat, while on the right hand side the amplitude spectrum of thin bed reflection contains two notches due to tuning effect. The distance between two notches measured (in Hz) is related to the thin bed thickness.

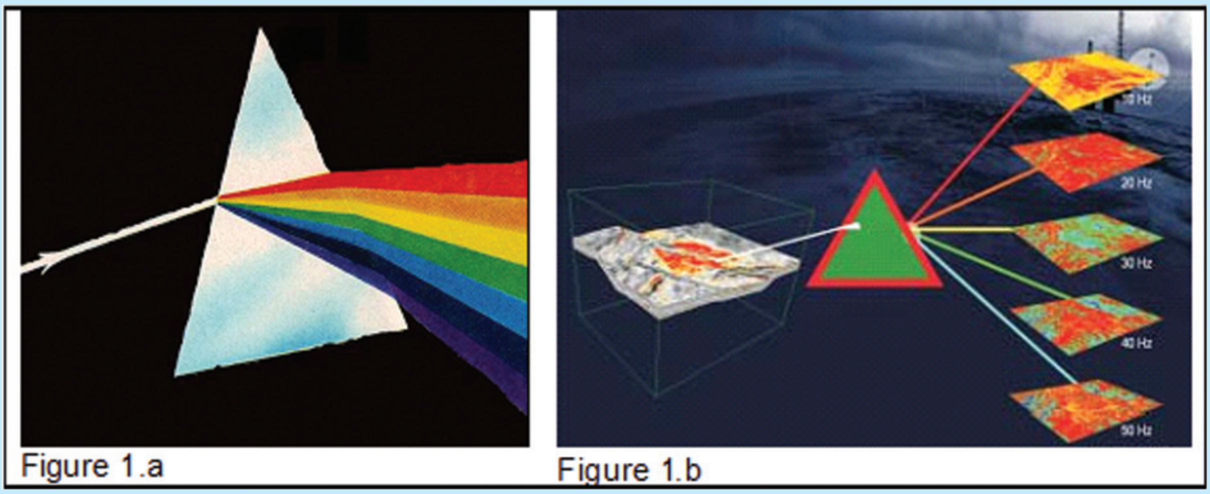


**Figure 1a**
**Spectral decomposition of white light**
**Figure 1.b**
**Spectral decomposition of a seismically detectable object (Kishore *et al,* 2006).**

## Spectral Decomposition Methods

There are several decomposition methods which are commonly used in seismic analysis, they can be grouped into three categories (Rojas, 2008), i.e., Short Time Fourier Tansform (STFT), Continuous Wavelet Transform (CWT), Stockwell Transform (1996), Matching Pursuit Decomposition (MPD) and Empirical Mode Decomposition (EMD), each having its own advantages and inconvenient (Castagna and Sun, 2006).

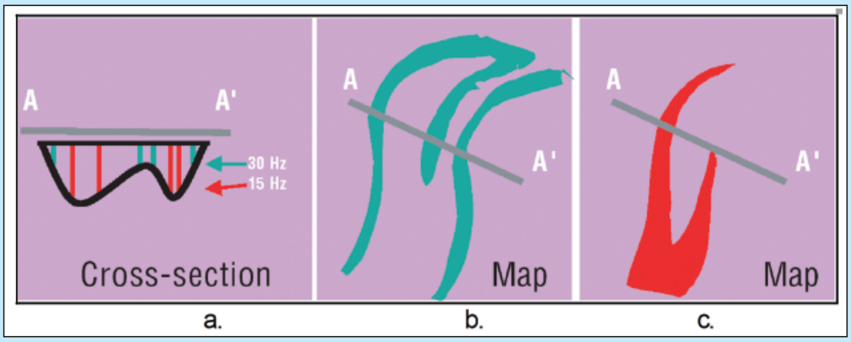


**Figure 2**
**Layer's thickness and tuning frequency,**
**a. : a geologic model cross section**
**b.: low frequency (15Hz) signal detect thick layer.**
**c. : high frequency signal detects thin layer detected by high frequency (30Hz). (Laughlin, *et al*, 2003)**

In the STFT, a time frequency spectrum is produced by taking the Fourier transform over a chosen window. When a seismic signal is transformed into the frequency domain using the Fourier transform, it gives the overall frequency behavior. In this method, the seismogram is segmented by multiplication with a window function. The Fourier transform of this windowed seismogram is then computed and the process is repeated by shifting the window in time.

