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Simposio de Evaluación de Formaciones: Maximizando la eficiencia a través de la innovación

SEDIMENTOLOGICAL CHARACTERIZATION BY NEW TECHNOLOGY INTEGRATED WIRELINE TOOLS IN DOBOKUBI FIELD, VENEZUELA

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RESUMEN

El yacimiento Dobokubi, ubicado al oriente de Venezuela, ha sido objeto de diversas interpretaciones de ambientes depositacionales y modelos geológicos debido a su complejidad, lo cual ha ocasionado dificultades importantes a las empresas operadoras a la hora de ejecutar el desarrollo del mismo. Las caracterizaciones previas han definido un sistema fluvio-deltaico, presentando inconsistencias referidas a la litología, tamaño de grano, índice de escogimiento y adelgazamiento de arenas prospectivas, lo que ha causado no solo una subestimación de las reservas, sino además, problemas durante la perforación de los pozos causados por falta de estabilidad de hoyo. Adicionalmente, se presentan dificultades en el seguimiento de los cuerpos de arenas de interés a lo largo de las ubicaciones propuestas debido a su falta de continuidad lateral.

La metodología aplicada en la construcción de una caracterización sedimentológica, mediante registros de guaya eléctrica, ha sido basada en la recopilación de información de cada pozo disponible (ubicación, litología, análisis petrofísico, presiones de formación, muestras de fluidos y descripción de coronas). Seguidamente se elaboró el procesamiento y la interpretación de todas las imágenes microresistivas disponibles para obtener las principales características sedimentológicas de los cuerpos de interés. Luego se llevó a cabo la identificación de facies, que requirió una interpretación sedimentológica detallada de las coronas existentes en el campo. Posteriormente, se realizó una caracterización multidisciplinaria de las facies definidas para identificar cuales presentan las mejores propiedades petrofísicas (facies de prospectivas) utilizando los registros de nuevas tecnologías de guaya eléctrica. Se continuó con la elaboraron correlaciones tomando en consideración las interpretaciones sedimentológicas llevadas a cabo en los pozos con coronas. Finalmente se identificaron las asociaciones de facies a través de los pozos y se desarrolló un nuevo modelo sedimentológico para el área de estudio.

El modelo sedimentológico anteriormente definido para este yacimiento ha sido reinterpretado como un modelo de depósitos hiperpicnicos, el cual ha cambiado el entendimiento de la extensión lateral, las geometrías, la orientación y la continuidad de los cuerpos de areniscas en Dobokubi. Esta reinterpretación ha introducido éste yacimiento como un objetivo exploratorio importante en el campo. Por lo tanto, el modelo propuesto proporciona gran parte de las soluciones a los problemas presentados por el operador del yacimiento, siendo este un modelo de depositación más óptimo y realista que coincide en gran medida con la evidencia geológica de los pozos del área.

Esta metodología representa una técnica para determinar con precisión los límites de las unidades litológicas, tipo de roca mediante la caracterización mineralógica, así como identificar las facies con las mejores propiedades petrofísicas, tipo de fluido y sus propiedades correspondientes.

INTRODUCTION

Dobokubi field is located in the northeastern part of Ayacucho Block, San Tomé Area in the Orinoco Belt, Maturin sub-basin (Fig. 1). The surface is approximately 542 squared-kilometers. It is one of the most significant reservoirs for production of hydrocarbons in the Orinoco Belt and represents the main interest for operators today.

Previously, the depositional environment of the Merecure Formation in the field was interpreted as being deposited in a fluvio-deltaic depositacional system, in which the sediments were deposited by fluvial flows (González de Juana *et al.*1980).

The main body in of the Merecure Formation has was interpreted as a fluvio-deltaic distributary channel accumulation. This interpretation led to several problems in explaining the occurrence of these sandstones, because in these zones we found as massive sandstones intervals, where it does not without have a clear genetic origin in the fluviodeltaic model for these sequences. However, there is a model that could explain the massive sands deposits, and existence. This model this is the hyperpycnal system.

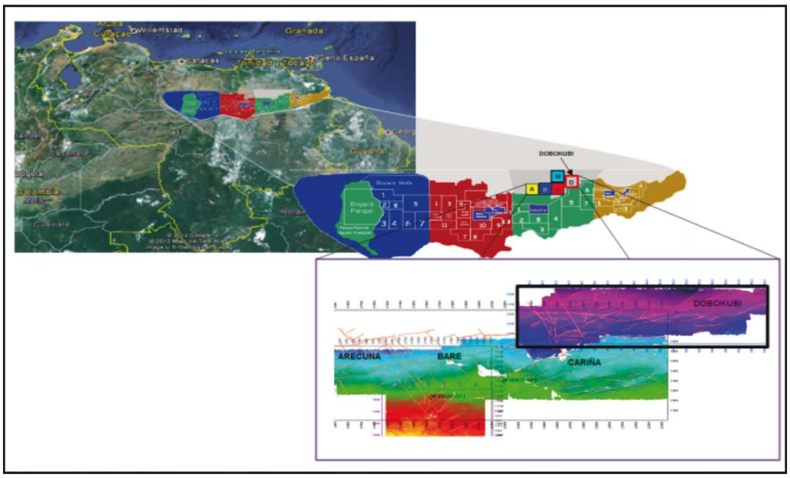


Figure 1. Dobokubi field location in the northeastern area of Ayacucho Block.

Recently, based on facies analysis from cores, most of the thick massive sandstone sequences have been reinterpreted as being deposited by sustained fluvial-derived hyperpycnal flows. Hyperpycnal flows originate when sediment-laden fluvial discharges plunge below the receiving water body due to their excess in density (Bates 1953; Mulder *et al.* 2001), mainly during a flood. During these periods, huge volumes of clastics are often transferred to the basin by subaqueous extension of the fluvial system: the hyperpycnal system (Zavala *et al.* 2006). The resulting deposits are hyperpycnites and constitute a type of long-lived, quasi-steady turbidite flow deposit having poorly known facies and facies associations.

Even though ancient hyperpycnal deposits are poorly documented in the literature, some advances have appeared in recent publications regarding ancient and modern successions (Mulder *et al.* 2001; Mulder *et al.* 2003; Zavala *et al.* 2006). Recently, hyperpycnal flows are receiving more attention as efficient mechanisms for transporting enormous quantities of sands to a basin (Mutti *et al.* 1996; Mulder *et al.* 2001; Gamero *et al.* 2005; Zavala *et al.* 2006).

A new genetic facies tract was proposed for hyperpycnal systems in marine settings (Zavala *et al.* 2011, Zavala 2008). Within this facies tract, hyperpycnal-related facies are classified according to the main processes active during the accumulation of hyperpycnites, from bed load (B facies), suspended load (S facies), and lofting (L facies) (Fig. 2). B facies accumulate in proximal areas because of shear forces from the overpassing turbulent flow, whereas L facies mainly develop at flow margin (levee) areas. S facies, however, are related to the progressive collapse and accumulation of turbulent-suspended materials when the flow progressively wanes in medium to distal areas. Consequently, quantifying the relationship between these three categories of genetically related facies allows determination of the position of a given hyperpycnite section within the entire depositional system. This genetic facies model was followed in this study for the analysis of the Dobokubi field.

