GC Identification of Isolated Complex Productive Reservoirs in Fault-Controlled Fluvial Systems*

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Search and Discovery Article #42323 (2018)
Posted December 10, 2018

*Adapted from the Geophysical Corner column, prepared by the authors, in AAPG Explorer, November, 2018. Editor of Geophysical Corner is Satinder Chopra (schopra@arcis.com). Managing Editor of AAPG Explorer is Brian Ervin. AAPG © 2018. DOI:10.1306/42323Vernengo2018

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General Statement

The Mina El Carmen Formation in the Golfo San Jorge Basin (GSJB), Argentina, contains a large number of isolated reservoirs that make a sizeable contribution to the overall production from the basin. The main reservoirs are linked to the sedimentary channels that have resulted from fluvial-lacustrine deposition in low-relief plains developed in proximity to volcanic areas. Consequently, the lateral variation of facies, pinchouts and sedimentary discontinuities generate low connectivity among the reservoirs. The thickness of the reservoirs is below seismic resolution, which makes the detection of the channel sands challenging.

The above-stated challenges can be overcome by evaluating the application of various interpretation tools and special processes, so that the reservoir sands can be detected and visualized in terms of their geometry, orientation, extension, thickness and position in the stratigraphic column.

Geologic Context

Located in central Patagonia, the GSJB is the most prolific basin in Argentina and ranks second in terms of the remaining hydrocarbon reserves, after the Neuquén Basin. More than 40,000 wells have been drilled throughout the basin so far, and it is expected that the basin will remain the center of activity for the decades to come. The GSJB encompasses parts of Chubut and Santa Cruz provinces and extends offshore onto Argentina’s continental shelf. The basin has already produced in excess of 3 billion barrels of oil and accounts for 48 percent of the country’s production.

The oil and gas productive Chubut Group in GSJB began with the Pozo D-129 Formation, which is mainly of lacustrine origin, with low to moderate organic content (0.5 to 3 percent total organic carbon), and is considered the primary source rock of the basin. The stratigraphic column continues upward with the Mina El Carmen and Comodoro Rivadavia formations (Upper Cretaceous), deposited under late sag conditions as fluvial-shallow lacustrine units and constitutes the main reservoirs of the basin. All these Cretaceous formations comprise the Chubut Group, which shows indications of intense volcanic activity during its depositional history. The units are a part of a regional fluvial system that flowed to the southeast. Active channels, exhibiting meandering, braided and low-sinuosity facies commonly occur. Consequently, the lateral or vertical changes in the fluvial architecture of Mina El Carmen Formation are well known. Once the hydrocarbons were generated in the source rock 50 to 80 million years ago, migration took place via a network of faults and pathways that were formed during extensional and compressional tectonic regimes that took place during those times.

The Early Cretaceous Pozo D-129 Formation is up to 1,500 meters (about 5,000 feet) thick and comprises conventional faulted and high permeability sandstones occurring at depths of 6,600 to 15,800 feet. The trap mechanisms seen in the basin vary from structural (faulted anticlines and tilted horst blocks) to stratigraphic pinchouts. The basin is currently producing 230 million barrels per day. Production from many of the wells is declining due to the long production history. Overlying these units there is a group of interbedded Tertiary deposits of marine and continental origin.

Applications

The study area is to the northern part of the GJSB and the structural interpretation recognizing the potential conditions for containing and producing hydrocarbons in the fluvial units comprising the Mina El Carmen Formation. The horizons and faults were picked after correlation with well log curves, which provided insights into the compartmentalization of the faulted blocks. Next, the seismo-stratigraphic analysis was performed for highlighting, isolating and characterizing amplitude signatures of interest and by making use of seismic attributes, such as instantaneous amplitude extraction, spectral decomposition and impedance inversion.

In Figure 1, we show the geobodies extracted within the Mina El Carmen Formation that are oriented in the north-south direction. The horizon picked near the top of the Mina El Carmen Formation is shown as well as a local master fault in red. The instantaneous amplitudes were computed over the geobodies and the variation in their color display illustrates the seismo-facies variations therein. The internal discontinuities that are intersecting the geobodies are also seen. The shown geologic architectural elements are interrelated and make up a complex hydrocarbon trap system. A few wells have been drilled before the channel interpretation depicted in Figure 1 was carried out, but the reprocessing of the seismic data and its detailed interpretation helped understand the geobodies spatial development. The wells drilled subsequently corroborated the existence of the presence of the fluvial channel reservoirs as was inferred.