In the CWT, the wavelet is scaled in such a way that the time support changes for different frequencies. By scaling and transforming this wavelet, we produce a family of wavelets which are function of scale parameter and translation parameter. Once a wavelet family is chosen, then a Continuous Wavelet Transform at scale and translation time can be defined.

The main method that is used in this paper is the CWT, so the MPD, Stockwell transform and EMD

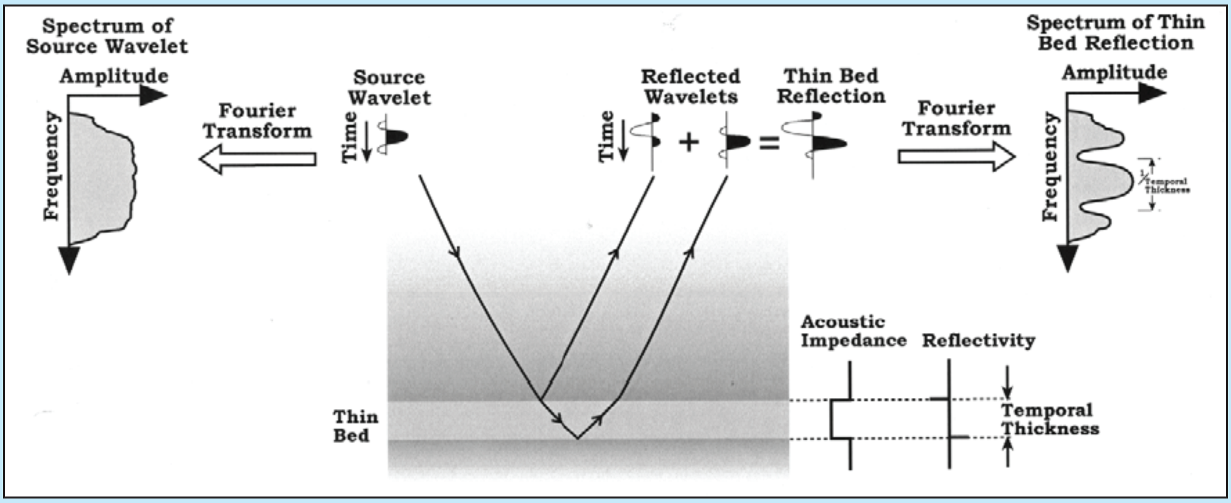


**Figure 3**
**Amplitude spectrum of a thin bed in which tuning thickness happens (Partyka *et al.*, 1999).**

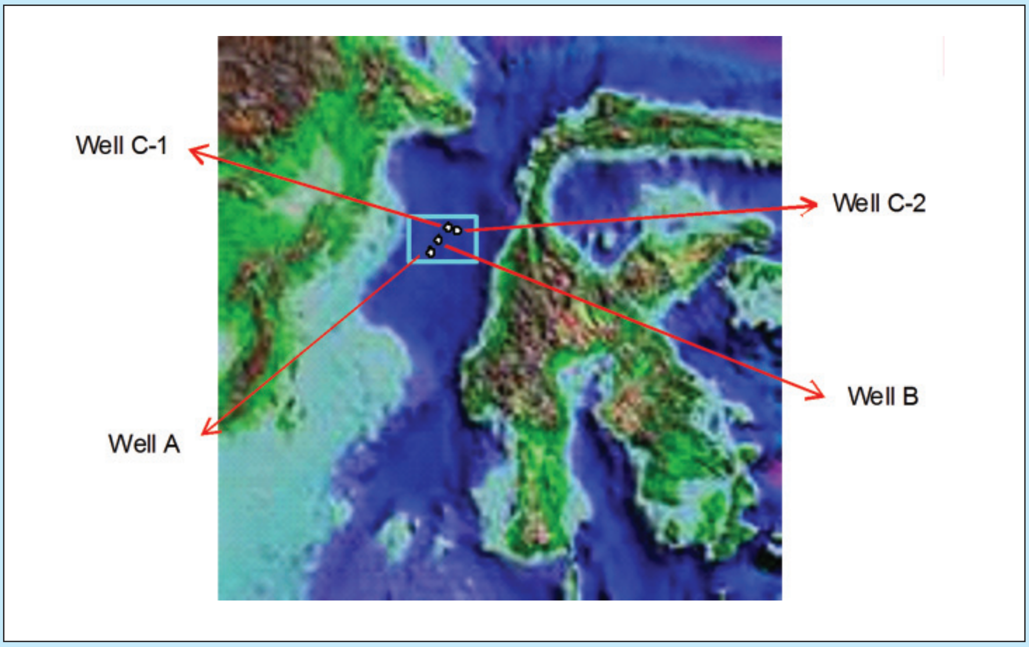


**Figure 4**
**The location of well A,B,C1 and C2 in the deep water part of Makassar Strait**

will not be discussed here. Following Castagna *et al*. (2003), in this paper, CWT was used to produce the CWT spectrum of the input signal. The multi spectral seismic images of reservoirs using spectral decomposition resembles to the multi spectral images obtained by remote sensing or satellite imagery techniques. The CWT approach involves the following steps (Sinha *et al.*, 2005; Chopra and Marfurt, 2006):