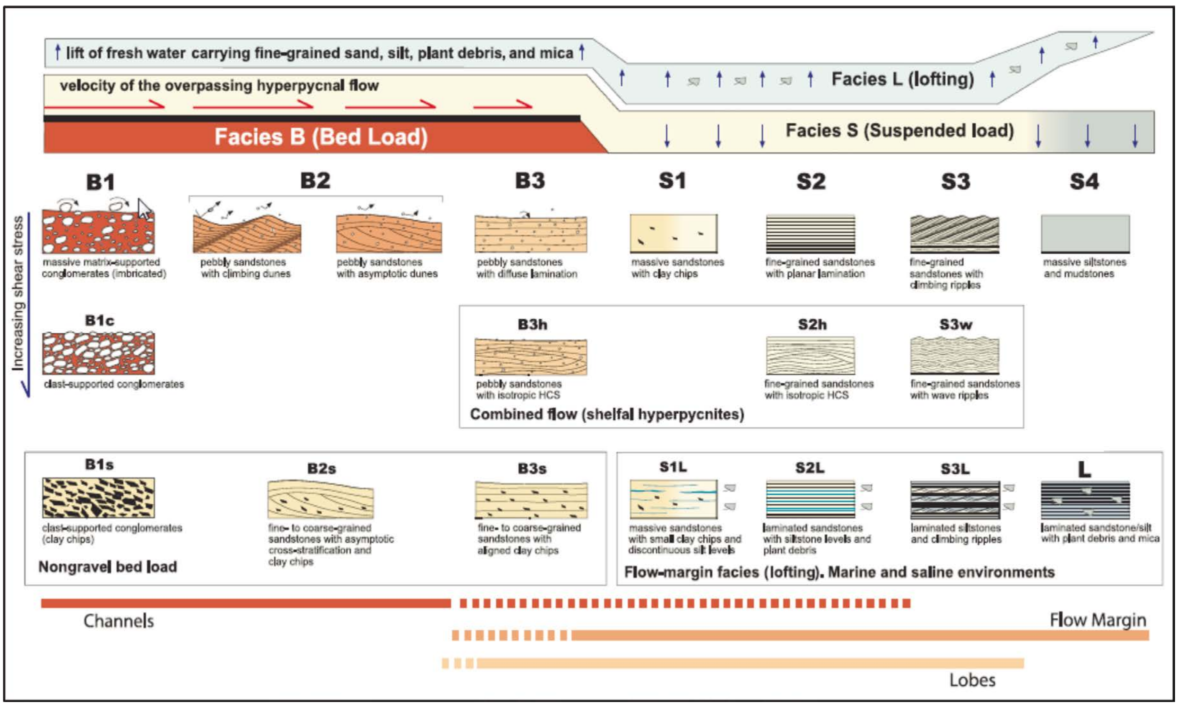


Figure 2. Genetic facies tract for the interpretation of hyperpycnal deposits (Zavala, 2008; Zavala *et al.* 2011).

The hyperpycnal facies model (Fig. 3) derived from studies of the Columbus Basin, Trinidad (Gamero *et al.* 2011) serves as an accurate analog for the interpretation of Merecure formation in Dobokubi field. The model suggests that the origin of the B4 sandstone could be related to the paleo-Orinoco River-related product of turbidity (hyperpycnal).

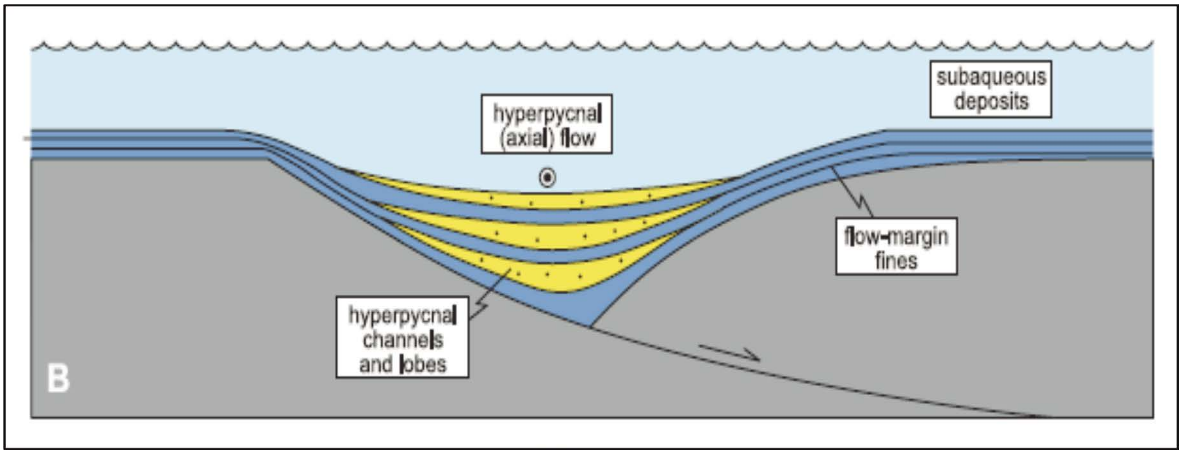


Figure 3. Hyperpycnal model in Pliocene sandstones in the Oilbird field, Southeast coast, Columbus basin, Trinidad (Gamero *et al*. 2011).

Borehole images provide high-resolution information on the layering, texture, and dip of rocks and sediments and permit core-like description of subsurface reservoirs. A proper integration of the electrical images with the conventional and advanced logs could provide an extremely powerful tool for reservoir characterization.

GEOLOGICAL FRAMEWORK

The study area covers approximately 542 squared-kilometers and is located within the Maturin subbasin, which forms the eastern part of the eastern Venezuela basin. The sedimentary fill of this basin consists of about 9000 m [29,500 ft] of marine and continental deposits accumulated in a passive margin setting (Cretaceous–Eocene) followed in the post-Eocene by a compressive foreland basin related to the oblique collision of the Caribbean plate against the South American plate. This oblique collision zone migrated progressively eastward during the late Oligocene–earliest Miocene, dividing the foreland basin into three areas: (1) a southern platform area, (2) a central foredeep, and (3) a northern region overthrust area (Parnaud *et al.* 1995). As a consequence of major foreland basin subsidence, a very thick succession of clastic sediments accumulated during the Oligocene and Miocene following a roughly east-west elongate depocenter. These clastic deposits consist of a basal coarse-grained succession (Merecure formation) followed in sharp contact by deep-marine fine-grained accumulations (Carapita formation). The Merecure formation is composed of up to 500 m (1640 ft) of alternating fine- to coarse-grained sandstones and shales. These sandstones of the Merecure formation grade northward into a fine-grained succession (Areo formation), interpreted as outer-shelf deposits (Stainforth 1971; Parnaud *et al.* 1995). These clastic deposits were mostly sourced from the cratonic Guyana shield located to the south. The Merecure formation is partially equivalent to the Naricual Formation, which corresponds to coarse-grained deposits supplied from the north that accumulated close to an early uplifted and deformed mountain front or "serrania" (Fig. 4) (Parnaud *et al.* 1995).

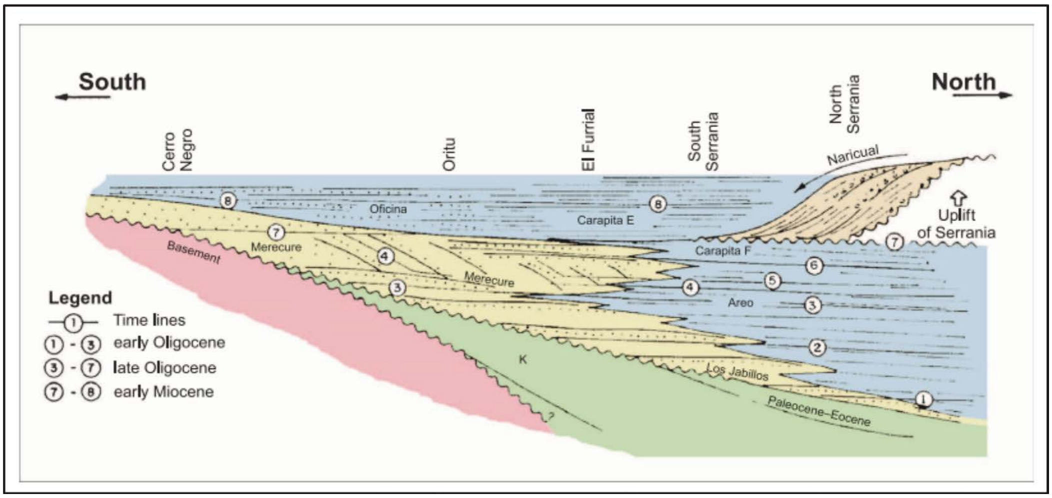


Figure 4. Conceptual regional cross section showing the deposition of Oligocene and early Miocene sediments. After Parnaud *et al.* (1995). K = Cretaceous.

