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# Modeling a fluvial-deltaic reservoir of high structural complexity

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## 1. Introducción

The 3D geological modeling is a technology that has been implemented for some years in certain areas of the Block X, which is located in Talara Basin in northwestern Peru (Figure 1). However, its implementation has not been imposed on 2D models made by hand. This work includes the geological modeling of the Lower Eocene Echinocyamus Fm. in an area covering 140 Km2 (Figure 1).

The problem in the modeling of this reservoir and that has limited its implementation has been the large number of existing faults and their complex truncations, as well as the incorporation of the logs of more than 1200 wells that penetrates the formation or only a part of it. It should be mentioned that we have 3D seismic data of approximately 80 Km2; however, these were low quality seismic data and were not used. Another point is the limited understanding of the depositional trends and their relationship to the quality of rock. Finally, the limited information of wells with porosity logs in the area creates uncertainties in the distribution of petrophysical properties.

To achieve the modeling of Echinocyamus formation, which has a high structural, depositional, and diagenetic heterogeneity, the existing geological complexities were simplified. This allowed us to understand the distribution and extent of the quality of the reservoir rocks.

## 2. Reservoir modeling

### *2.1. Structural Model*

The high structural complexity is controlled by two major normal fault systems (SW-NE and E-W). This intense faulting related to these systems compartmentalizes the reservoir causing multiple structural blocks of different geometries.

The 3D structural framework of the reservoir was generated modeling faults of considerable vertical displacement and incorporating litho-stratigraphic tops of 426 wells with complete stratigraphic section. This was done to greatly reduce the structural complexity resulting in the generation of structural mega blocks. Figure 2 shows the distribution of the mega blocks that comprise the Echinocyamus formation.

### *2.2. Sedimentological and stratigraphic Model*

From the description of 12 cores in the area, two depositional domains were established: a deltaic domain, where prodelta, delta front and delta plain sub environments were recognized; and a fluvial domain, composed mainly of bars and channel-fill deposits (Daudt, 2006; Daudt & Scherer, 2006, Schlumberger, 2008).

The construction of the stratigraphic framework of the Echinocyamus formation was based on the identification of sequence stratigraphy surfaces and stacking pattern analysis in well logs; the result was the definition of three genetic sequences (sensu Catuneanu et al., 2011) of four-order resolution (sensu Gabaglia Raja et al., 2006) (Figure 3). The lower genetic sequence, called Clavel-Cabo Blanco, is composed of shelf deposits generated during highstand normal regression at the bottom and at the top by fluvial deposits generated during lowstand normal regression changing to transgressive deposits towards the top. The middle sequence, called Verde-Somatito, consists of coarsening upward cycles (parasequences sensu Wagoner et al., 1990) that comprise progradational deltaic successions deposited during highstand normal regression at the bottom; the top of this sequence consists of fluvial deposits generated during lowstand normal regression changing to transgressive deposits towards the top. The upper sequence, called Ballena, consists of deltaic deposits that correspond to highstand normal regression truncated at the top by an unconformity that marks the end of the Eocene (48.5 Ma, Pozo, 2002).

The sedimentological interpretation was extrapolated to each studied well by creating two electrofacies logs associated with the interpreted depositional domains and sub environments. The first comprises the electrofacies Fluvial and deltaic; and the second, the electrofacies Channels & bars, overbank, Prodelta, Delta front, and Delta Plain. Sequence stratigraphy surfaces were also extrapolated to the wells by correlation of logs.

Electrofacies logs and different stratigraphic maps made for each genetic sequence were used to determine the extent and distribution of depositional elements of the reservoir. For example, Figure 4 shows the predominance of fluvial deposits over deltaic deposits in the studied area. These electrofacies logs and maps were also used to condition the modeling of depositional heterogeneities between wells using the Truncated Gaussian Simulation technique (TGS). The results are shown in Figure 4.

### *2.3. Quality rock model*

The reservoir rocks of the Echinocyamus formation correspond to the feldspathic litharenite sensu Folk (1968). The main component of this reservoir is quartz, followed by physically and chemically unstable materials such as volcanic lithic fragments, feldspar and plagioclase. The quality of these rocks is strongly controlled by various diagenetic processes, which were widely studied by Daudt (2009). The most important diagenetic products that cause a negative impact on the porosity and permeability are illite-smectite generation, occurrence of albite by replacement of feldspar, and occurrence of pseudo matrix. Petrophysical studies for reservoir rocks of this formation show that porosity values vary from 5 to 16% and permeability from 0.1 to 5md.

