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Simposio de Geofísica: La Geofísica como vínculo entre el conocimiento de la tierra y la sociedad

PHASE DECOMPOSITION AS A DIRECT HYDROCARBON INDICATOR: MIEMBRO CUTRAL CO, CUENCA NEUQUINA, ARGENTINA

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RESUMEN

El uso de la fase sísmica como indicador directo de hidrocarburos: Miembro Cutral Co, Cuenca Neuquina, Argentina.

El objetivo de este trabajo fue identificar y predecir la ubicación y extensión de los intervalos productores de gas del Miembro Cutral Co utilizando la técnica de descomposición de fases. El Miembro Cutral Co se caracteriza por depósitos turbidíticos arenosos de baja porosidad (que van del 8-20%). Estos intervalos productores de gas son de espesor variable (20 a 85 m) y se caracterizan en los datos sísmicos por su baja impedancia acústica.

La descomposición de fase es el proceso de analizar los componentes dependientes de la fase de una traza sísmica; Los depósitos delgados saturados en gas mostrarían una anomalía de amplitud en el componente menos 90˚ con respecto a los depósitos de espesor similar sin presencia de gas. Este es un efecto de la caída de impedancia causada por la presencia de hidrocarburos.

La relación amplitud-frecuencia-fase se establece analizando el atributo en modelos sintéticos a lo largo del pozo. Esto nos permite determinar el contenido de frecuencia necesario para representar la respuesta sísmica de la capa de interés como la de una capa delgada, definiendo el espesor mínimo de resolución. Las capas de interés muestran una redistribución de amplitudes a una frecuencia dominante de 20 Hz.

El estudio de los componentes dependientes de la fase sísmica nos permitió predecir la extensión total del reservorio productor conocido más allá de la ubicación del pozo. La anomalía de amplitud en el componente de fase menos 90˚ puede correlacionarse con el intervalo productivo en el pozo y mapearse lejos del mismo, dando una idea de la extensión real del reservorio. Estos resultados junto con estudios previos del área de interés se usaron para detectar nuevas oportunidades y mejorar la ubicación del pozo.

INTRODUCTION

The Cutral Co area within the Neuquén Basin has been widely explored for hydrocarbon production since 1950. The interval of interest is part of the Molles Formation and known as the Cutral Co Member. This is characterized by turbidite sequences with sand and shale layer intercalations deposited during a submarine fan paleo-environmental setting.

The current analysis is performed and focuses on one well (CCo-93), where one reservoir of approximately 80 m thickness (with porosities that range between 8-20%) has been and is being constantly producing gas. Also, other intervals with hydrocarbon saturation were identified along the column. Therefore, the main objective is to define the geometry and areal distribution of this gas associated amplitude anomaly to design the right drilling plan. The petrophysical evaluation for well CCo-93, in the Cutral Co Member (figure 1), shows the criteria applied to define the prospective gas layers. The cut-offs used in the analysis (effective porosity higher than 8%, and water saturation below 65%) revealed many gas-saturated intervals, which were grouped according to their visibility on the seismic data. The shallower intervals of interests (gas producing interval represented by the green marker, and gas-saturated interval represented by the purple marker on figure 1) are characterized by several stacked pay intervals, while the deeper gas-saturated intervals (purple marker on figure 1) are thinner and represent more isolated pay intervals.