A few kilometers to the north of the channel shown in Figure 1, we show another isolated fluvial channel in Figure 2a, interpreted similarly. The colors of the instantaneous amplitude on the geobodies exhibit the lateral seismo-facies variation, but the fault seen in red on the structural map at the top of the fluvial system seems to show the discordance on the channel geobody distribution. In Figure 2b, we show the zoomed version of the channel geobody so that it exhibits the seismo-facies variation better. The two wells drilled in the red and yellow facies marked on the figure turned out to be producers, adding support to the interpretation.

The spectral decomposition of seismic data has been frequently used for examining geological features at individual or specific frequencies, within the seismic bandwidth. Such applications lead to detection of thin layers, and their geologic characteristics not easily interpreted on seismic amplitudes. Many articles on spectral decomposition have appeared in the pages of Geophysical Corner:

Spectral Decomposition’s Analytical Value, Search and Discovery Article #41260 (2013)

Spectral Decomposition Helps Define Channel Morphology, Search and Discovery Article #41272 (2014)

Spectral Decomposition for 3-D Geomodeling, Search and Discovery Article #41408 (2014)

Spectral Decompostion for a More Accurate Image, Search and Discovery Article #41807 (2016)

Likewise, impedance inversion of seismic data enables interpretation of the subsurface target zones as geologic intervals separated by acoustic impedance contrasts, rather than as acoustic impedance interfaces, displayed and interpreted on seismic data.

Both the above processes were carried out for the seismic data volume at hand. In Figure 3 we show horizon slices near the top of the Mina El Carmen Formation from the spectral decomposition frequency volume at 36 hertz (Figure 3a), and the P-impedance volume. Notice how the frequency and P-impedance slice displays show the fluvial channel definition as well as its thickness variation intersected with the discontinuities in red. The drilled wells shown as black lines corroborated this interpretation.

Finally, in Figure 4, we show examples of different channels that were recognized in the northern flank of the GSJB. The frequency horizon slices at 35 hertz exhibit the fluvial channels clearly. In contrast, the horizon slice from the RMS amplitude cube close to the top of the fluvial system and shallower than the other shows smaller width channels and in a more complex system.

Conclusions

Application of appropriate interpretation tools to understand the sedimentary systems and their associated structural schemes is one of the most important goals for seismic interpreters, especially in geological environments with a high degree of complexity. Spectral decomposition and acoustic impedance inversion, taken together, are relevant to establish the dimensions and orientation of the sedimentary bodies present in the study area. Due to the existence of trustworthy data, the interpretation carried out in the case study described above was done with a greater degree of certainty. There are plans to use these applications in more remote areas with advanced wells prospects.

Acknowledgements

We would like to thank Pan American Energy LLC for permission to show the examples, and Satinder Chopra of TGS, Calgary, for the rewriting several many parts of this article.