MERECURE FORMATION IN DOBOKUBI FIELD CHALLENGES

The complexity of the structural architecture of Dobokubi field is the main reason for the interpretations of its depositional environment. Because of these different interpretations, different geological models have been created for this field.

In the last years, the operator has faced some operational difficulties in trying to apply the previous sedimentological characterization for Merecure formation in Dobokubi field as a fluviodeltaic depositional system. Among the inconsistencies and the operational issues raised are the following:

- Lithology, grain size, shape, and sorting.
- Presence of dispersed clays or other minerals.
- Prospect sands thinning in Dobokubi field causing underestimation in the reserves calculation.
- Optimization problems at proposed locations in the Merecure formation in Dobokubi field resulting from lateral loss of the sand of interest so that the operator cannot get a good prognosis for wells drilled.
- Wellbore stability problems increasing operational costs.

Recent advances in the understanding of a new category of clastic depositional system, termed a hyperpycnal system, have provided a new frontier for the understanding of clastic facies in marine and lacustrine environments. A new sedimentological characterization has been proposed for the Merecure formation in Dobokubi field integrating core data, borehole images, and petrophysical and reservoir analysis. Sedimentological evidence suggests that the origin of the sandstones in the Merecure formation in Dobokubi field could be related to fluvial-derived hyperpycnal flow deposits.

The previous fluvio-deltaic sedimentological model was changed in the Merecure formation in Dobokubi field into a hyperpycnal depositional model. As a consequence, there were changes in the interpretation of lateral extension, geometries, orientation, and continuity of the Merecure reservoir sands; this concept has reintroduced the Merecure formation as an exploratory target in this field. The hyperpycnal depositional model provides the answers to the interpretation problems in this field, being a modern and more realistic depositional model that matches very well with the reservoir geology.

HIGH TECHNOLOGY TOOLS APPLIED

Geology tools

Fullbore Formation Microimager

The formation micro-imager is a microlaterolog scanning tool that records micro-laterolog images with a vertical resolution of 5 mm from 192 electrodes placed on eight tool pads (Fig. 5). Borehole images provide high-resolution information on the layering, texture, and dip of rocks and sediments and permit core-like description of subsurface reservoirs. They reveal laminations and heterogeneity, which are not captured on most of the petrophysical logs due to poorer vertical resolution. Borehole images can provide the interpreter with a wealth of information uniquely useful to interpret sedimentary textures and structures, depositional and diagenetic fabrics, and structural and stratigraphic evolution of subsurface reservoirs.

Figure 5. Fullbore formation microimager pad and flap.

Petrophysical Tools

Elemental Capture Spectroscopy Sonde

The most valuable tool for mineralogical analysis is the elemental spectroscopy sonde (Fig.

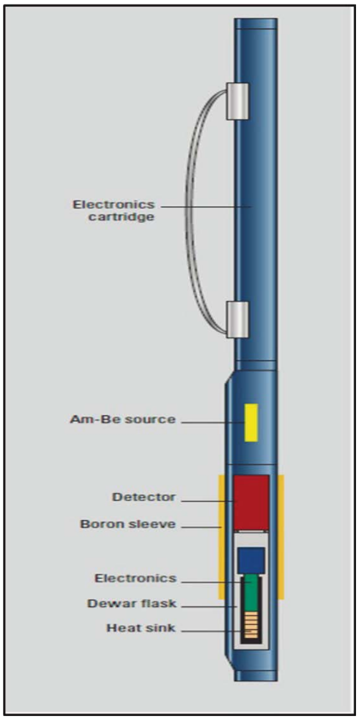


Figure 6. Elemental Capture Spectroscopy Sonde.

6). The elemental capture spectroscopy measurement provides valuable information regarding the clay content and main mineral concentrations within the formations; it also provides estimation of matrix density, which enables calculation of porosity corrected for grain density.

Expert Magnetic Resonance Service

An advanced magnetic resonance tool (Fig. 7) was run to acquire a saturation profile, which provides diffusion-based fluid typing as a continuous depth log with three independent depth of investigation. An additional advantage of the technology in heavy oil reservoirs is that it allows distinguishing free formation water from the filtrate in the oil-bearing sands and thus provides critical input to production planning.

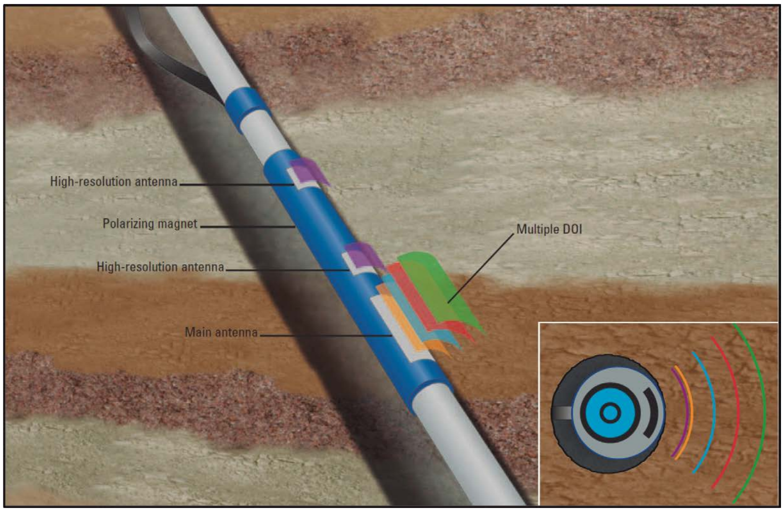


Figure 7. Expert Magnetic Resonance tool.

Multifrequency Dielectric Dispersion Service

The multifrequency array dielectric tool (Fig. 8) provides salinity-independent measurement of water-filled porosity and enables shallow and deep zone analysis. Oil-filled porosity is defined by the difference between total porosity and dielectric water-filled porosity, additionally to which, in the wells drilled with water-based mud (WBM), the difference between shallow and deep porosity in the oil-bearing zones provides an indicator of movable hydrocarbon and helps to identify most prospective intervals for production.

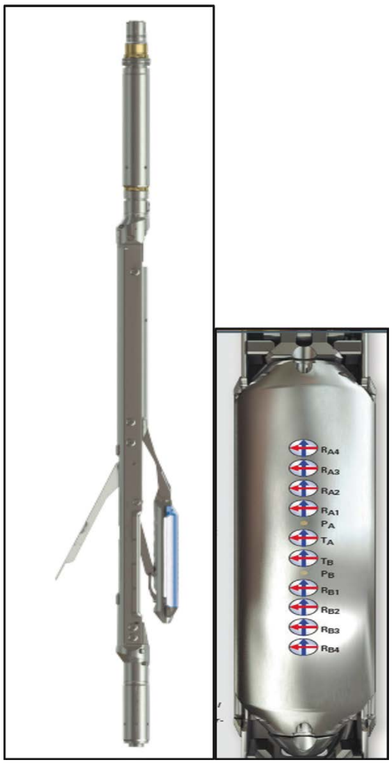


Figure 8. Multifrequency dielectric dispersion service and pad antenna configuration.