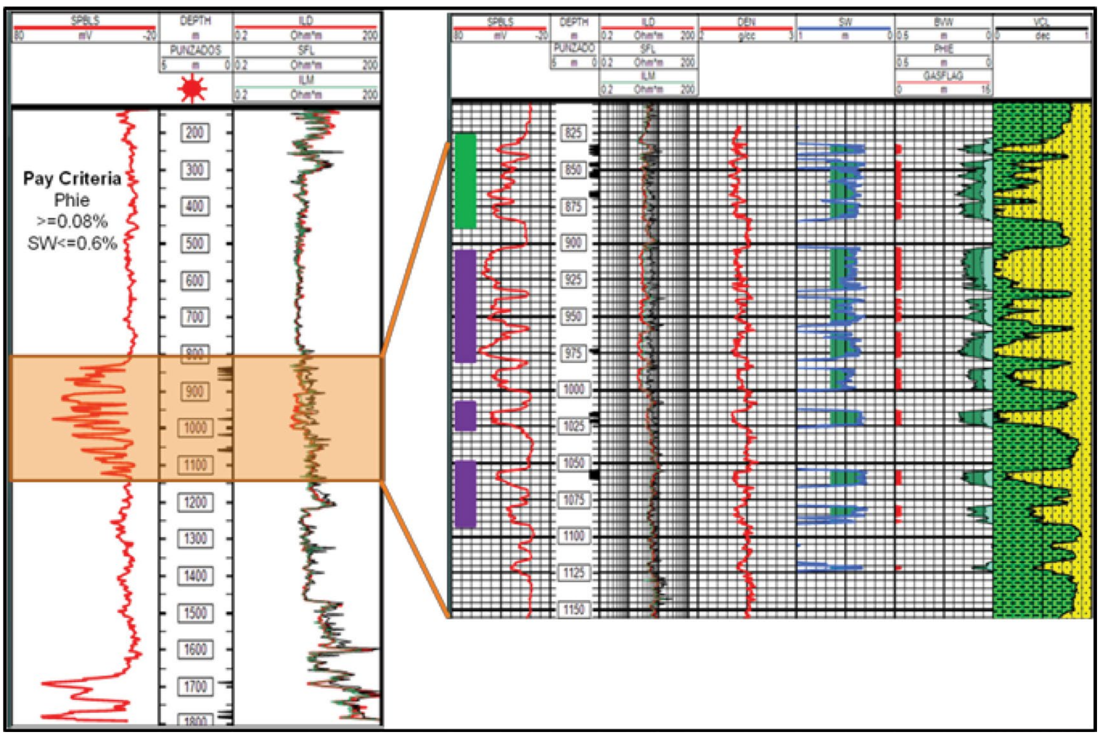

Figure 1. Petrophysical analysis showing the gas-saturated intervals and the effective porosity and water saturation cut off of higher than 8% and below 60%, respectively. The main interval of interest is the one currently producing gas highlighted in green. The purple blocks highlight the gas-bearing intervals also studied in this work.

PHASE DECOMPOSITION

Phase decomposition is a method that allows to separate the seismic trace into phase dependent components by producing a seismic trace for each phase (i.e. phase gather). It presents a similar approach to spectral decomposition, but in the phase domain. As Castagna *et al.* (2016) explain the seismic trace's response is dependent on three factors: amplitude, frequency, and phase. The equation of the trace shows this dependency. By solving the time frequency analysis in band-limited data, the seismic trace becomes dependent on amplitude and phase alone, which consists of the amplitude's response at the different phase components. These phase dependent components are sorted into a phase gather. Figure 2 (from Castagna *et al.*, 2016) shows the phase gather response in a trace where the phase components stride every 10°, from -170° to 180°. We can observe the amplitude response of the seismic trace moving across the phase components.

The seismic trace can also be separated into Even and Odd responses, where pairs of reflections of the same sign and equal amplitudes generate an Even response, and pairs of equal amplitude and opposite signs generate Odd responses, as shown in figure 3. A combination of Even and Odd responses, and the ratio of their respective amplitudes, add back to the original trace and respond in a particular phase component.

Phase decomposition can be used as a thin layer and fault detection tool, as well as a method