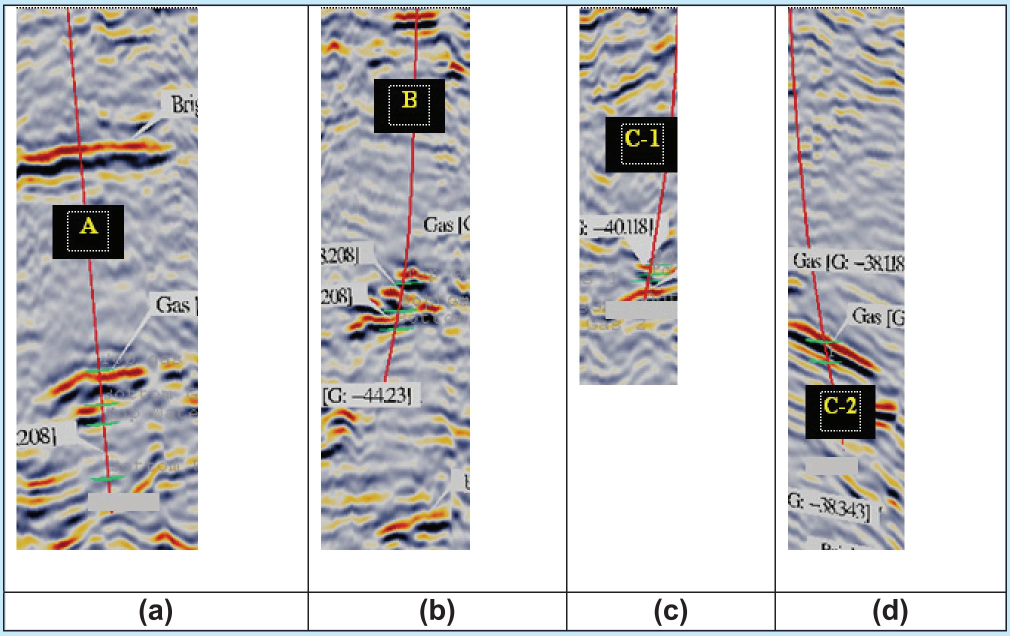


**Figure 5**
**(a) a segment of seismic section crossing well-A.**
**(b) a segment of seismic section crossing well-B,**
**(c) a segment of seismic section crossing well-C,**
**(d) a segment of seismic section crossing well-D**

1. Decompose the seismogram into wavelet components: S(ω,τ) as a function of the scale (σ) and translation shift (τ), ω is the frequency.
2. Multiply the complex spectrum of each wavelet used in the basis function by its CWT coefficient and sum the result to generate 'instantaneous frequency gathers'.
3. Sort the frequency gathers to produce eitherconstant frequency cubes, time slices, horizon slices or vertical sections.

Basically, the wavelet transform of a function f (t) for a specific frequency ω expressed by equation (2) can be obtained by translation and dilatation of a mother wavelet given by equation (1) and finding the wavelet coefficient in each step. Equation (2) looks like convolution integral of the input signal with the complex conjugate of mother wavelet for a given scale.

