Enhancing geological features delineation by combining a relative geological time model with the matching pursuit spectral decomposition

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Summary

Emphasizing geological features outlines is one of the seismic interpretation objectives. The spectral decomposition process allows extracting the distinctive frequencies encompassing an energetic maximum relative to a geological target and mapping it through a Red-Green-Blue viewer. Subsequently, geoscientists have to create horizons and navigate through several volumes to accurately interpret data. Instead of working on a few key events, the proposed method generates a Relative Geological Time model. A dense pile of horizons is extracted from this model which increases the number of surfaces available to better define the distinctive frequencies. In this paper, the Matching Pursuit algorithm is compared with both the Short Time Fourier Transform and the Continuous Wavelet Transform methods. A case study is presented on the Maui field, offshore New Zealand, in the Taranaki basin, illustrating a better delineation of the turbidite channels with the presented technique than with the classic workflow.

Introduction

Spectral decomposition methods are widely used and effective to highlight geological features according to their frequency contents whilst extracting them as 3D objects remains a cumbersome task. Indeed, the selection of frequencies, crucial to guarantee the precision of results, is location-dependent all along the geological object. The interpreter usually picks the frequency directly on seismic lines generating a high level of uncertainties. On top of that, the spectrograms accuracy varies according to the spectral decomposition method and their parameters. All these limitations generate a high level of uncertainties and therefore risks. In this abstract, an optimized method is proposed to improve the detection and the frequencies selection of a geological feature, based on a pile of horizons and the matching pursuit algorithm.

Theory and Method

To assess the geological targets, the traditional approach consists of navigating through the seismic volume and visually identifying the signal event on lines or time slices. Yet, a single object generally lies on several lines and the geoscientists have trouble to juggle the volume geometries. To overcome this issue, a few key stratigraphic consistent horizons are picked to better picture the feature. Coupled with attributes mapping such as the spectral decomposition, it improves its delineation and the estimation of its frequency content. Following this assumption, the proposed method is based on the generation of a high density of horizons derived from a Relative Geological Time (RGT) model.

The RGT model comes from a comprehensive seismic interpretation technique (Pauget et al., 2009) (Figure 1). A signal-driven grid is computed by creating horizon patches at peaks, troughs, zero-crossings and inflection points of amplitudes. Then, they are tracked by correlation within the entire volume. Finally, a relative age is assigned to each horizon to define the final model. The geoscientist keeps the full control of its interpretation and must check and manually refine the grid, increasing its accuracy to get the optimum solution. Once the model is obtained, a volume of dense horizons can be created thanks to its relative geological times. Signal can be extracted on each of these horizons, making possible the mapping of a variety of attribute straightforward. This method has been proven and applied to several case studies and geological contexts (Gupta et al., 2008; Lemaire et al., 2010; Lacaze et al, 2011; Vidali et al., 2012; Rahman et al., 2021).

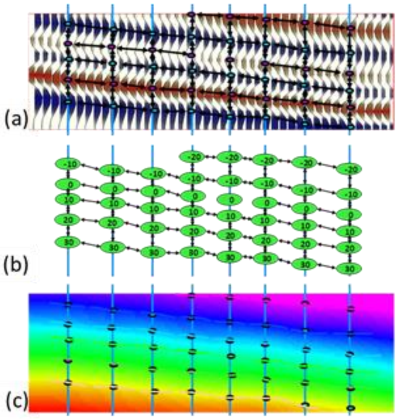

Figure 1: Creation of a Relative Geological Time model. a) Horizon patches along seismic polarities tracked by correlation, b) relative ages assignation, c) final model with relative ages interpolation.