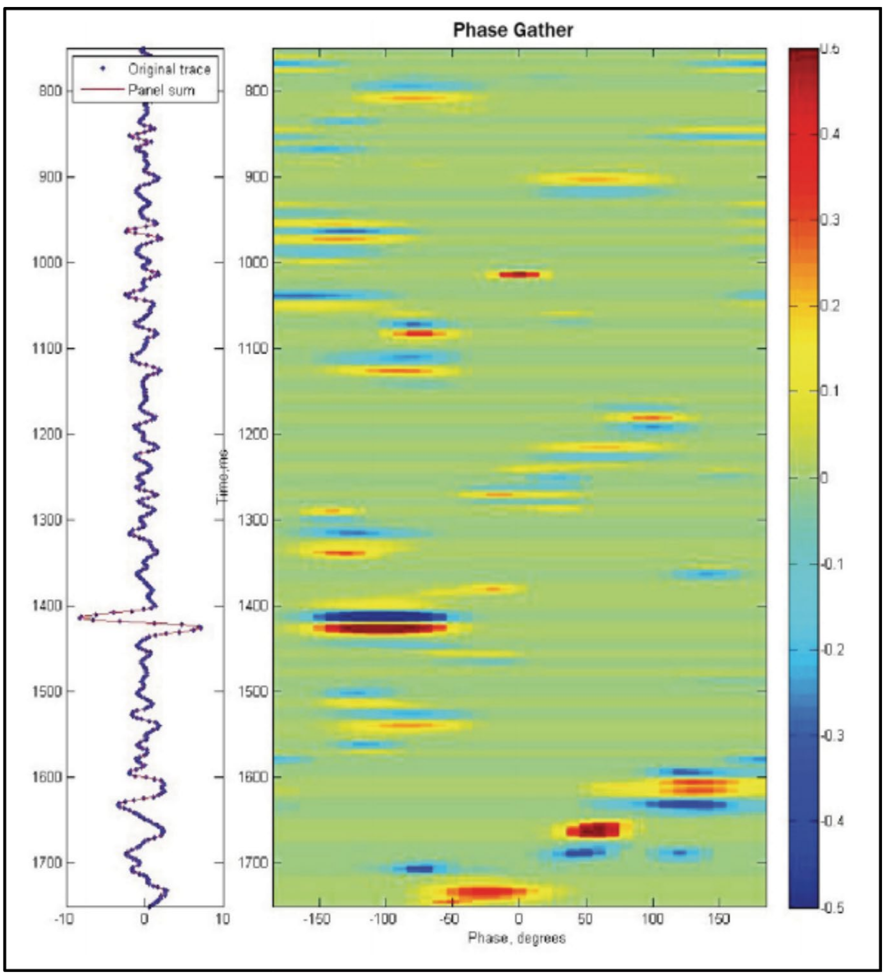

Figure 2. Phase Gather (right panel) showing the dominant phase response at each sample of the seismic trace (left panel).

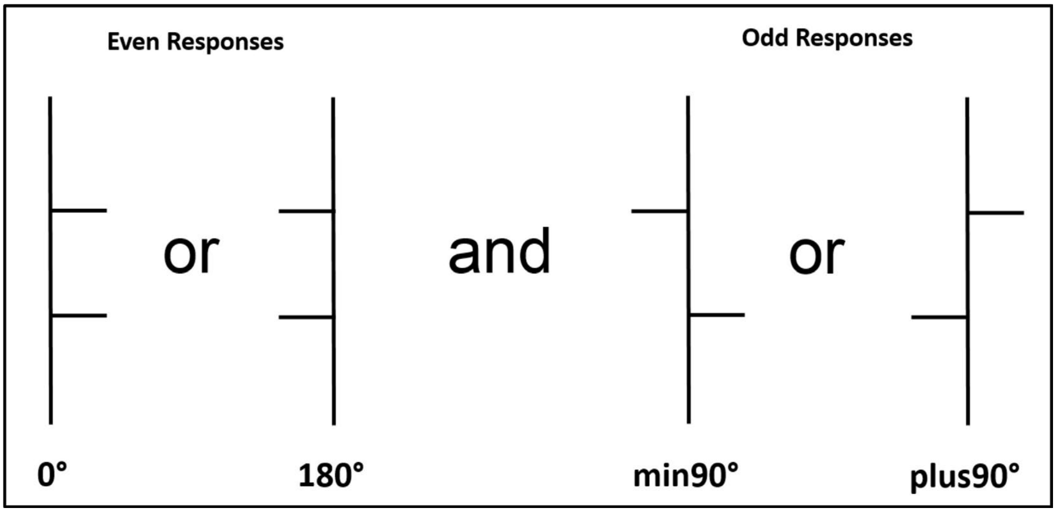

Figure 3. Even and Odd reflectivity models and their corresponding relationships to phase components.

to highlight subtle stratigraphic features. It can also be used as a direct hydrocarbon indicator. As Meza (2016) explains ''the "hydrocarbon effect" or change in amplitude caused by the addition of gas to a brine-filled layer, is -90° phase-rotated with respect to a zero-phase wavelet". In the case of Cutral Co Member's intervals of interest, the encasing lithology is of low relative impedance with respect to the surrounding shales; the addition of hydrocarbons to the reservoir will produce a further drop of impedance, resulting in a bright spot in the conventional seismic, and an evident amplitude anomaly in the minus 90˚ component. Figure 4 shows a schematic model of the expected response in the case of the Cutral Co Member.