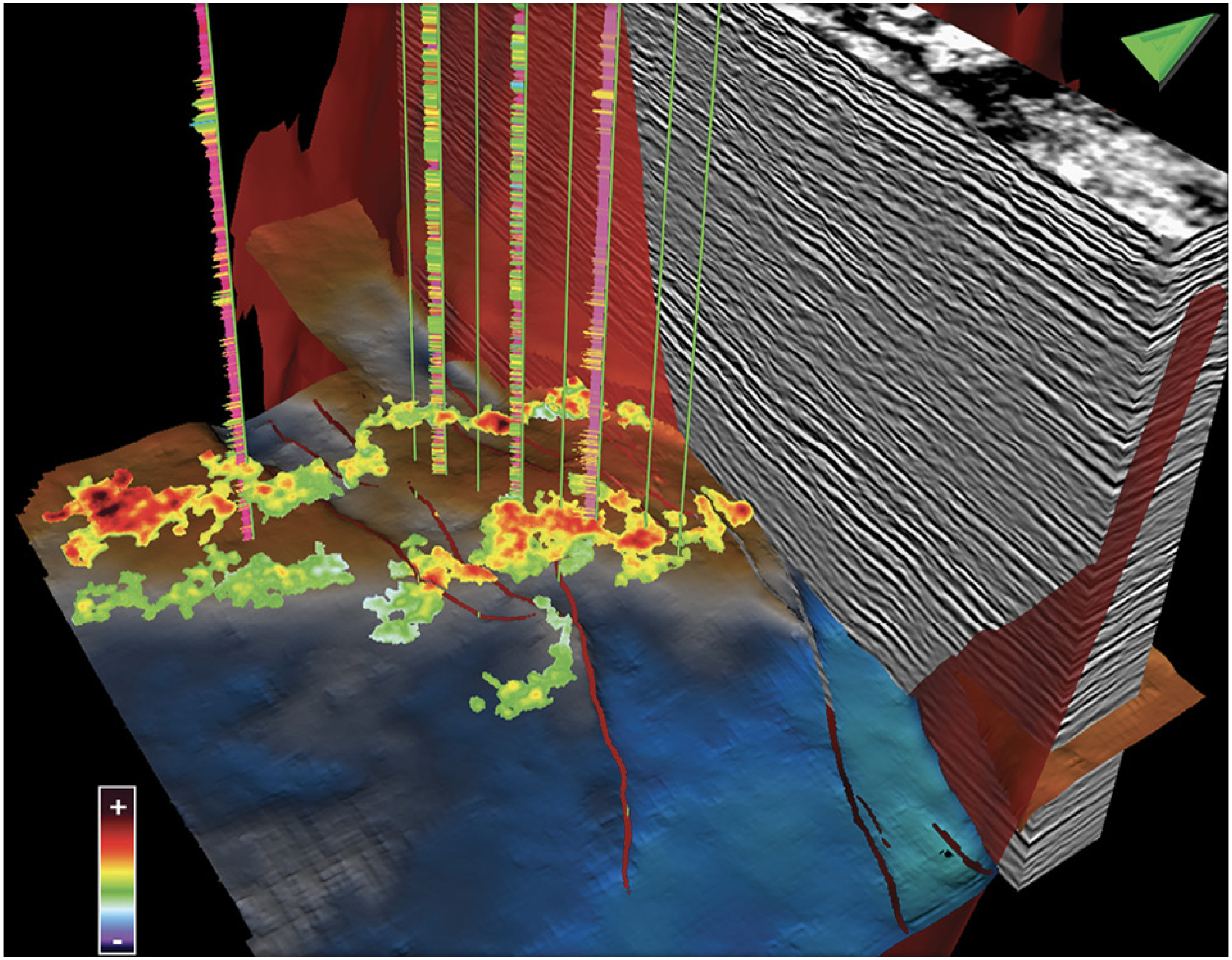

Figure 1 (far left). Extracted geobodies that conform with the existing fluvial system, together with the some of the wells drilled (some with well logs), one of the interpreted horizon and one of the main faults. The instantaneous amplitude attribute was applied to extracted geobodies with north-south general arrangement. The variation in the colors of the attributes indicates the seismo-facies variations and internal discontinuities existing in each geological body. The horizon near Mina El Carmen Formation top and the local master fault (in red) are also shown. The heterogeneity of the sequences is interpreted by the lateral variations in the amplitudes as well as the instantaneous amplitudes on the extracted geobodies.