Reservoir

Wireline Formation Testing Measurement

Wireline formation testing measurement (Fig. 9) has long been recognized as important for collecting essential dynamic data information for reservoir engineering such as: accurate real time formation pressures measurements and mobility estimation, reservoir downhole fluid analysis and sampling and permeability estimation, among other applications.

Figure 9. Wireline Formation Testing tool.

METHODOLOGY

The methodology applied in building a sedimentological characterization with new-technology integrated wireline tools to the Merecure formation in Dobokubi field incorporated the following steps:

- Gathering field information. In this step, the relevant and necessary information that was available for each well in the field from high-technology logs (location, lithology, petrophysical analysis, reservoir analysis, and core analysis) was gathered for an accurate sedimentological characterization.
- Borehole image processing and interpretation. This step involved the processing and interpretation of all available borehole images in the field from the fullbore formation microimager data. The data were processed and interpreted to obtain the main sedimentological features in the resistivity images. The images provide detailed sedimentary information for all rock types, which is a great value for sedimentological modeling.
- Facies identification and analysis. This step involved the sedimentological interpretation of well cores available in the field to understand the depositional origin of these sediments and predict their distribution and continuity.
- Prospect facies characterization. Interpretations from different domains (geology,

petrophysics, and reservoir engineering) were integrated to identify the facies with the best properties (prospect facies). The data used were from the new-technology wireline tools for elemental capture spectroscopy, magnetic resonance, multifrequency dielectric dispersion, fullbore formation microimages, and wireline formation testing measurement (Fig. 10).

- Well log geological correlation. Well log correlation provided the means to extend the sedimentological interpretation on the cored well to the remaining wells in the field to refine the existing correlation.
- Model development. Identification the facies associations across the wells was used in the development of a new depositional model.
- Results analysis. The results were analyzed and the analysis highlighted the key findings of this investigation that enabled a new sedimentological characterization based on interpretation of measurements from new-technology integrated wireline tools.

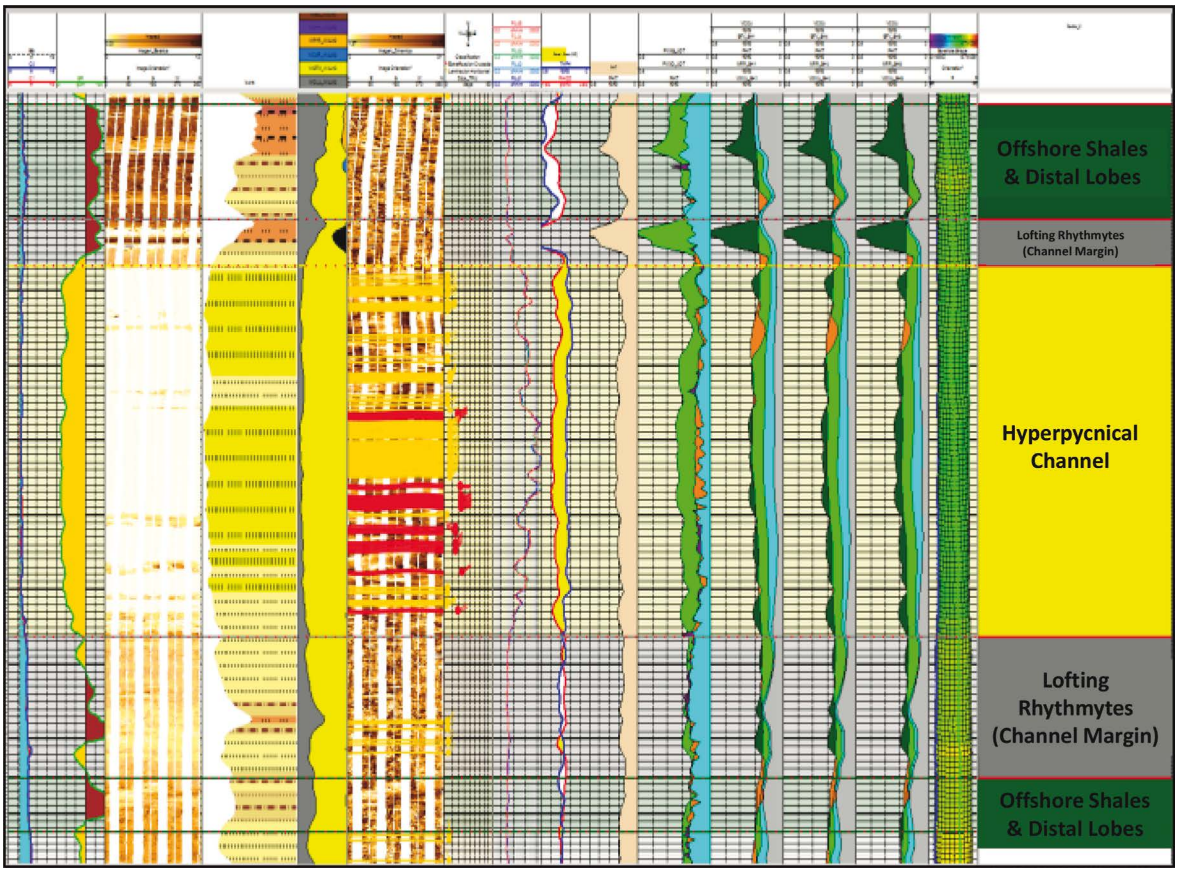
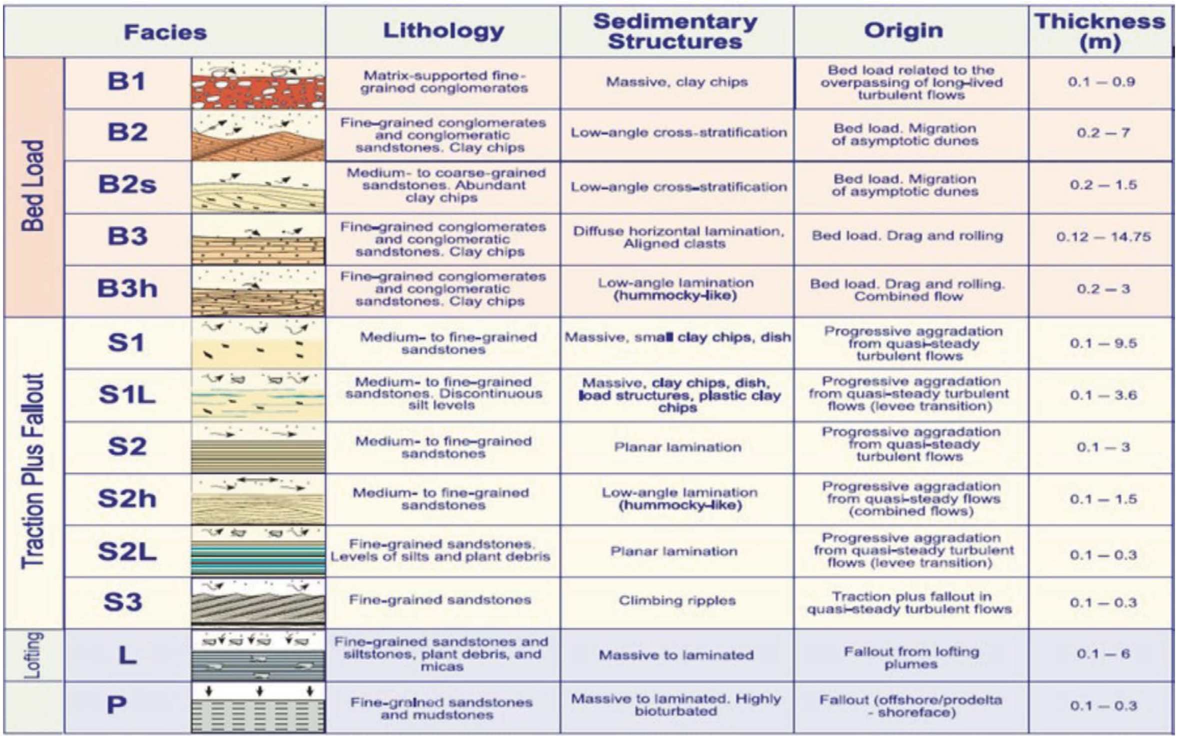


Figure 10. Integration using new-technology wireline tools.