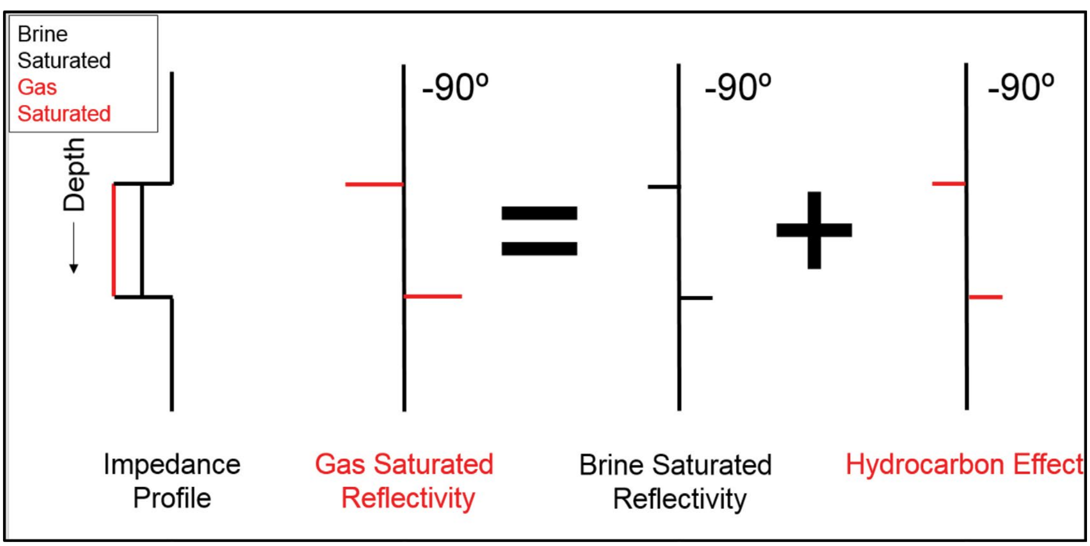

Figure 4. Reflectivity model for a low impedance gas saturated reservoir showing the hydrocarbon effect. The low impedance brine saturated reflectivity shows the effect of the reservoir, that with the added hydrocarbon, generates the gas saturated reflectivity, which is anomalously bright.

RESULTS

Following the workflow presented by Barbato *et al.* (2017), a synthetic model is built to establish the amplitude/frequency/phase relationship (Figure 5). The model shows a suite of well logs measured at the borehole as well as the seismic to well tie. We can also observe 4 panels of synthetic frequency gathers, where the 'offset' axis represents increments of frequency content every 5 Hz. The 'INPUT' panel shows the original synthetic frequency gathers. The other 3 show the results from phase decomposition applied to them, where the 'EVEN' and 'ODD' responses show the amplitude separation between both components. The minus 90˚ component is also shown, as this is the main phase band of interest (given that both the lithology and hydrocarbon responses are expected to be in this component). As observed, the Cutral Co Member is showing an amplitude anomaly in the minus 90˚ component at approximately 15-20 Hz. This is an indication that the seismic dominant frequency required to achieve the optimal tuning thickness to study the attribute's response is close within that range. Higher frequency content would resolve the layer, forcing the top of base of it to act as free interfaces, and moving the energy to the EVEN component. We can also observe other amplitude anomalies in the deeper section of the well that correspond to other targets. These show different dominant frequency because of their different thicknesses.

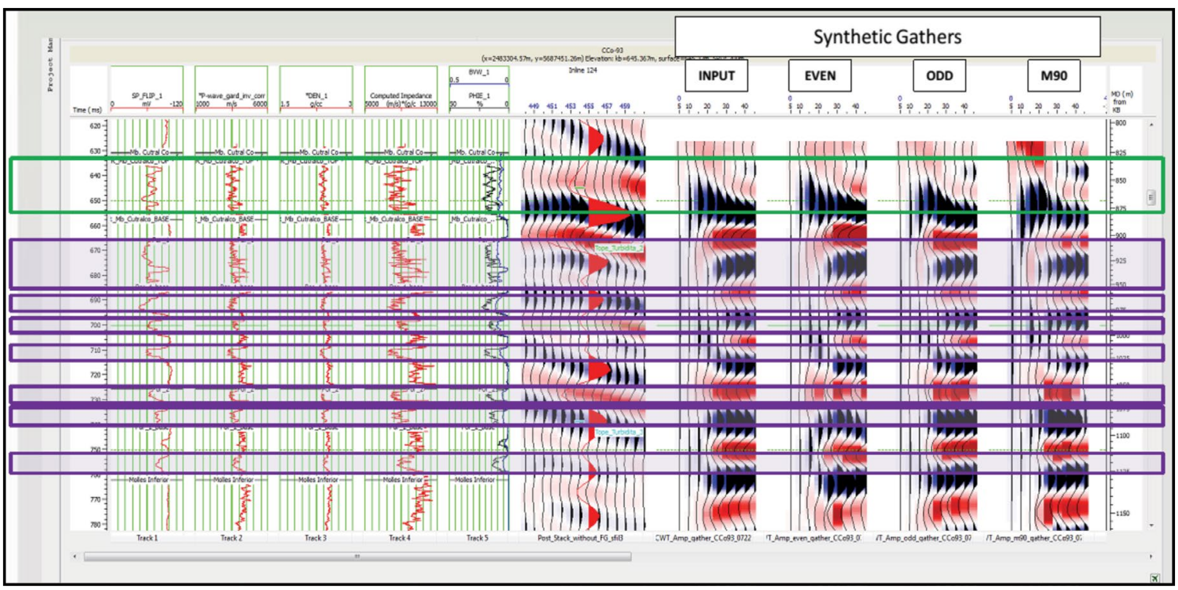

Figure 5. The synthetic gathers do not show a very evident separation between Even and Odd at the target reservoir, the main amplitude difference is between 10 and 20 Hz. The -90˚ component appears to become brighter towards the lower frequency end (5-20 Hz). We can also observe that close to this frequency content we are below resolution of the target sand.