To characterize and classify the quality of rock to an operational scale, spontaneous potential, gamma ray, porosity and borehole image logs were studied and were integrated with core data (Figure 5). This allowed us to identify permo-porous intervals in wells giving rise to an electrofacies log comprising three rock types referred to S_Reservoir, corresponding to good quality sandstones; S/F_Reservoir, corresponding to mainly regular to poor quality sandstones; and F_NR corresponding to non-reservoir facies (left in figure 5). Each of these electrofacies has a porosity and permeability distribution which was calibrated using core data and well logs.

The rock quality model (right in figure 5) is composed of the rock type model, populated from the Sequential Indicator Simulation technique (SIS); the porosity model, using the Sequential Gaussian Simulation technique (SGS); and permeability model, obtained by porosity-permeability relationships for each rock type associated with a type of depositional domain. Additionally a cumulative flow capacity ($\sum kH$) model (Figure 5) was generated; this model represents the sum of the products of the permeability by the thickness of each cell.

## 4. Classification of zones

From the structural, depositional and rock quality models, 5 zones were delimited and are shown in table 1. Each of these zones has a unique heterogeneity, highlighting zones II and III, which have favorable structural and depositional features. Table 1 also shows that rock quality from zone I is regular to poor, this is mainly attributed to the depositional component. The poor rock quality in zones IV and V is mainly controlled by the structural component.

## 5. Conclusions

The depositional and structural components positively impact the central part of the area, as they present greater thicknesses of reservoir rocks of fluvial environment with a better quality of rock than in deeper blocks. In the southwestern part, more restricted intervals of reservoir rocks are presented; however, good to regular quality of rock is still preserved. The impact on the quality of rock of the lowest structural blocks in the east of the area is attributed directly to overburden pressure, despite having high net to gross values.

## Acknowledgments

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## Illustrations

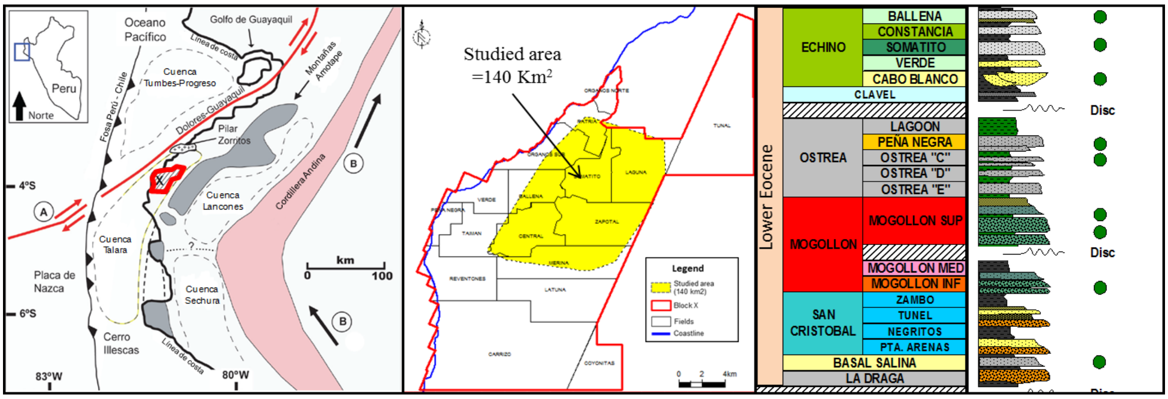



**Figure 1.** Location of Block X (left), study area (center) and stratigraphic column of the Echinocyamus formation (right).

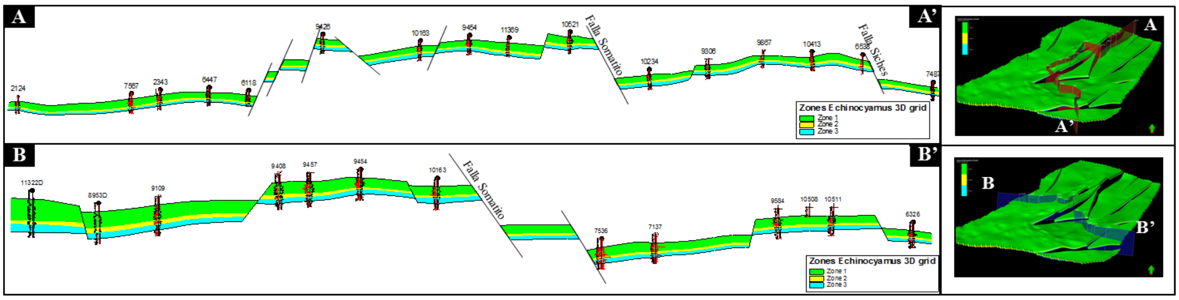



**Figure 2.** Longitudinal and transverse section depicts the distribution of the mega blocks of the Echinocyamus formation.