Facies Identification

Borehole images were calibrated to core data. This enabled us to develop borehole-image criteria for a variety of sedimentary structures and stratification styles and to identify depositional facies. Facies classification was done using the genetic and predictive facies analysis of hyperpycnal systems (Zavala *et al.* 2011). The 12 hyperpycnal facies types can in turn be grouped into B, S, and L processes and deposits. The characteristics of the identified facies are summarized in Fig. 11.



Facies		Lithology	Sedimentary Structures	Origin	Thickness (m)
Bed Load	B1	Matrix-supported fine-grained conglomerates	Massive, clay chips	Bed load related to the overpassing of long-lived turbulent flows	0.1 – 0.9
	B2	Fine-grained conglomerates and conglomeratic sandstones. Clay chips	Low-angle cross-stratification	Bed load. Migration of asymptotic dunes	0.2 – 7
	B2s	Medium- to coarse-grained sandstones. Abundant clay chips	Low-angle cross-stratification	Bed load. Migration of asymptotic dunes	0.2 – 1.5
	B3	Fine-grained conglomerates and conglomeratic sandstones. Clay chips	Diffuse horizontal lamination. Aligned clasts	Bed load. Drag and rolling	0.12 – 14.75
	B3h	Fine-grained conglomerates and conglomeratic sandstones. Clay chips	Low-angle lamination (hummocky-like)	Bed load. Drag and rolling. Combined flow	0.2 – 3
Traction Plus Fallout	S1	Medium- to fine-grained sandstones	Massive, small clay chips, dish	Progressive aggradation from quasi-steady turbulent flows	0.1 – 9.5
	S1L	Medium- to fine-grained sandstones. Discontinuous silt levels	Massive, clay chips, dish, load structures, plastic clay chips	Progressive aggradation from quasi-steady turbulent flows (levee transition)	0.1 – 3.6
	S2	Medium- to fine-grained sandstones	Planar lamination	Progressive aggradation from quasi-steady turbulent flows	0.1 – 3
	S2h	Medium- to fine-grained sandstones	Low-angle lamination (hummocky-like)	Progressive aggradation from quasi-steady flows (combined flows)	0.1 – 1.5
	S2L	Fine-grained sandstones. Levels of silts and plant debris	Planar lamination	Progressive aggradation from quasi-steady turbulent flows (levee transition)	0.1 – 0.3
	S3	Fine-grained sandstones	Climbing ripples	Traction plus fallout in quasi-steady turbulent flows	0.1 – 0.3
Lofting	L	Fine-grained sandstones and siltstones, plant debris, and micas	Massive to laminated	Fallout from lofting plumes	0.1 – 6
	P	Fine-grained sandstones and mudstones	Massive to laminated. Highly bioturbated	Fallout (offshore/prodelta - shoreface)	0.1 – 0.3

Figure 11. Main characteristics of the sedimentary facies identified in the Merecure formation from core studies (Zavala *et al.* 2011).

Facies Related to Bed-Load Processes (B Facies)

Type B facies include different coarse-grained deposits related to shear/drag forces exerted by the overpassing long-lived turbulent (hyperpycnal) flow over coarse-grained materials lying on the flow bottom. Three main categories of B facies are recognized, here termed B1, B2, and B3 (Gamero *et al.* 2011).

The B facies category includes coarse-grained sandstones and fine-grained conglomerates with abundant sandstone matrix. Main facies types of this category are massive (B1 facies; Fig. 12), low angle cross-bedded (B2 facies; Fig. 13), and roughly laminated (B3 Facies; Fig. 14) coarse grained deposits, commonly composing thick beds showing gradual and recurrent facies changes (Gamero *et al.* 2011).

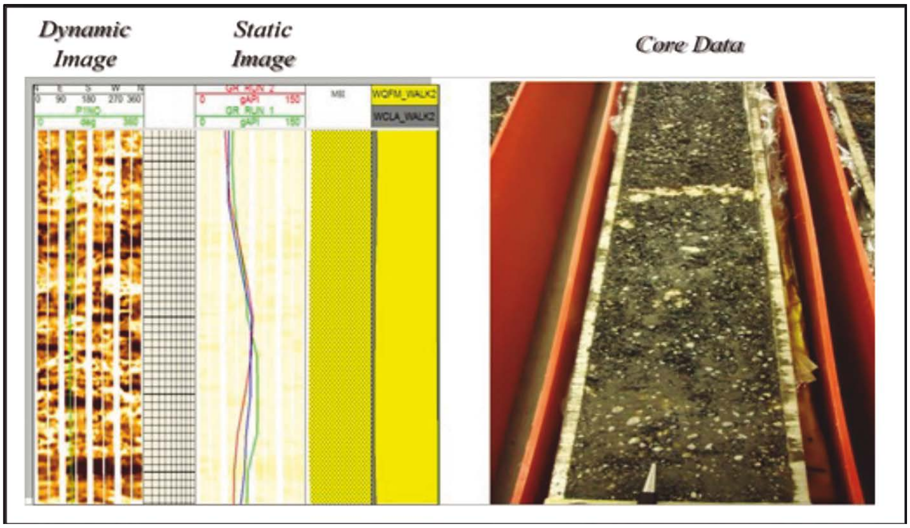


Figure 12. B1 facies.

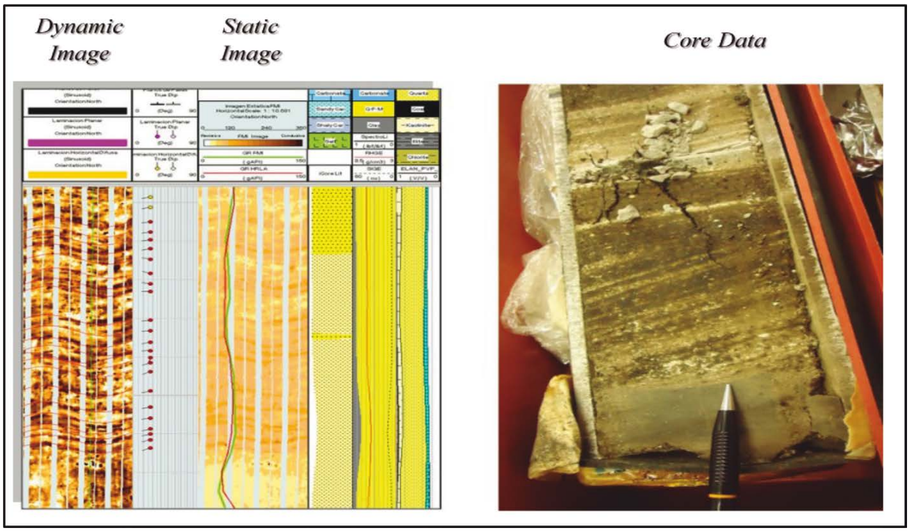


Figure 13. B2 facies.