The same workflow is then reproduced seismically. Spectral Decomposition is applied in order to generate the frequency gather and the 20 Hz amplitude component is isolated. Phase Decomposition is later applied to this component. Figures 6, 7, 8, y 9 show the results of the input, even, odd and minus 90° components, respectively, generated from 20Hz central frequency seismic data. As we can observe, bright amplitudes are seismically present through the intervals that the well crosses. The different sands are highlighted by the GR log, and their respective thicknesses are shown. The Even component appears to lose amplitudes with respect to the input (as expected, since these are low impedance gas sands) and most of the energy distribution moves to the Odd component. The minus 90° component further separates the amplitude distribution and we can observe that the gas-producing interval is clearly identified as an amplitude anomaly with respect to background in the section. The other gas-bearing intervals are also present in the section, except the 20m sand, which at this frequency content is too thin for detection. The

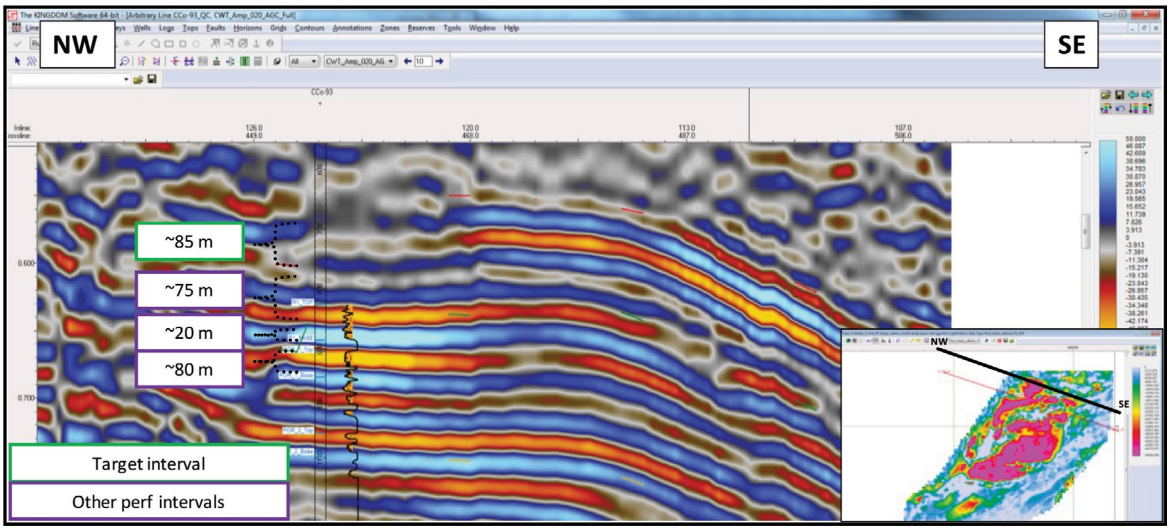

Figure 6. Arbitrary line showing the seismic data's spectral decomposition response at a dominant frequency of 20 Hz. There are amplitude anomalies present in all the observed sands.