## III. APPLICATION

The CWT discussed above has been applied to the 3D seismic lines in the South Makassar straight. For the sake of the secrecy we will only chose a

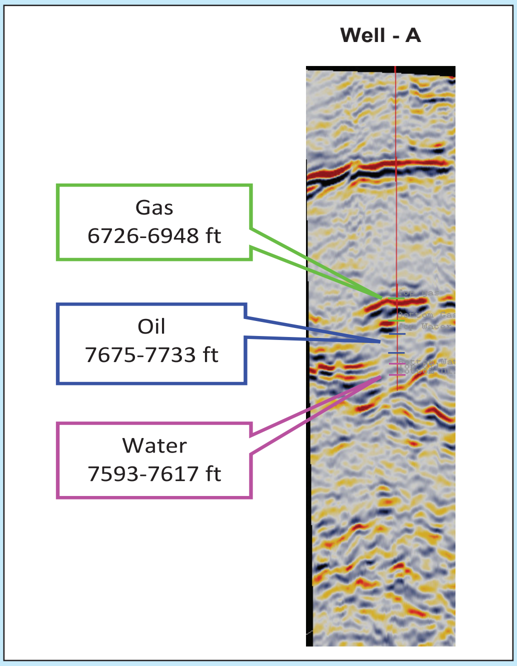


**Figure 6**
**This is an enlargement of Figure 5a : A segment of seismic section crossing well-A which penetrates gas zone, oil zone and water zone**

$$\psi_{\sigma,s}(\tau) = \frac{1}{\sqrt{\sigma}}\psi\left(\frac{t-\tau}{\sigma}\right) \qquad (1)$$

$$F_w(\sigma,\tau) = \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{\sigma}}\psi^*\left(\frac{t-\tau}{\sigma}\right)dt \qquad (2)$$

very limited seismic section crossing certain wells (see Figure 4).

## IV. RESULTS AND DISCUSSION

Figure 5 are the seismic sections across five bore holes which are used to test the method described in the paper. There are bright spots which were found in each well. We will draw conclusion (seismically) what signifies bright spots which contain oil, gas or water ? These bright spots can be seen clearly in seismic section as indicated by red color. They are found in different depth. The CWT spectrum was

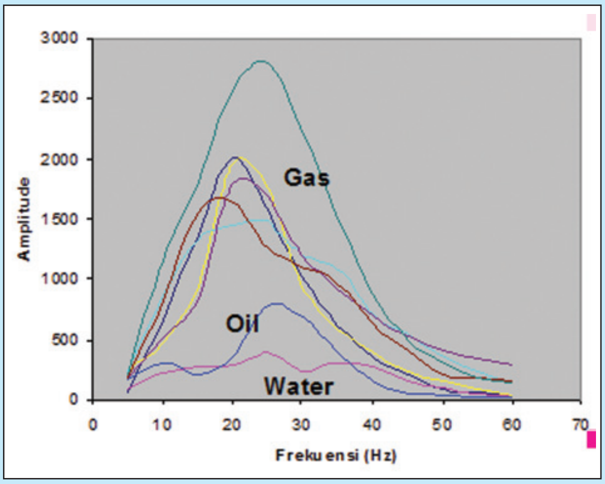


**Figure 7**
**The CWT spectrum applied to seismic data which crosses well A, B, C1 and C2. The CWT spectrum from six gas zones penetrated by four wells are relatively high compared to oil and water**

