Use of Seismic Geomorphology to Re-define Mature Fields: Application of Spectral Decomposition and Neural Networks to 3D Examples from Canada and Colombia*

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Abstract

The field development and recovery from new fields need better definition of the field boundaries. The geological maps drawn for the reserve estimates do not usually use seismic input. In the past, the reasons were obvious that seismic data did not provide hard reservoir numbers with accuracy. This led to over simplified models of the reservoir with incorrect production estimates.

During last 10 years, the seismic reservoir characterization methods such as spectral decomposition, neural networks and deterministic inversion have progressed to the extent where they can re-define the field boundaries and bring out the geomorphology and even diagenesis of the reservoir rocks. Numerous studies from geologists and geophysicists alike have shown by example the benefits of using seismic information for stratigraphic details.

For this study, seismic frequencies and amplitudes are used to create high-resolution reservoir thickness and facies maps while the well data is used to constrain them. Within the Deep Basin of Alberta, the Cretaceous fluvial section is very tight with prolific high porosity reservoirs trapped between very low permeability sand and shale. During the exploitation, many thinner porosity segments are not perforated due to the understanding that the completion in the thicker zone will drain the full extent of the formation, which is not the case. Practically those thinner segments remain un-drained and have the potential to add new reserves within the existing mature fields.

From the study of mature fields in WCSB, the seismically defined model is then also applied to few fields in Llanos and Putumayo basins of Colombia. It is shown by examples that the application of integrated seismic reservoir characterization early in the development can enhance the production and can provide better forecasting of reserves.

Case Study # 1 - Bilbo3D, Cardium light oil play, Alberta, Canada

Shoreface sand of the Cardium Formation is one of the most prolific hydrocarbon reservoirs in the WCSB and to-date has produced 1.8 billion barrel of conventional light oil. According to the recent estimates, the Cardium Formation may hold up to 15 Billion bbl of oil in place. With new technologies like multi-stage fracturing of horizontal wells and various flooding techniques, the recovery factor could reach as high as 20% thus putting the remaining oil potential to be more than a billion barrel. A large amount of this remaining oil is trapped in tight sand located in the Ram River member. Exploration for Cardium sand is traditionally done using offset drilling, well log correlations and geological mapping. Seismic amplitude information is used but there are a few issues, which do not allow clear separation of sedimentary cycles.

Within this study seismic sequence stratigraphy, seismic geomorphology, deterministic inversion, volume curvature and neural network based facies analysis are integrated with extensive geological and well log analysis work to predict thicknesses, paleo-trends, permeability barriers and natural fracture trends within the Cardium sand (Figure 1). By knowing these factors better horizontal well planning can be achieved thus exploiting hidden high permeability trends. Seismic reservoir characterization using state-of-the-art tools are applied to uncover subtle stratigraphic features.

The Wapiti-Bilbo-Kakwa area is located at the northwestern edge of the Cardium sand fairway. Cardium Main sandstone, also known as Kakwa member, has been part of Alberta tight oil plays. Few studies published by the author showing the presence of oil within hidden shorefaces. Seismic attribute analysis of 3D data shows promising results to help build a finer lithological facies model. 3D seismic covering the paleo-shoreline has significant geomorphologic features, which could not be identified using well-log data alone. Seismic waveform facies analysis provide better understanding of thickness of sand, while linear filtering and dip-steering provides indicators of shore-face beach berms, channel systems and also paleo-depositional directions.

As shown in Figure 2, seismic waveform facies analysis could clearly differentiate between lagoon, fluvial and beach facies. The importance of lagoonal facies is its oil saturation compared to fluvio-deltaic area to the southwest and wet high porosity beach sands to the northeast.

The Cardium Formation comprises of numerous small unconformities, which makes their geometry very complex. Seismic signatures of these complexities need to be observed parallel to the depositional time lines. Seismic sequence stratigraphic tools including ‘horizon cube’ are applied to slice through the seismic to better understand the features, which could create permeability barriers and thus could become detrimental to the well productivity.