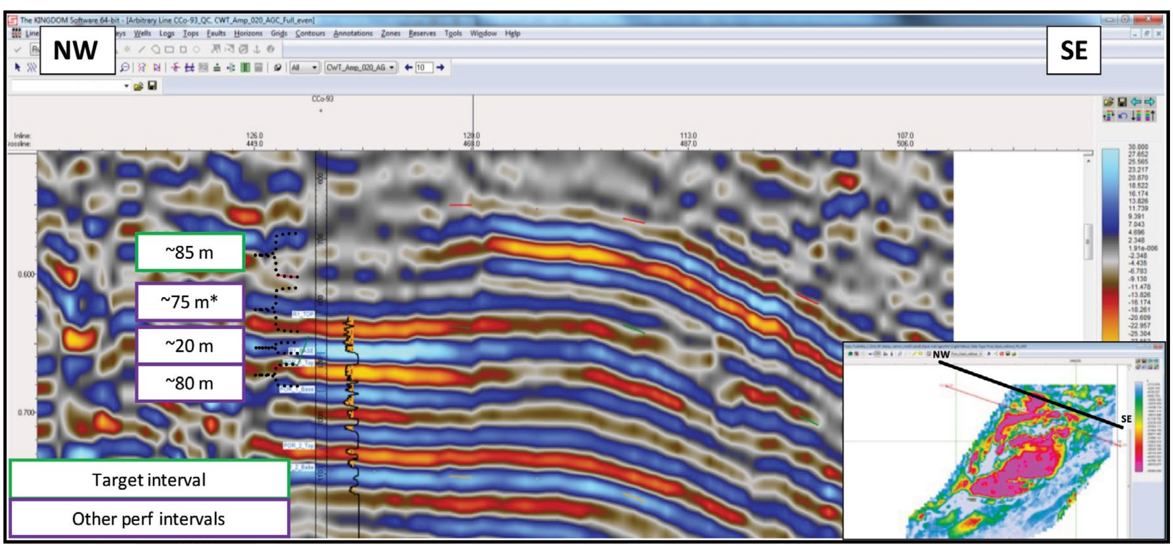

Figure 7. Arbitrary line showing the Even component of the seismic data's spectral decomposition response at a dominant frequency of 20 Hz. There is an amplitude re-distribution as energy moves between phase components.

section shows the stacked sands and how they become more anomalous away from the well, suggesting other potential drilling opportunities.

Amplitude extractions in the horizon of interest show that the amplitude anomaly is present in the input seismic (Figure 10). After the decomposition we can observe a redistribution of energy. This is more evident in the minus 90° phase component, where the turbidite pattern is more noticeable, and the amplitude anomaly crosses the well (as expected). We can also observe an extension of the original amplitude anomaly, as well as more defined amplitude anomalies away from the well. This is an effect of removing interference from other overlying and underlying layers to their corresponding components (figure 11).

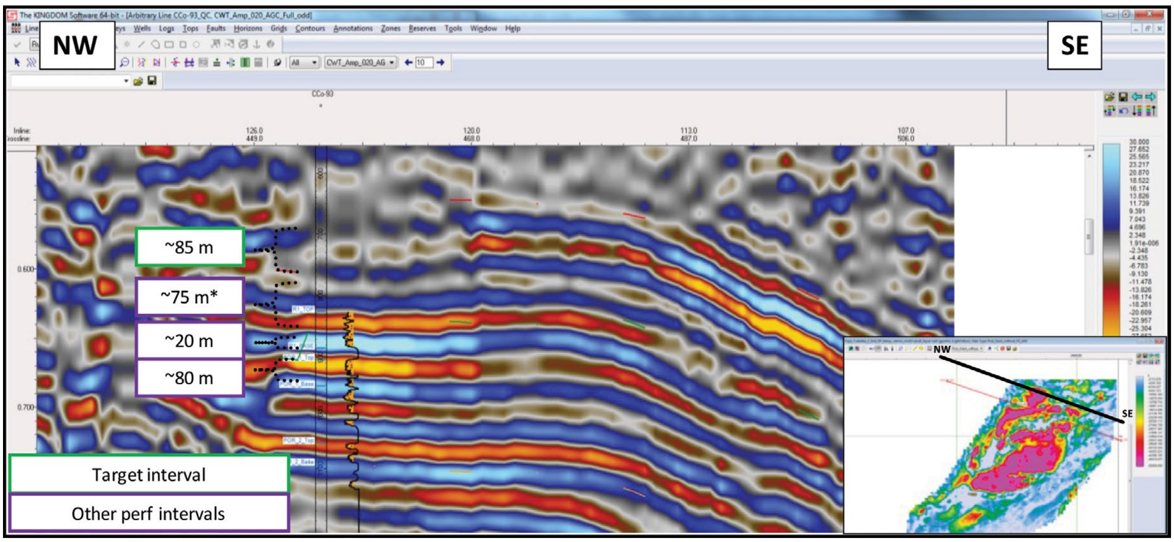

Figure 8. Arbitrary line showing the Odd component of the seismic data's spectral decomposition response at a dominant frequency of 20 Hz. There is an amplitude re-distribution as energy moves between phase components.