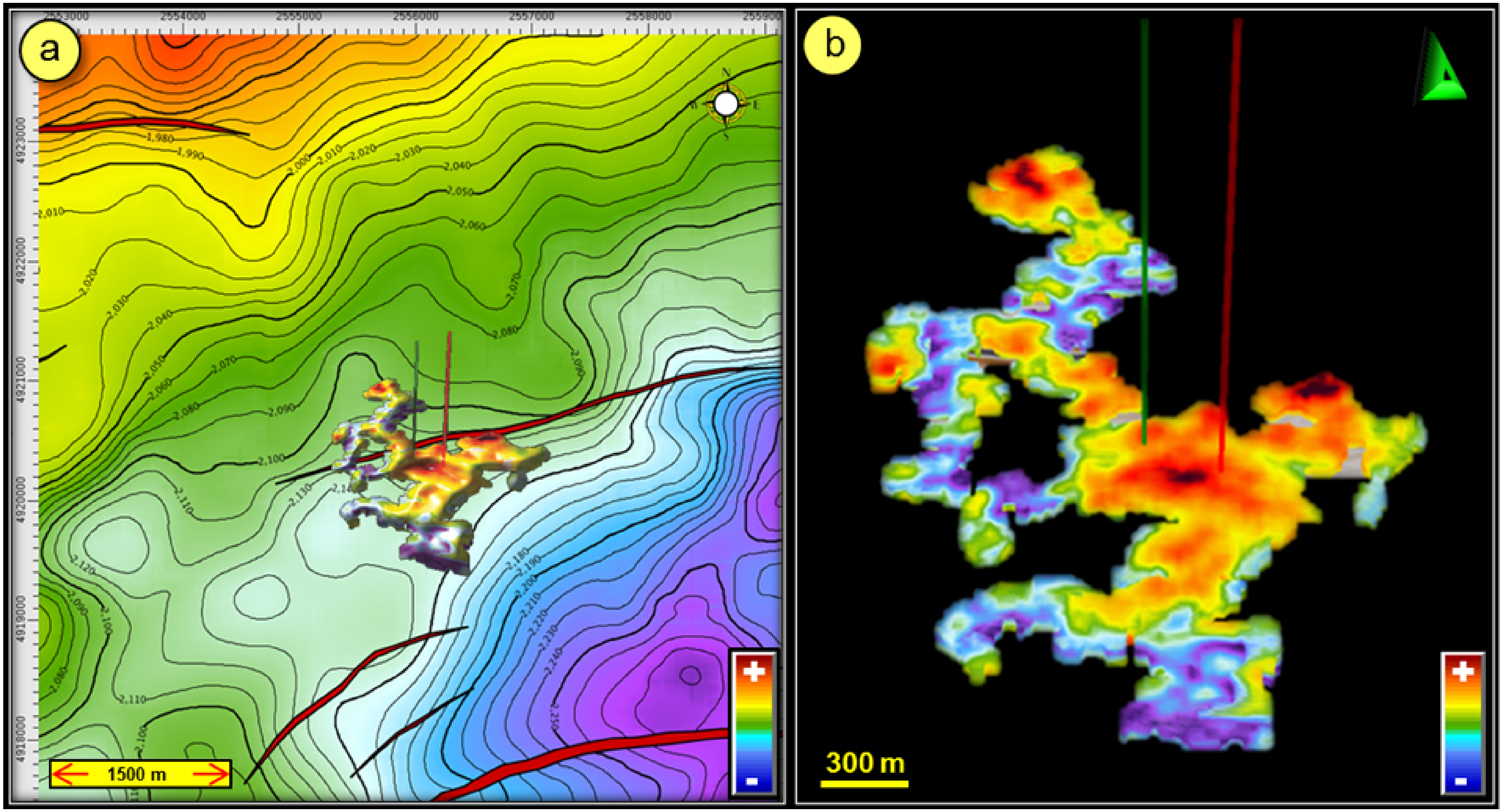

Figure 2. Probably fault controlled fluvial channel geobody (low seismic resolution and small fault displacement). (a) This one is covisualizated with the structural map referred to a marker above of the fluvial system. (b) This detail of the fluvial geobody shows the seismofacies arrangement inside of it. The two productive wells were drilled in the red-yellow facies. The 3D perspective visualization allows us to understand the general geometry and detailed shape of each part of the isolated channel.