Spectral decomposition with RGB color blending is a tool, which is extensively used in the visualization to separate the areas of various thicknesses and to learn the frequency tuning of thin intervals. An RGB blended cube with 30, 40 and 60 Hz frequency shows the variation in the main sand separating the effects of the lithologies above and below the target tight sands.

Within the Cardium Formation, its seismic signature contains information from the whole interval including sands and shales and thus represents depositional facies. Neural Network based seismic facies analysis (UVQ - Unsupervised Vector Quantisers) provides another way of analyzing the seismic data. Seismic facies map is a similarity map of actual traces to a set of model traces that represents the diversity of various trace shapes present in an interval. Although the seismic facies is very broad in recognizing seismic geomorphology, it does classify the interval into diagenetic groups, which are usually associated to similar rock and fluid character of the formation.

Further to the above analysis, dip-steered volume curvature attributes are helpful in defining not only the depositional trend but also the natural fracture trends, which can enhance the permeability of reservoir zone.

Case Study # 2 - Putumayo Basin, Colombia

Putumayo basin is the northern extension of the Oriente basin of Ecuador. The oil and gas traps are usually found in structural closures, which were re-activated normal faults. The largest accumulation in the Colombian side is Oritto field. Although the exploratory and production drilling is based on a homogeneous reservoir throughout the structure, most often that is not the case.

Spectral decomposition provides new insight to the extents and possible risks in developing the existing reservoirs as the extent of the reservoir and their quality varies within a structural closure. As shown in Figure 3, the frequency is attenuated following the field outline with dominant blue color, 30 Hz. Moreover, non-connected reservoirs may have their own oil-water contact and may affect the total producible reservoirs estimated for a field. As the present development of oil and gas in Putumayo basin shows, there is more to finding oil and gas in Putumayo basin than just mapping the structures.

Llanos basin is one of the most prolific basins of Colombia. It contains one of the largest heavy oil field Rubiales (~4.7 BBO in-place). Since 2008, Llanos basin has seen highest levels of exploration and drilling campaigns. The oil is trapped in variety of trap forms which have both structural and stratigraphic components. In the Llanos plains, Carbonera Formation is one of the main reservoirs. Oil has been moving up-dip from Cretaceous source rocks and is been trapped whenever suitable permeability barriers are available.

As an analogy, the lower Carbonera is very similar in deposition to Cretaceous Mannville Formation of WCSB. Contrary to Mannville plays of Alberta, which has been one of the main producers, the fluvial channel system of Oligocene Carbonera has been targeted only for structural traps to date. Stratigraphic traps might be present where lithic channels could provide lateral seal for meandering channel system. One of the main reason remained sparse availability of 3D seismic data. Even if the 3D data exist, it was difficult to distinguish between porous and shaly channel systems.

Following the geomorphologic development of Carbonera Formation with the help of seismic facies and spectral decomposition tools (Figure 4), various channels thicknesses and lithology could be determined. Interval analysis at various stages of deposition shows the truncation of one channel system by another thus creating the opportunity of trapping. The frequency slices parallel to key marker horizon show the truncation of northeast trending channel system by a SE-NW trending lineament with bright amplitude anomaly. Although beyond the scope of this study, the possible traps can be analyzed for their AVO response to further reduce the risk.

Conclusions

High-resolution seismic geomorphology associated with seismic attribute analysis can help distinguish paleo-geographic features and natural sediment lineaments with high stratigraphic detail. Moreover, the areas with different lithology and fluid types can be recognized using interval analysis through spectral decomposition and waveform facies analysis. Seismic reservoir characterization tools allow better development drilling and if followed in conjunction with other data may result in better application of fracture simulation and eventually better yield of oil with minimum vertical or horizontal wells.