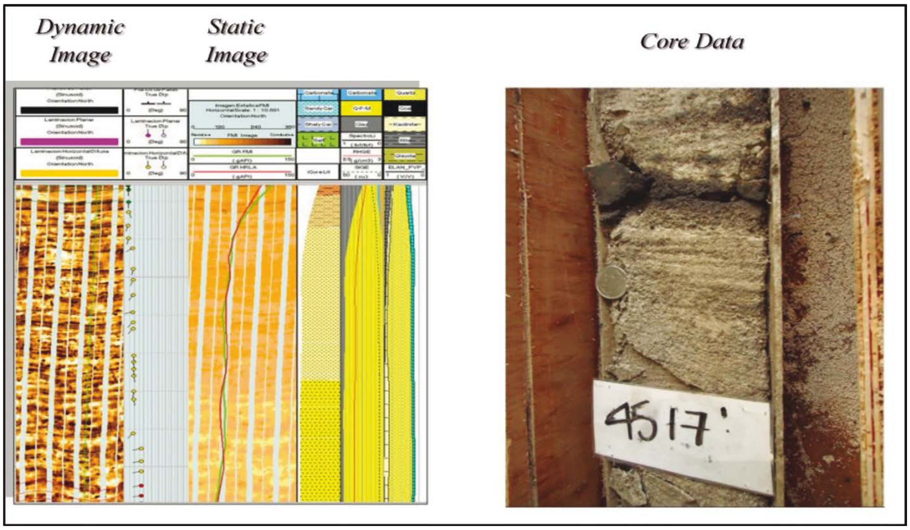


Figure 14. B3 facies.

In terms of petrophysics, B facies are characterized as clean sands, as shown by spectroscopy and gamma ray; also, the water saturation is low in this facies. The resistivities typically associated with this facies are the highest ones in the interval.

According to the reservoir information, several pretests were acquired in this zone and they showed the same pressure formation tendency and connectivity across the B facies. A pressure gradient was constructed to identify the fluid type, and it is very similar to that expected for heavy oil. Variation of the drawdown mobility values suggest some degree of heterogeneity in facies B, which is in agreement with laminations observed on the images, log, and cores.

Related to the Collapse of Suspended Load (S Facies)

S facies are mostly fine grained and are composed of mostly fine-grained sediments that

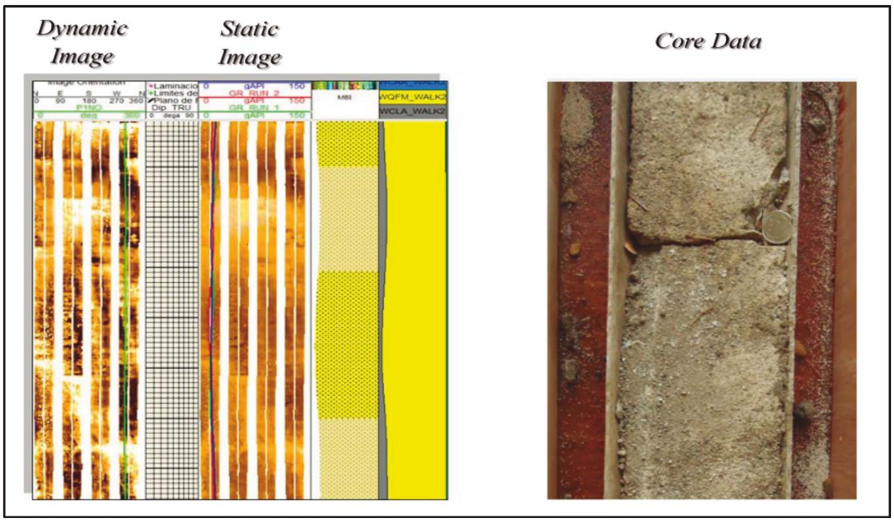


Figure 15. S1 facies.

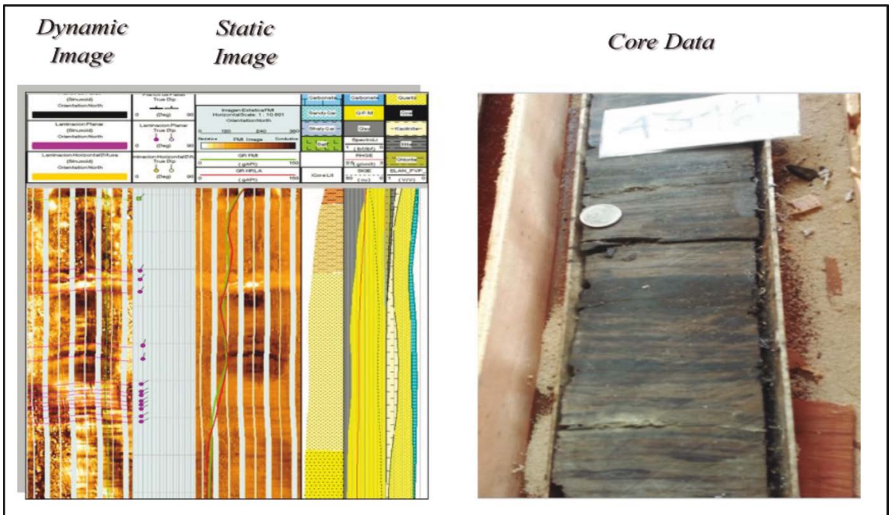


Figure 16. S2 facies.

were transported as suspended load, forming thick and commonly complex intervals that can be massive or display traction and fallout sedimentary structures (Gamero *et al.* 2011). The main types of S facies are massive (S1 facies, Fig. 15), laminated (S2 facies, Fig. 16), and rippled (S3 facies) deposits.

S facies are shaly sands, with higher gamma ray than that of the B facies. In addition, the spectroscopy shows a higher clay volume than the B facies. Water saturations are medium in this facies; the water content tends to be greater than that of the B facies. The resistivities associated with this facies are lower than those of the B facies.

Facies Related to Flow Lofting (L Facies)

L Facies is characterized by thin couplets of siltstones and sandstones having great lateral extension and commonly showing abundant intercalations of plant debris and micas (Gamero *et al.* 2011).

The L facies is the result of the fallout of very fine-grained sands, silts, plant debris, and micas from lofting plumes mainly on the margins of the flow. The transition from the flow axis to flow margin is characterized by massive sandstone beds interbedded with beds containing abundant plant debris (S1L facies, Fig. 17).

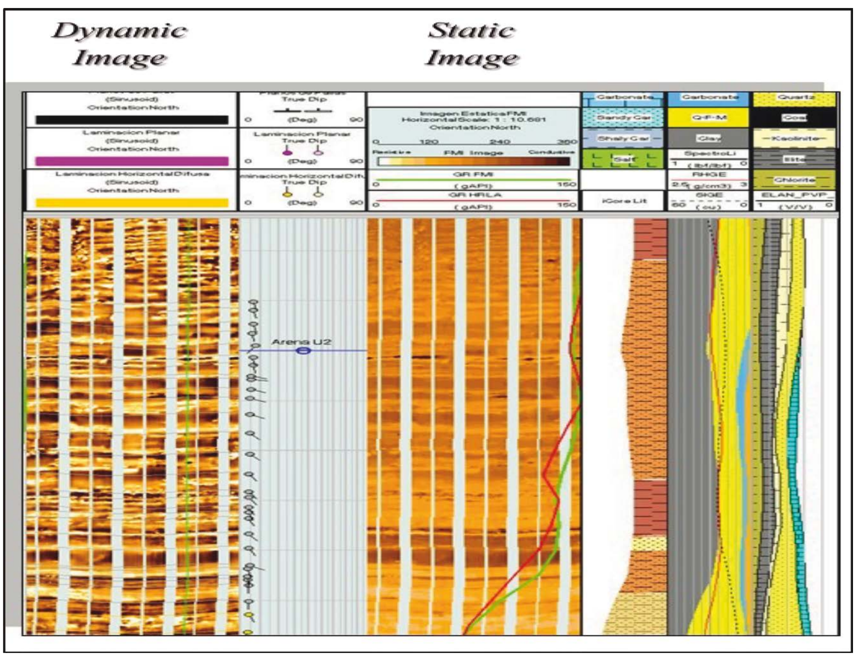


Figure 17. S1L facies.