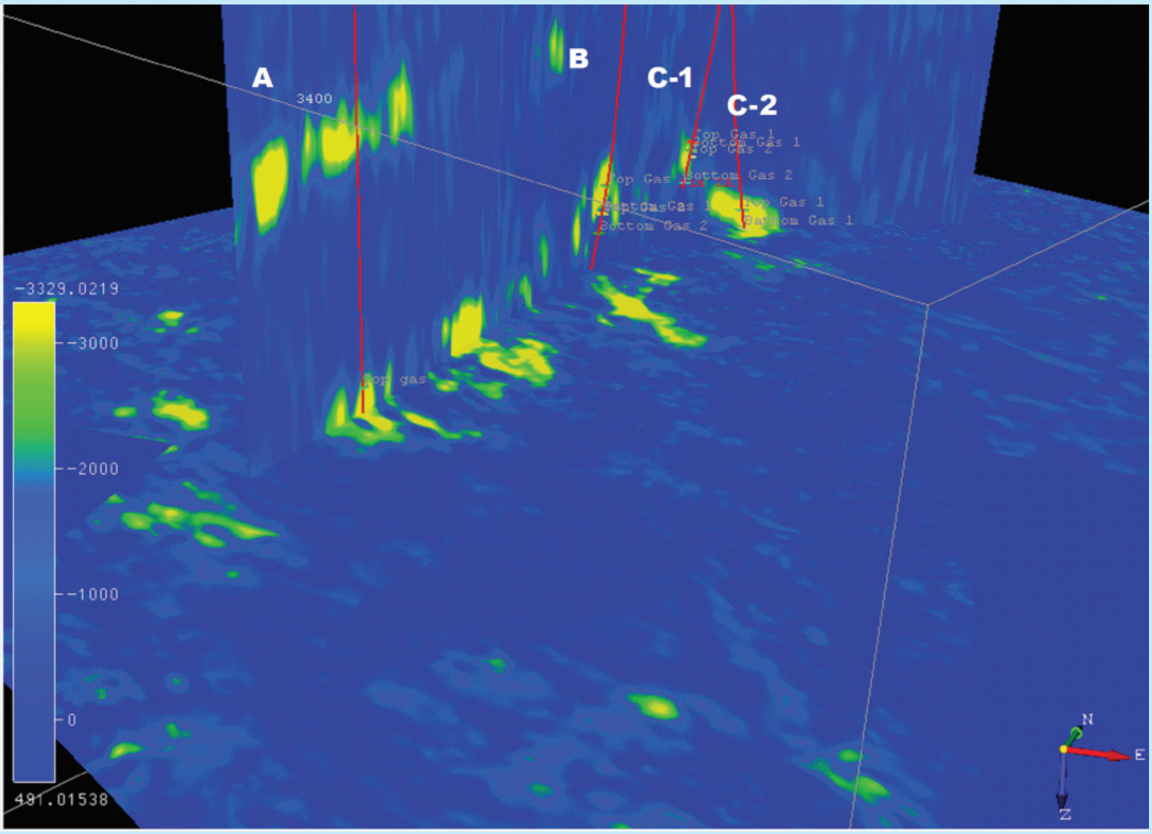


**Figure 8a**
**Bright spots, yellow color (manifested as CWT spectrum gradient) found in seismic sections which cross four wellbores A, B, C1, C2**