We conclude in this study that using seismic reservoir characterization along with high quality 3D data and target oriented processing can make a huge difference in understanding the geology when it comes to development drilling and locating the areas of maximum yield and to find new hidden plays.

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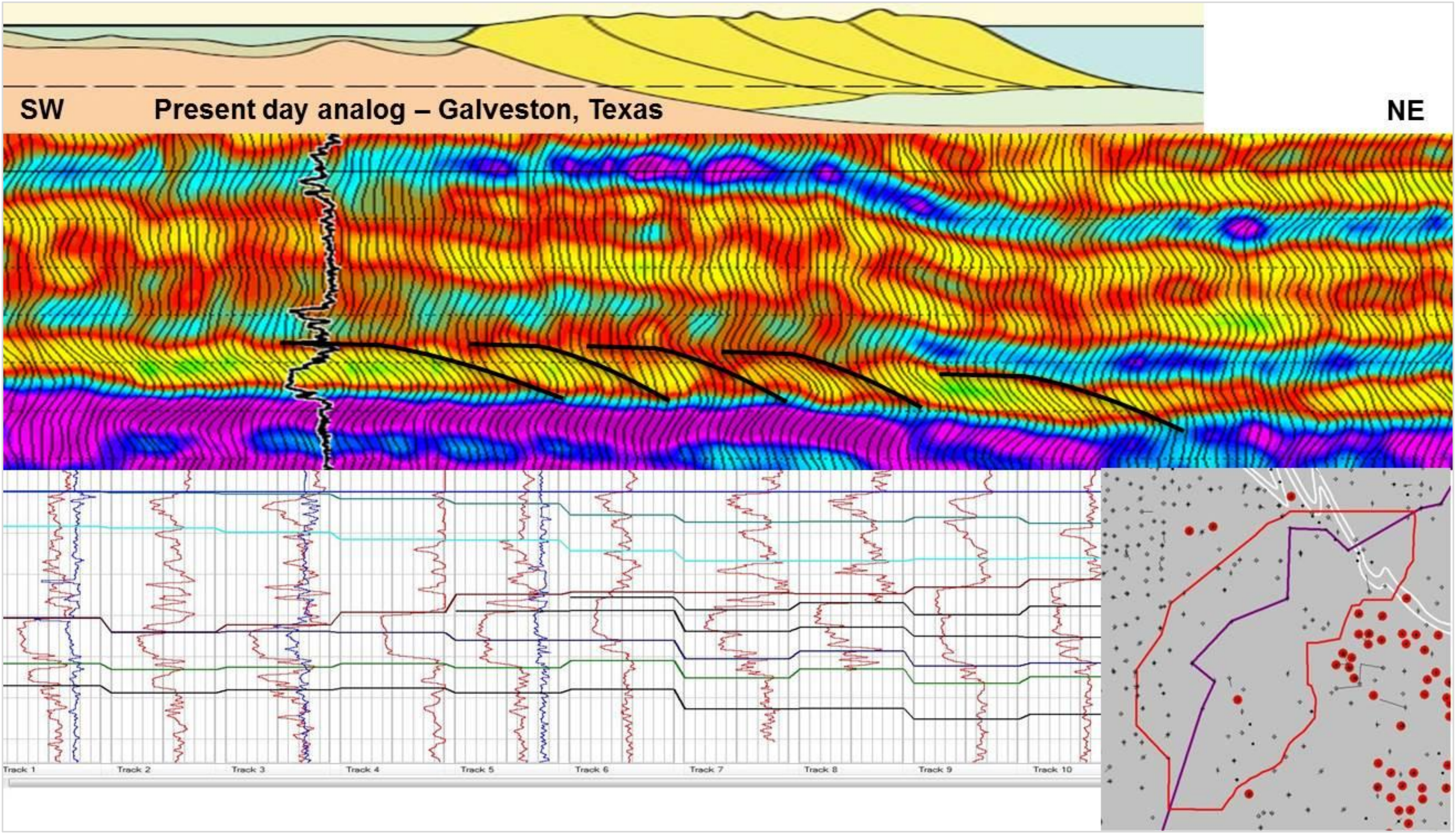

Figure 1. Deterministic inversion section through the Cardium shoreface reveals the stacking pattern of main beach simiar to now days Galveston area in Houston, Texas. The pro-grading sands contain individual shale barriers and thus contain additional reserves not realized due to oil below water scenario.