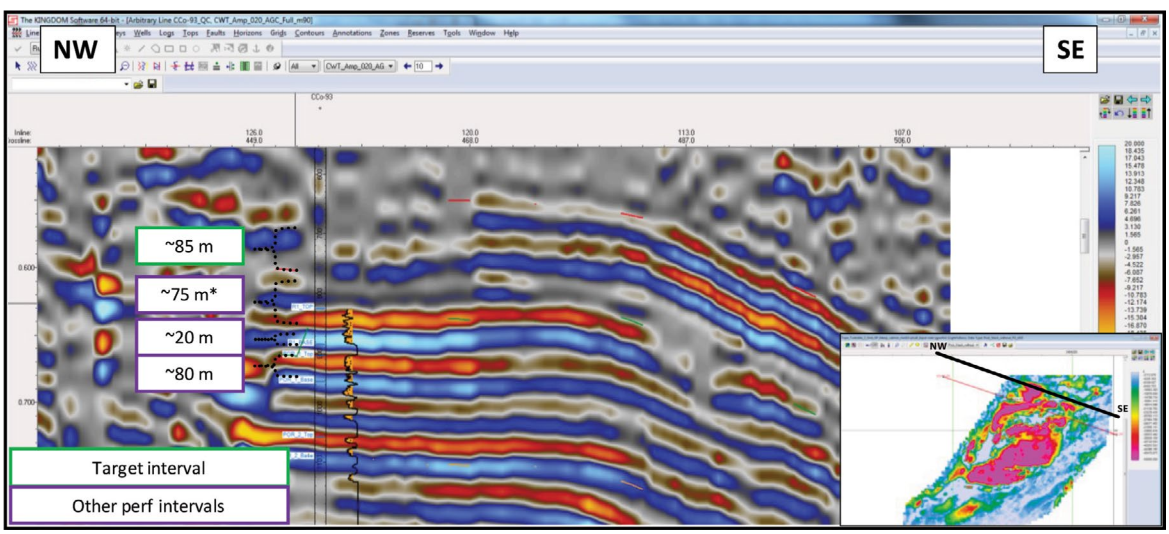

Figure 9. Arbitrary line showing the minus 90° component of the seismic data's spectral decomposition response at a dominant frequency of 20 Hz. The component shows amplitude anomalies at the pay sands present at the well location.

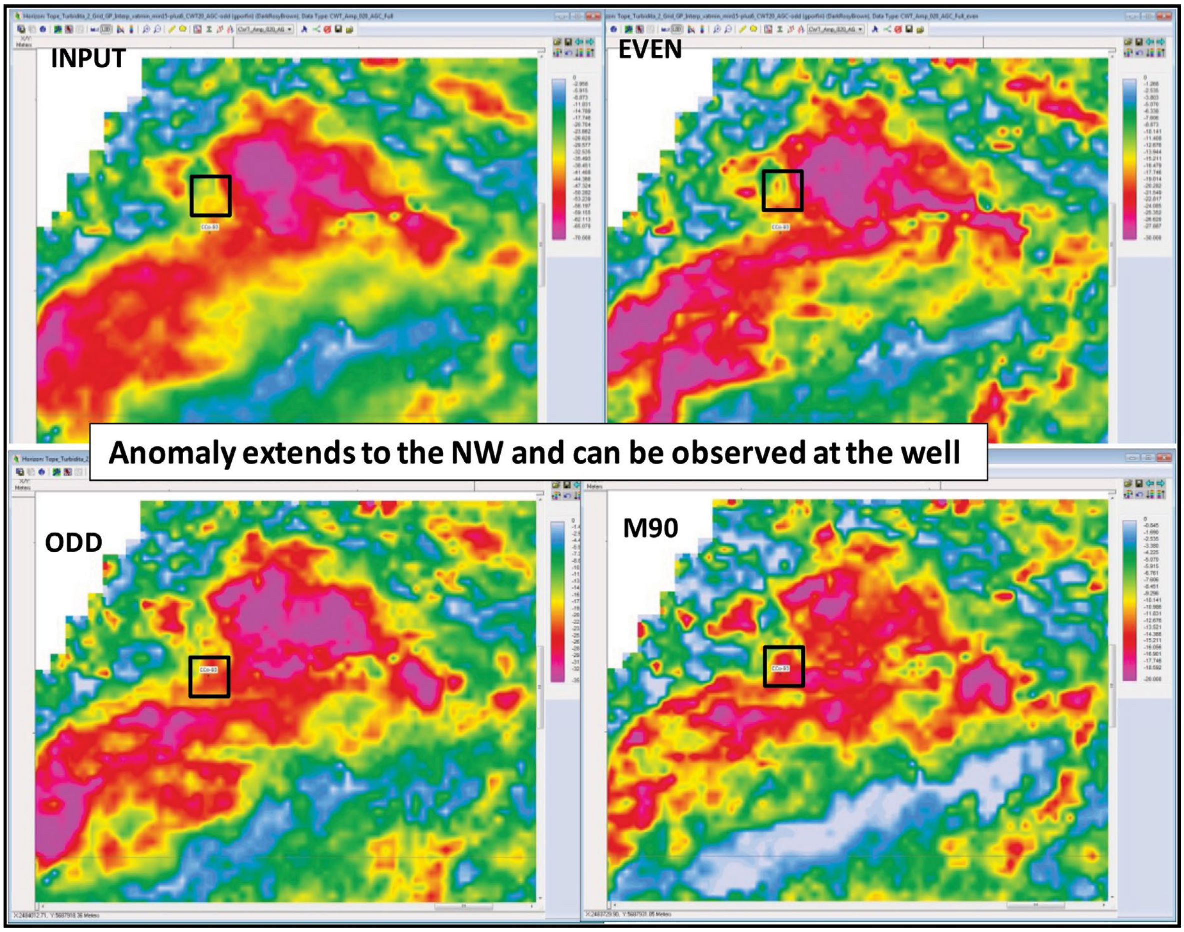

Figure 10. Amplitude extraction at the producing interval along the horizon. The amplitude extractions show an energy re-distribution amongst the phase components. The well (black box) remains within the anomaly (as expected) but the geometries change. As noted, the gas saturated interval is highlighted in the minus 90° component which gives an idea of the areal extension away from the well not apparent on the input seismic data.