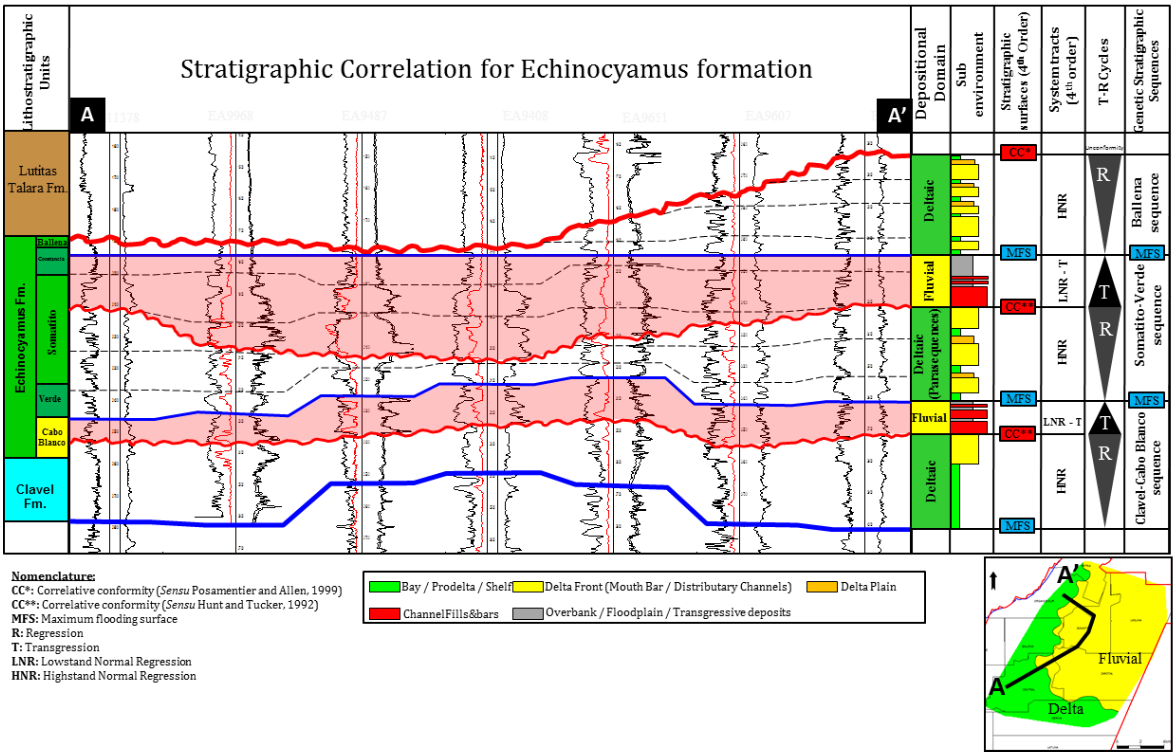



**Figure 3.** Genetic sequence model for the Echinocyamus formation.

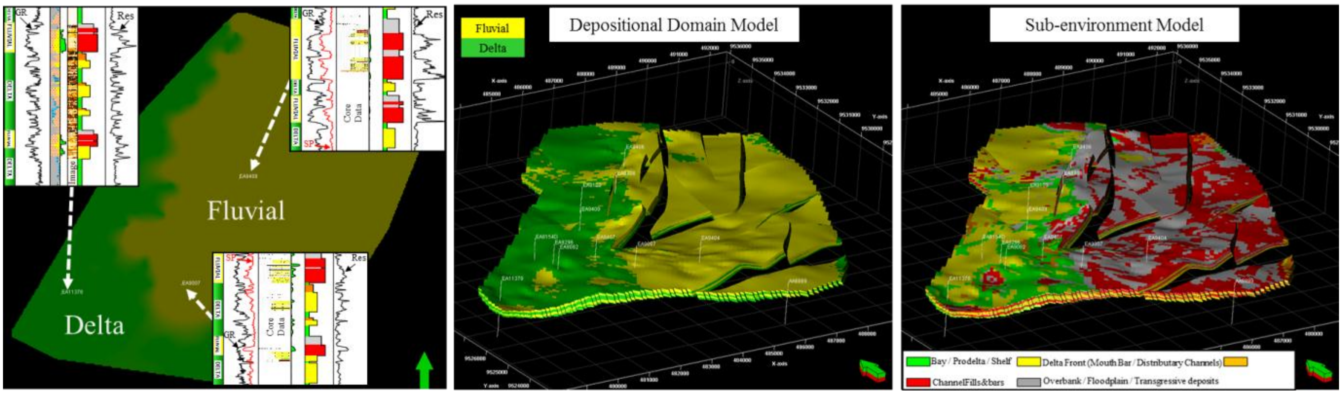



**Figure 4.** Predominance of depositional environments (left), depositional domains model (center) and depositional sub environments model (right).

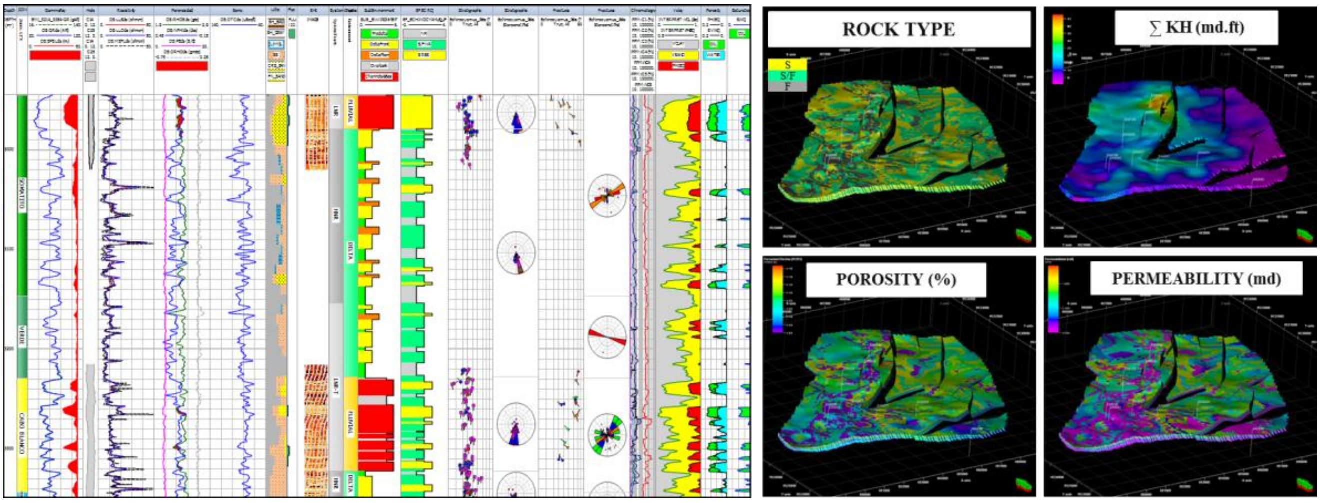



**Figure 5.** Integration of well logs for the classification of rock type (left). Quality rock model composed of rock type, porosity, permeability and cumulative flow capacity models (Right).

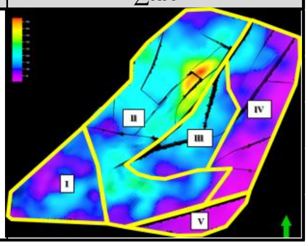
| Zone | Structural Component | Depositacional Component | NTG | RockQuality | Cumulative flow capacity ∑kH |
|---|---|---|---|---|---|
| I | High (-1000 a -1500) | Delta | Low to medium (0.32-0.43) | Good to Regular |  |
| II | High (-800 a -1800) | Fluvial-Delta | Medium to high (0.52-0.79) | Good | |
| III | Medium (-2000 a -2800 | Fluvial | High (0.65-0.78) | Good to Regular | |
| IV | Low (-3000 a -4500) | Fluvial | High (0.67-0.76) | Poor | |
| V | Low (-3200 a -4500) | Delta | Medium (0.45-0.55) | Poor | |

**Table 1.** Summary of reservoir characteristics for each defined zone.