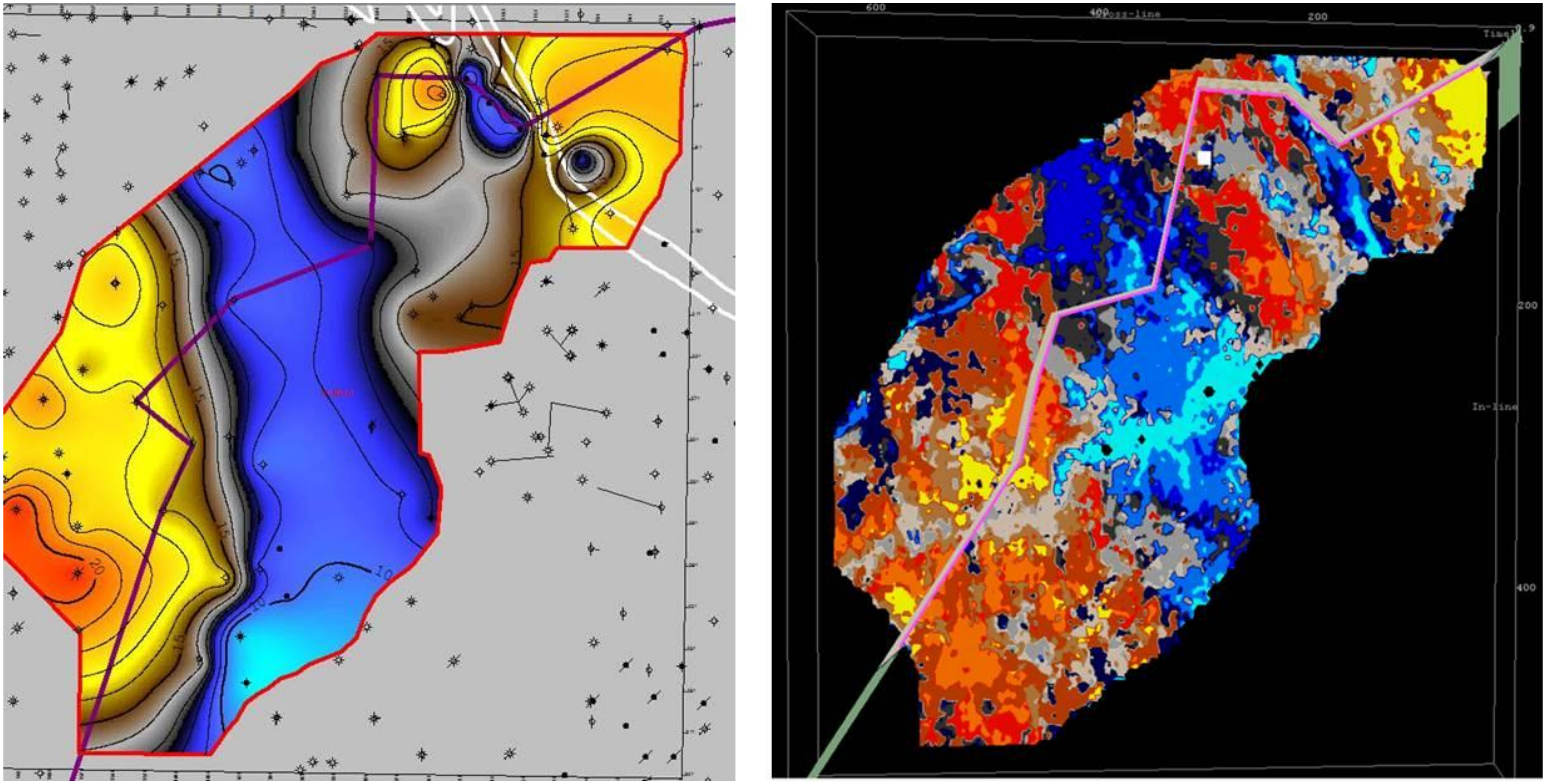

Figure 2. Conventional isopach without seismic input (the shoreface wells clearly show bulls eye and on the right, neural networks based seismic facies map which captures all aspects of the depositional pattern.