CONCLUSIONS

The study of the phase dependent components at 20 Hz central frequency seismic data allowed the recognition of the Cutral Co Member's producing interval at the well location and its interpretation away from the well. In addition, gas-bearing intervals (from the petrophysical evaluation) at the well appeared as bright spots across the section and can work as a guide to look for presence of reservoir-type rocks.

The amplitude extraction maps along the horizon of interest show the anomaly at the minus 90° component which when compared to the input suggests extended areal distribution.

This technique adds insight to the amplitude anomaly distribution interpretation and combined with other tools can be used to detect new opportunities and improve well placement.

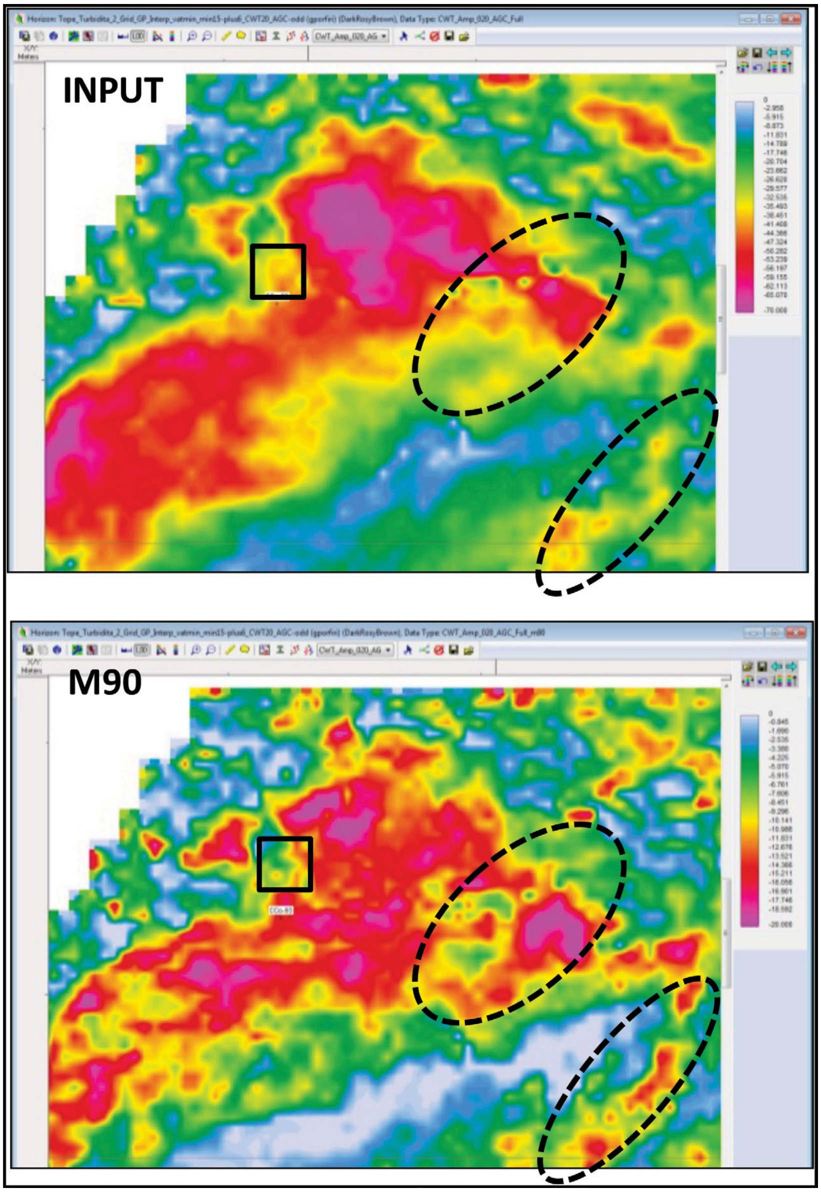

Figure 11. Detailed comparison of amplitude maps along the producing interval of the input seismic data with 20 Hz central frequency (upper image) vs. minus 90° phase component. The amplitude anomaly is present at the well location (black box), and can be mapped away from the well showing new amplitude anomalies to the SE (dotted ovals). These results, when compared to the input anomaly distribution, could be used to detect new opportunities and improve well placement.

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