Several spectral decomposition methods exist and are largely used for seismic interpretation such as the Short Time Fourier Transform (STFT), the Continuous Wavelet Transform (CWT) and the Matching Pursuit (MP) algorithm. STFT performs a Fourier transform inside a sliding window (Cohen, 1995), implying a time frequency resolution dependent to the window length. The CWT convolves the seismic signal with different compressed-dilated wavelets (Daubechies, 1992; Sinha et

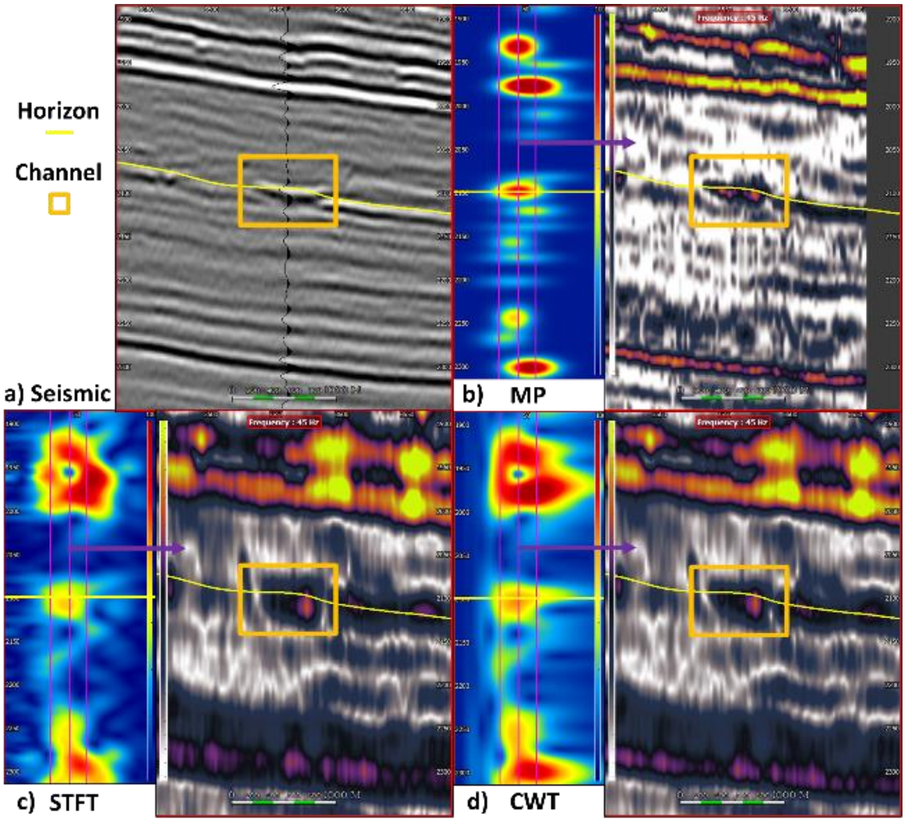

Figure 2: Spectral decompositions of the Maui seismic data at 45Hz. a) Seismic volume, b) Matching Pursuit, c) Short Time Fourier Transform, d) Continuous Wavelet Transform. The horizon intersection is in yellow, the channel area in orange and the picked frequencies in purple.

al., 2003), allowing a multi-resolution analysis of the signal which is not possible with the STFT. The CWT gives high frequency resolution at low frequencies and high temporal resolution at high frequencies. On the other hand, the MP does not require any windowing process, hence it has a superior temporal and frequency resolution compared to the STFT and CWT methods. The MP independently decomposes each seismic trace in a linear combination of wavelets. The best wavelets are chosen by cross-correlating the seismic trace with a collection of wavelets by varying different parameters: frequency, phase, scale and time delay (Mallat and Zhang, 1993). To reduce the search domain, a complex trace analysis can be performed to provide a preliminary guess of the frequency, phase and time delay before proceeding to a local optimization (Liu et al., 2004). For the three methods described above, a spectrogram can be estimated along a trace representing its time-frequency spectrum and provides a way to select the singular frequencies. Once the spectrally decomposed volumes are computed, they can be blended in a Red-Green-Blue (RGB) viewer.

The high number of generated stratigraphically-consistent horizons coupled with the high resolution accuracy of the MP algorithm ultimately results in the enhancement of geological features delineation.

New Zealand case study

The Maui field belongs to the Taranaki basin, offshore New Zealand. Cretaceous and Paleogene periods consist of a rifting stage triggered by the break-up of Gondwanaland. Simultaneously, a predominantly transgressive deposits system took place, leading to the development of a thin terrestrial to shallow marine deposits. A regional post-rift subsidence occurred during the Paleocene – Eocene epochs, where transgressive sequences can be observed. A subsidence allowed the deposition of a carbonates shelf during the Oligocene epoch. Finally, through the Neogene period, marine and terrigenous rocks were deposited during a regressive sedimentary cycle of across the basin. The proposed method is applied to this geologically complex dataset and a RGT model was obtained from Cretaceous to

Miocene (Durot et al, 2017). A dense pile of horizons was then generated from this model, allowing the mapping of attributes such as spectral decomposition results.