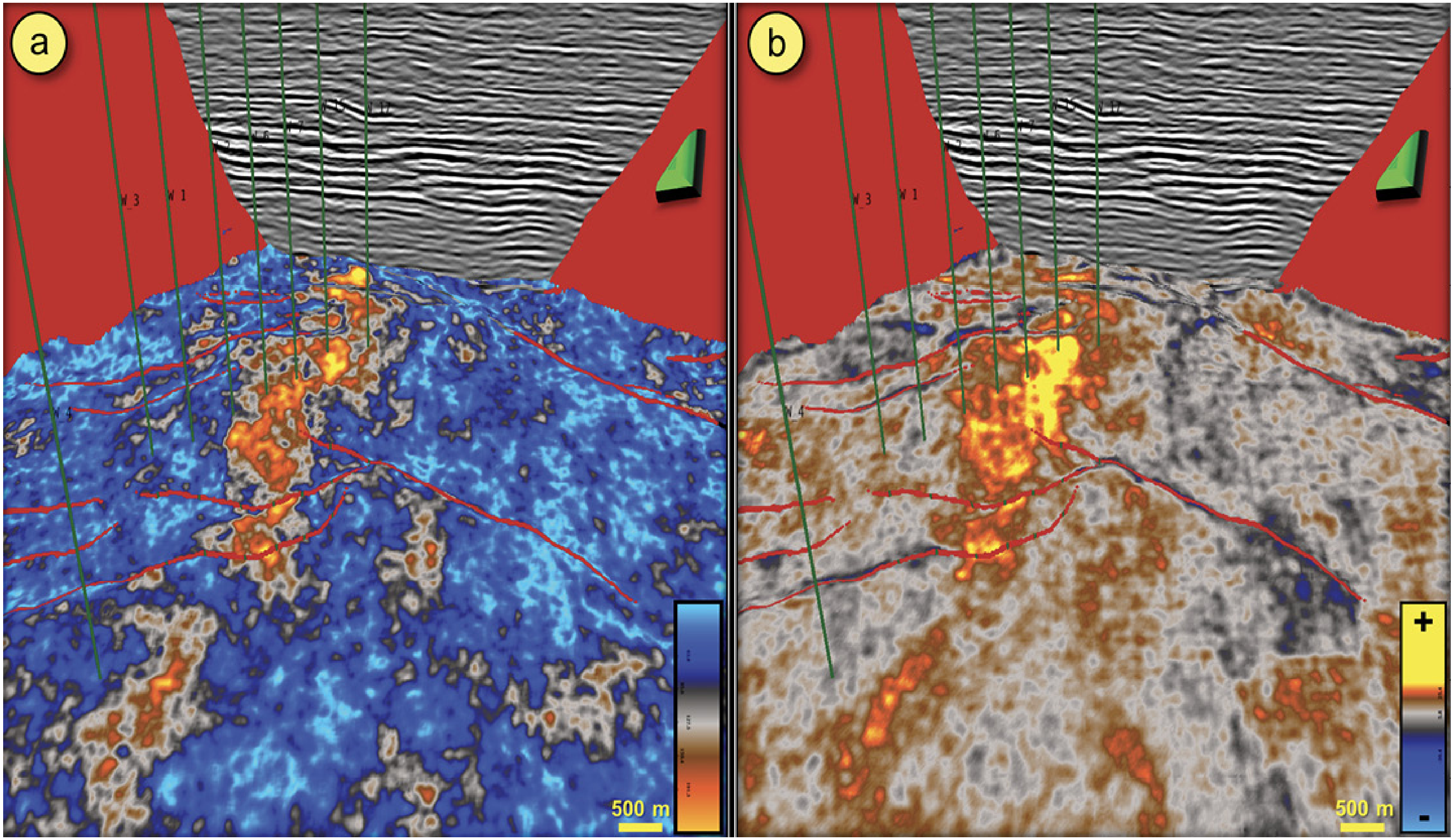

Figure 3. Chair displays showing (a) spectral decomposition frequency horizon slice at 36 hertz, and (b) P Impedance horizon slice near the top of Mina El Carmen formation. By animating the different frequency slices it was possible to appreciate the best definition of the fluvial environment with its associated geologic sub-environments, as well as thickness variations, including thickness. The stratigraphic limits shown by the spectral decomposition were corroborated by well data.