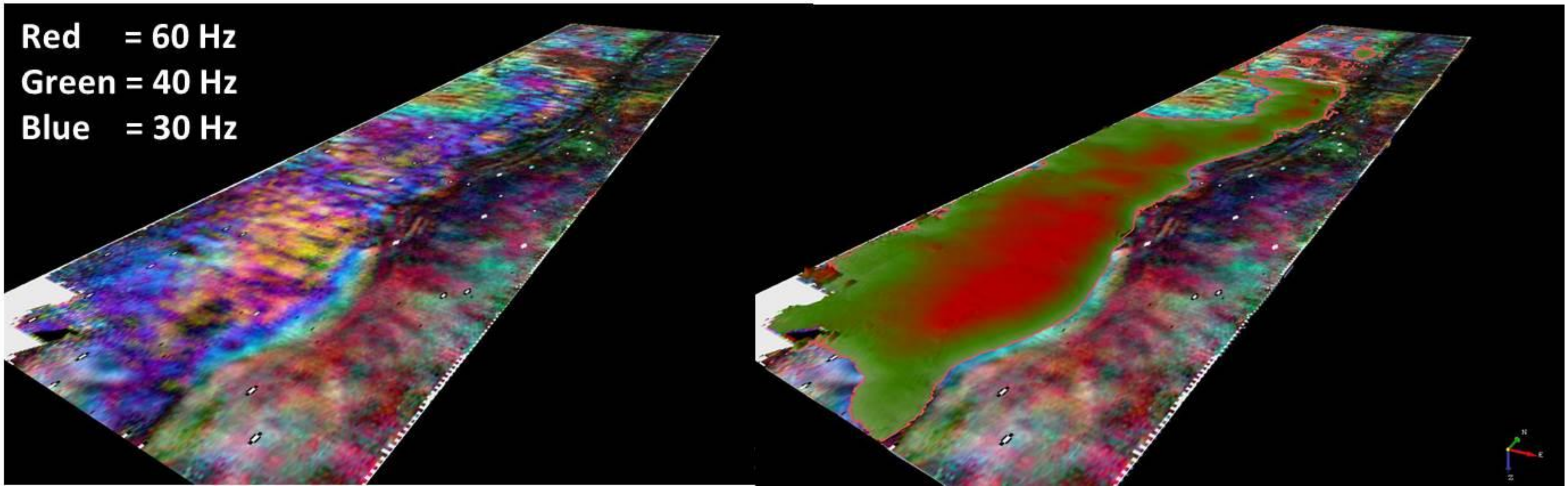

Figure 3. The structural closure of a 110 MMbbl field where 3D shows hanging wall closure. By using Spectral decomposition, the field margins and hydrocarbon bearing area can be correlated to frequency attenuation.