The three previously described spectral decomposition methods has been applied to a specific turbiditic channel. Its intertwined geometry associated with the overlapping of several surrounding channels, responsible for blurring areas, makes the interpretation difficult and tedious. This visualization challenge might be overcome by the RGB mapping. Spectrograms are computed to display the optimum contrast for highlighting the channel (Figure 2). For the STFT method, a vertical window of 21ms is used by estimating the best balance between time and frequency resolution. The CWT and MP are performed using Morlet wavelets. From the generated spectrograms, the frequencies (32Hz, 45Hz, 57Hz) are then extracted and their corresponding volumes are computed. The MP algorithm is an iterative technique, therefore the computation time is slightly longer than the CWT or the STFT methods, but the vertical resolution is more accurate on seismic sections. Indeed, the MP presents a resolution similar to the seismic by comparison with the two other methods. With the CWT and the STFT, the resulted decomposed amplitudes vertically spread out and are therefore visible on more horizons than expected. Consequently, some features could be concealed and the delineation of each individual event could be more uncertain, leading to wrong volumetrics estimations.

The same approach is applied on the neighboring channels and then extracted in three dimensions (Figure 3). Thanks to the combination of RGT modelling, enabling the interpretation of a high number of horizons, and the accuracy of the MP algorithm, the delineation of the channels is easier to observe, improving their overall modeling and understanding.

Conclusions

This abstract introduces a method to emphasize the spectral decomposition results. From a Relative Geological Time model, a set of horizons is generated based on the seismic interpretation to better visualize the geological events such as channels. Different spectral decomposition methods were applied on the Maui 3D dataset, but the Matching Pursuit algorithm showed strong benefits by its frequency and time resolutions. Thus, the delineations of the target channels are improved and consequently their extraction. Thanks to the