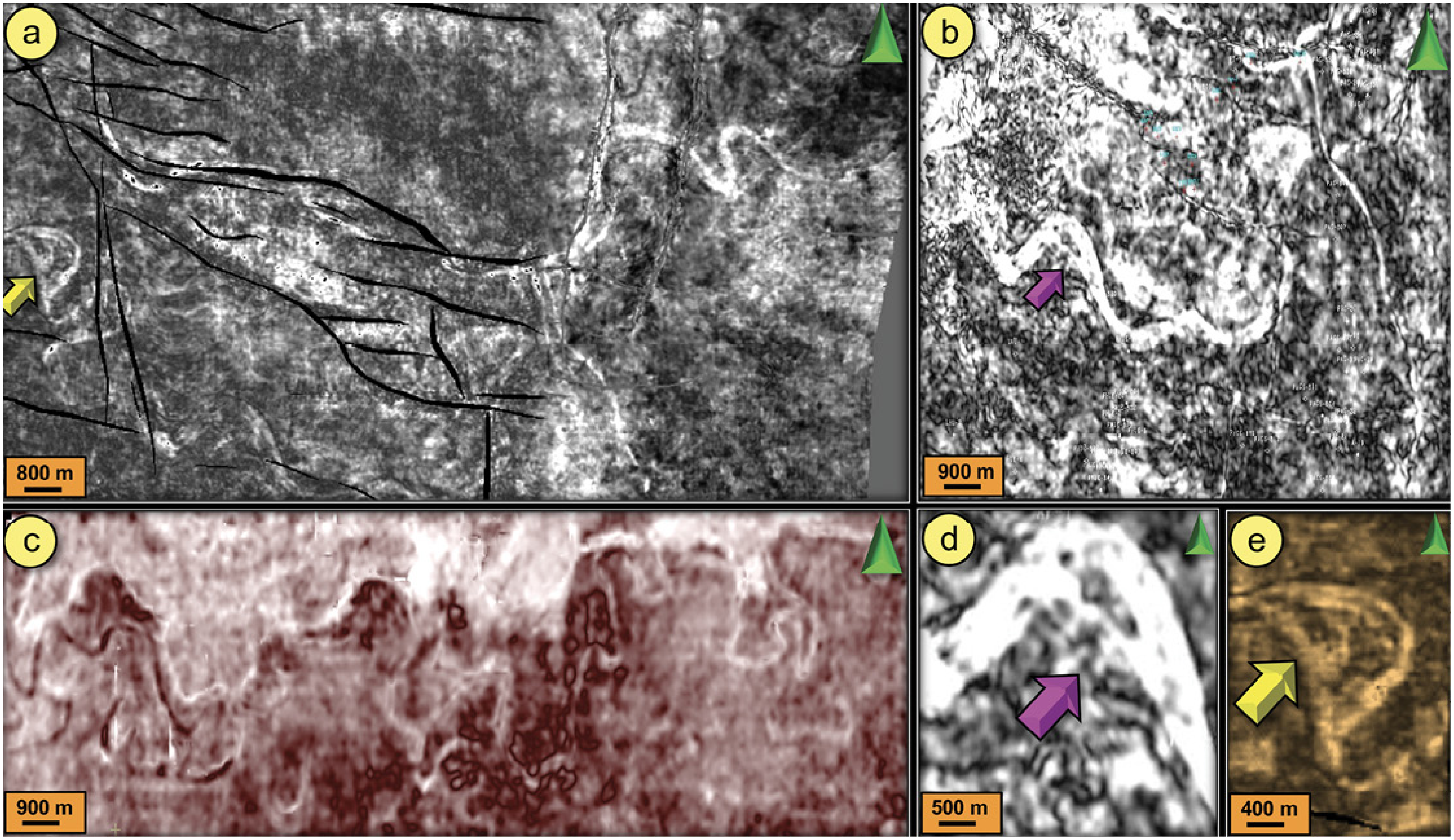

Figure 4. (a) and (b) The figures show examples of fluvial system channels surrounding the study area, visualized with SD frequency slices (35 Hz). (c) Fluvial channels close to the top of the studied system. In this case it is possible to appreciate a horizon slice from RMS amplitude cube. (d) and (e) Detail of abandoned meanders. These examples of SD frequency slices allow to appreciate the sinuosity degree of the meanders and evaluate the deposition energy of the system and the better positons to found reservoirs of interest.