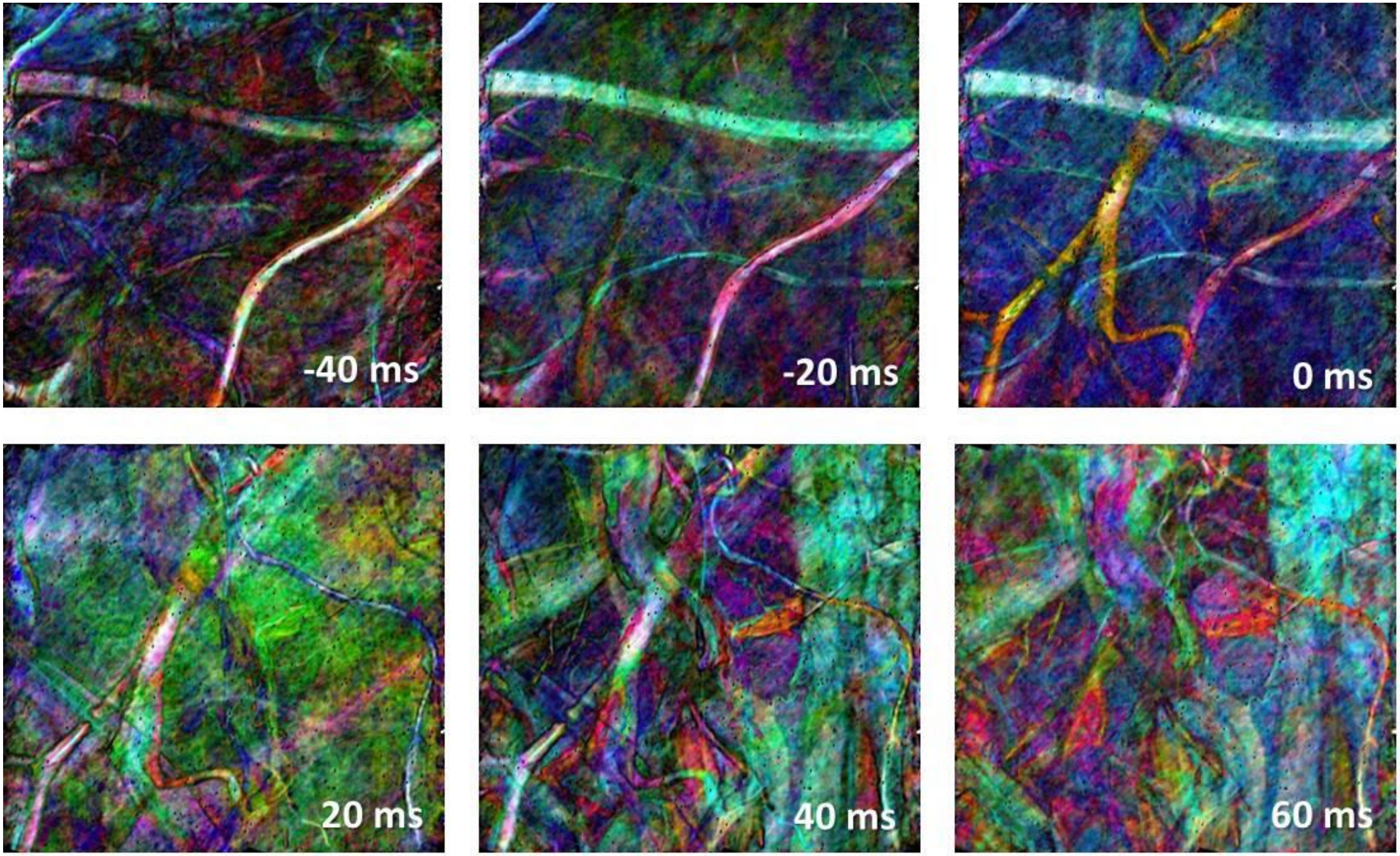

Figure 4. RGB color blended horizon slices using the mixing of three spectral bands (30, 40 and 60 Hz). As most of the Carbonera sand is deposited in a fluvial flood plain the changes in geomorphology is visible through periodic slices. Starting from 40 ms below a consistent seismic marker (-40 ms) to 60 ms above the marker (60 ms) one can follow the changes in depositional directions and style.