This L facies deposits are shale bodies with high gamma ray and high volume of clay in the spectroscopy. Water saturations are high and the resistivities are low.

Facies Association – Analysis

This study applied a genetic facies approach for performing facies analysis and the further development of a depositional model. Zavala *et al.* (2011) proposed a genetic facies approach that distinguishes facies based on the main transport mechanisms involved during their deposition, resulting in a conceptual-based classification. Facies associations were identified based on gamma ray log trends, elemental capture spectroscopy, and lithofacies columns integrated with the vertical stacking of facies interpreted from borehole images and core data. These facies associations are discussed below.

Channel-Axis Facies Association

Description

The channel-axis facies association is composed of stacked thinning-upward successions (between 6 and 15 m [20 and 50 ft] thick), characterized from the base to the top by massive and stratified medium grained sandstones interbedded with pebbly conglomerates and asymptotic cross-bedded sandstones and overlain by parallel-laminated sandstones interbedded with massive sandstones. This facies association shows composite beds with a predominance of bed-load facies (Fig18). This facies may appear over an erosive basal boundary, followed by parallel bedded sandstones with interbedded aligned resistive clasts, cross-bedded sandstones, and parallel-laminated and massive sandstones interbedded with thin horizontal beds. This facies association commonly shows a blocky to fining-upward gamma ray pattern (Gamero *et al.* 2011).

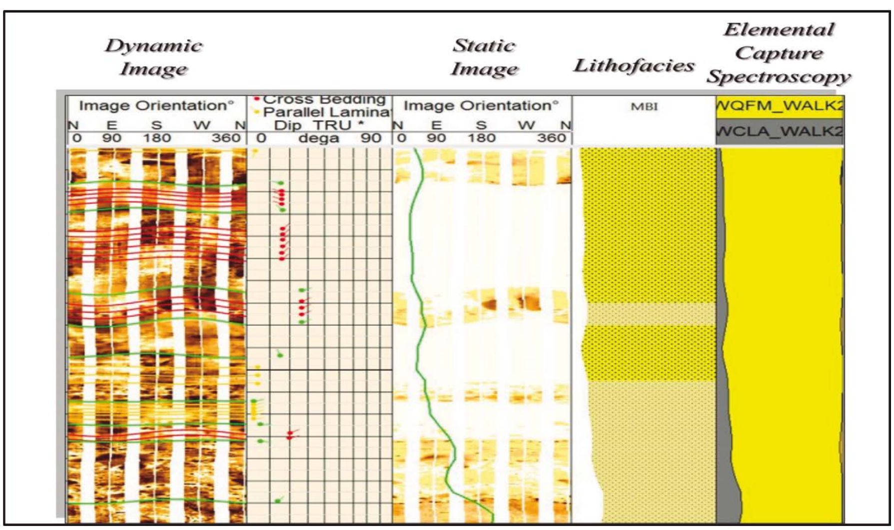


Figure 18. Channel-axis facies association.

Interpretation

This facies association is interpreted as channel axis deposits. A channel axis is dominated by bed load facies (B2s, B3s, and B1s). In this case, composite beds can be very thick (up to 15 m [50 ft] thick), depending on the duration of the hyperpycnal flow and the available accommodation space. These composite beds evolve laterally into lofting rhythmite packages. Composite beds are coarser grained and better developed in the center of the channelized flow (Zavala *et al.* 2007).

Channel-Margin Facies Association

Description

This facies association is composed of stacked fining and coarsening-upward successions (between 1 and 4 m [4 and 14 ft] thick), characterized by a vertical recurrence of parallel-laminated and massive sandstones (S1 and S2 facies) interbedded with thin (<0.3-m [1-ft]-thick) shale/siltstones/carbonaceous levels (S1/L). The recurrence of these facies creates thick (>15-m [50-ft]-thick) internally complex sandstone beds with no clear facies boundaries, defined as composite beds by Zavala *et al.* (2007) (Fig19). These facies appear in the images as interbedded, parallel-laminated, and massive sandstones interbedded with thin horizontal beds. These deposits may show stacked coarsening-upward and fining-upward gamma ray patterns (Gamero *et al.* 2011).

Interpretation

Composite beds typically display a vertical succession of different facies, showing cyclical recurrence and transitional to sharp passages between them. These cyclical and gradual changes are

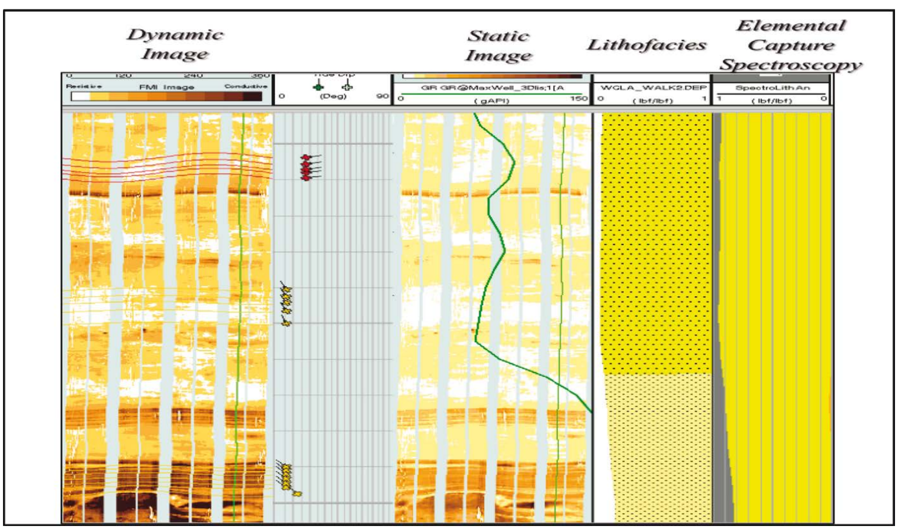


Figure 19. Channel-margin facies association.

the result of near-continuous deposition from a fluctuating quasisteady turbulent flow. This facies association is laterally related to amalgamated channel-fill facies. In this facies association, composite beds are almost entirely composed of suspended-load facies (S1, S2, and S3) (Gamero *et al.* 2011).

Proximal Levee Facies Association

Description

The proximal levee facies association is composed of stacked coarsening -and thickening- upward successions (between 3 and 8 m [10 and 26 ft] thick). These successions are characterized, from base to top, by heterolithic or lofting facies (L, S2L, and S3L facies), consisting of sharp-based parallel or massive sandstones (up to 0.5 m [1.5 ft] thick) interbedded with thinly laminated shales and siltstones (up to 0.3 m [1 ft] thick), followed by 0.6- to 1-m [2- to 4-ft]-thick sharp-based ripple- to parallel-laminated sandstones (S2 and S3 facies) (Fig. 20). This facies association appears in the images as a thin horizontally layered interval that grades upward into 0.3- to 0.6-m [1- to 1.5-ft]-thick parallel and/or ripple-laminated sandstones interbedded with thinly horizontally layered beds, overlain by 0.6- to 1-m [2- to 4-ft]-thick parallel to massive sandstone beds. This facies association shows a coarsening-upward (funnel-shaped) gamma ray pattern (Gamero *et al.* 2011).