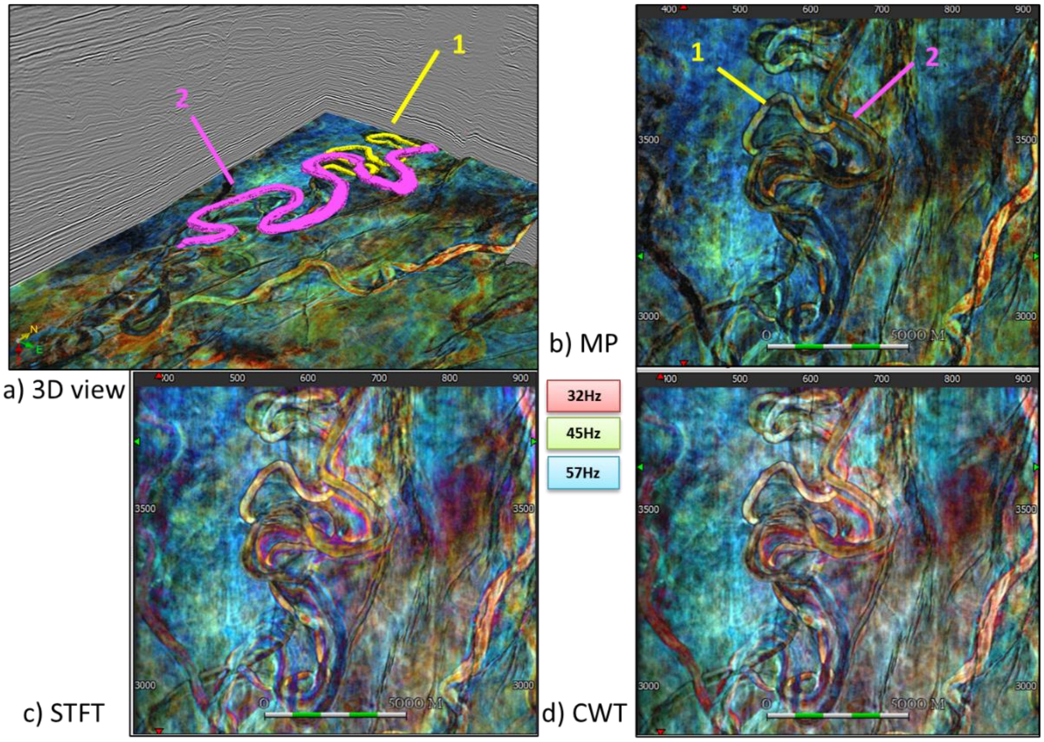

Figure 3: Delineations of two channels. a) 3D view of the extracted geobodies with the seismic in background. RGB mapping of frequencies 32Hz-45Hz-57Hz using b) Matching Pursuit, c) Short Time Fourier Transform and d) Continuous Wavelet Transform.

combination of the high density of horizons available and the RGB mapping of attributes, the accuracy of the geobodies analyzes at reservoir scale are increased and could improve volumetrics estimations.

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REFERENCES

Ab Rahman, S. S., M. H. Husen, G. J. Soto, S. Bing Bing, N. H. M. Jamin, R. Rosli, and M. C. Poppelreiter, 2021, Application of spectral decomposition technique to delineate the evolution of karst on carbonate platforms of Central Luconia, Offshore Sarawak, Malaysia: Applied Sciences, **11**, 11627, doi: https://doi.org/10.3390/app112411627.

Cohen, L., 1995, Time-frequency analysis: Prentice-Hall, Signal Processing Series.

Daubechies, I., 1992, Ten lectures on wavelets: CBMS-NSF Regional Conference Series in Applied Mathematics.

Durot, B., M. Mangue, B. Luquet, J. P. Adam, and N. Daynac, 2017, Innovative and interactive methods emphasizing geological events through spectral decomposition New Zealand case study: 79th Annual International Conference and Exhibition, EAGE, Extended Abstracts, 1–5, doi: https://doi.org/10.3997/2214-4609.201700526.

Gupta, R., T. Cheret, F. Pauget, and S. Lacaze, 2008, Automated geomodelling a Nigeria case study: 70th Annual International Conference and Exhibition, EAGE, Extended Abstracts, doi: https://doi.org/10.3997/2214-4609.20147601.

Lacaze, S., F. Pauget, M. Lopez, A. Gay, and M. Mangue, 2011, Seismic stratigraphic interpretation from a geological model — A North Sea case study: 81st Annual International Meeting, SEG, Expanded Abstracts, 1134–1139, doi: https://doi.org/10.1190/1.3627403.

Lemaire, R., F. Pauget, S. Lacaze, T. Cheret, M. Mangue, and C. Horno Kort, 2010, A multi scale approach on large seismic volumes — Tunisia case study: 72nd Annual International Conference and Exhibition, EAGE, Extended Abstracts, doi: https://doi.org/10.3997/2214-4609.201400729.

Liu, J., Y. Wu, D. Han, and X. Li, 2004, Time frequency decomposition based on Ricker wavelet: 74th Annual International Meeting, SEG, Expanded Abstracts, 1937–1940, doi: https://doi.org/10.1190/1.1851176.

Mallat, G., and Z. Zhang, 1993, Matching pursuits with time frequency dictionaries: IEEE Transactions on Signal Processing, **41**, 3397–3415.

Pauget, F., S. Lacaze, and T. Valding, 2009, A global approach to seismic interpretation based on cost function and minimization: 79th Annual International Meeting, SEG, Expanded Abstracts, 2592–2596, doi: https://doi.org/10.1190/1.3255384.

Sinha, S. K., P. S. Routh, P. D. Anno, and J. P. Castagna, 2003, Time frequency attribute of seismic data using continuous wavelet transform: 73rd Annual International Meeting, SEG, Expanded Abstracts, 1481–1484, doi: https://doi.org/10.1190/1.1817573.

Vidalie, M., F. van Buchem, I. Schmidt, and A. Uldall, 2012, Seismic stratigraphy of the lower cretaceous Valhall Formation, Danish Graben, North Sea: 74th Annual International Conference and Exhibition, EAGE, Extended Abstracts.