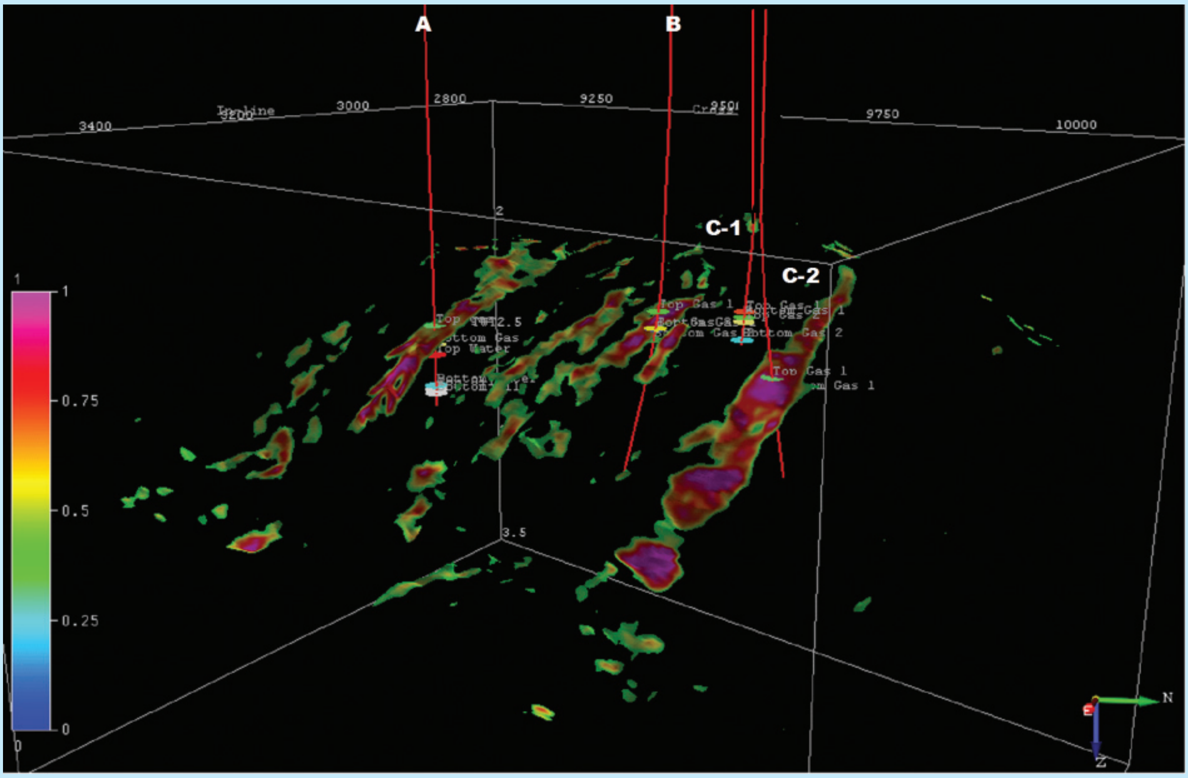


**Figure 8b**
**The distribution of maximum amplitude of CWT spectrum gradient representing gas deposit**

applied to the seismic trace which crosses the well and the result is given in Figure 7.

It can be seen clearly that the CWT spectrum for gas, oil and water can be distinguished clearly yielding a precise identification of fluid type in the reservoir rock using the seismic data.

There are four wells available for this study. In well-A there are one layer which contain gas zone, one layer which contain oil and one layer which contain water zone (see Figure 6). In well-B there are two layers containing gas, in well-C1 there are two layers containing gas, in well-C2 there are one layer which contain gas. The CWT spectrum of gas, oil and water is illustrated in Figure 7.

We propose CWT spectrum gradient as an effort to boost the different between gas, oil and water. In this case the spectrum gradient is the different between the spectrum of dominant frequency and local determined frequency of data then, divided by the difference value of frequency itself. The result is illustrated in Figure 8a and 8b.

## V. CONCLUSION AND RECOMMENDATION

CWT spectrum is a powerful tool for differentiating oil, gas and water from seismic section. For better result, the spectrum should be validated first using well controls. It should be noted that bright spot can also be originated by tuning thickness or coal seam. The CWT spectrum gradient is useful to boost the difference mentioned above.

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## REFERENCES


1. **Castagna, J.S., Sun, Siegfiel d R,** 2003, Instantaneous Spectral Analysis : Detection of Low frequency shadow associated with hydrocarbon, The Leading Edge, February.
2. **Castagna, J.P.** and **Sun, S**., 2006, Comparison of Spectral decomposition methods, First Break, vol.24, pp.75-79.
3. **Chopra, S.** and **Marfurt, K.,J.,** 2006, Seismic attribute mapping of structure and stratigraphy, SEG Distinguished Instructure Short course, series.Tulsa.
4. **Hall, M.**, and **Trouillot, E.,** 2004, Predicting stratigraphy with spectral decomposition, Canadian SEG National Convention.
5. **Johann, P.,** and **Spinola, M.**, 2003, Spectral decomposition reveals geological hidden features in the amplitude maps from deep water rese3rvoir in the Campos Basin, Landmark Technical review, pp.75-78
6. **Kishore, M.,Sharma, S.,Kumar B.** and **Srivastava, A.,** 2006. An approach to net thickeness estimation using spectral decomposition, Geohorizons, January, pp58-61.
7. **Laughlin, K., Garossino, P. ad Partyca, G**., 2003, Spectral decomposition for seismic stratigraphic patterns, Search and Discovery Article #400096.
8. **Partyka, G.J., Gridley,** and **Lopez, J.A.**, 1999, Interpretational applications of spectral decomposition in reservoir characterization, The Leading Edge, 18,pp.353-360.
9. **Rojas, N.A.,** 2008, Spectral Decomposition applied to elapse seismic interpretation at Rulison field, Grafield County, Colorado, Ph.D. Thesis Colorado School of Mines, USA.
10. **Sinha, S., Routh, P.,Anno,P., Castagna,J.,** 2005, Spectral Decomposition of Seismic Data with Continous Wavelet Transform, Conoco Research.
11. **Stockwell, R.,G., Mansinha, L.,** and **Lowe, R.P.**,1996, Localization of the complex spectrum : the S-transform, IEEE Trans.Signal Process, vol.44, no.4, pp.998-1001.
12. **Suprajitno Munadi and Humbang Purba,** 2009, Spectral Decomposition made simple, LEMIGAS Scientific contributions to Petroleum Science & technology, Vol. 32, No.,2 , pp.94-102, August.