Interpretation

This facies association is mostly composed of facies types originated by traction plus fallout processes with minor intercalations of lofting-related deposits. These characteristics suggest a marginal (lateral) position with respect to the main flow, and these deposits are interpreted as having accumulated in proximal levee areas (thickening-upward successions) located proximal to a channelized system (Gamero *et al.* 2011).

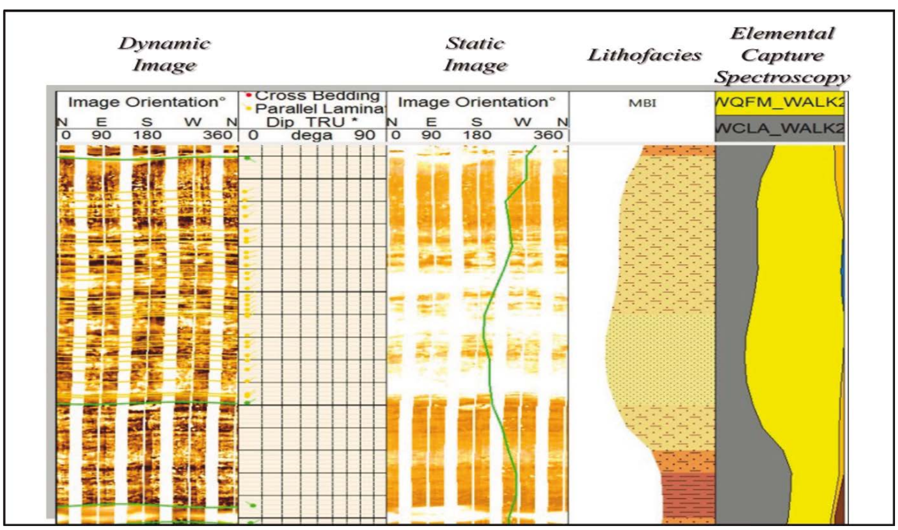


Figure 20. Proximal levee facies association.

Distal Levee Facies Association

Description

The distal levee facies association is composed of stacked coarsening-upward successions (between 1 and 3 m [5 and 10 ft] thick), characterized from base to top by lofting facies (L, S3L), followed by 0.3- to 0.5-m [1- to 1.5-ft]-thick sharp-based, parallel-laminated, very fine-grained sandstones interbedded with thinly laminated argillaceous siltstones (S2L facies, Fig. 21). These facies appear in the images as highly and thinly laminated siltstones that grade upward into 0.3- to 0.5-m [1- to 1.5-ft]-thick parallel-laminated sandstones, composed of a small-scale coarsening-upward (funnel-shaped) gamma ray pattern (Gamero *et al.* 2011).

Interpretation

This facies association is characterized by traction plus fallout processes that alternate with pure fallout from lofting plumes. The complex internal characteristics of these deposits could have originated from fluctuations in velocity and concentration during a single hyperpycnal discharge. This facies association is interpreted as having accumulated in a distal levee of a channelized system (Gamero *et al.* 2011).

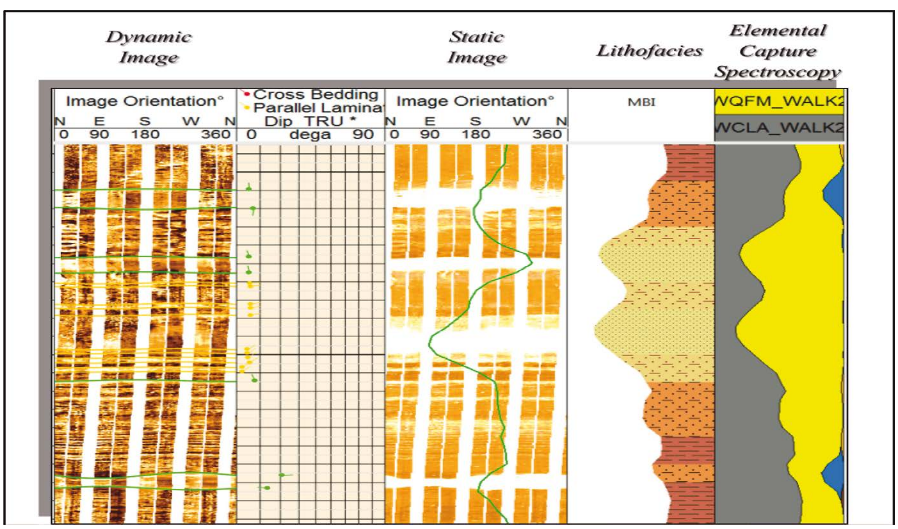


Figure 21. Distal levee facies association.

Lofting Facies Association

Description

The lofting facies association is composed of thinly laminated light gray siltstones with plant remains and lignite. In the analyzed cores, this facies association commonly does not show any evidence of bioturbation, with remarkably well-preserved laminae. This facies association appears in the images as highly and thinly laminated siltstones, with corresponding high gamma ray (Fig. 22).

Interpretation

Hesse *et al.* (2004) were the first to recognize lofting-related facies associated with ice-rafted debris in Pleistocene deposits of the Labrador Sea. The recognition of lofting facies in marine environments is extremely important because it allows the diagnosis of a direct fluvial connection and a hyperpycnal origin for the associated deposits (Zavala *et al.* 2006b; Zavala 2008). Lofting facies, in outcrops and cores, are composed of thinly laminated siltstones separated by thin intercalations of plant debris and micas, and their identification is very useful to predict the lateral occurrence of hyperpycnal channels in subsurface studies. This facies association is dominated by facies L commonly associated with S3L and S2L facies.

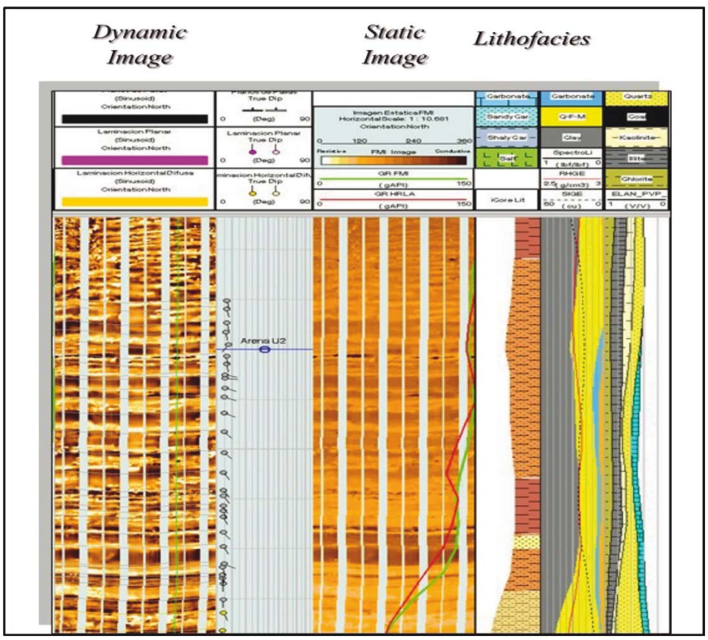


Figure 22. Lofting facies association.

CONCLUSIONS

The previous fluviodeltaic sedimentological characterization was changed in the Merecure formation in Dobokubi field to a hyperpycnal depositional system. Consequently, there were changes in the prediction of lateral extension, geometries, orientation, and continuity of the reservoir sands. This reinterpretation has reintroduced the Merecure formation as an exploratory target in this field.

Facies analysis conducted in the Merecure formation, Dobokubi field, through calibration of core data, borehole image, petrophysical, and reservoir evaluation, provided valuable information for finding the more prospective facies. Sedimentary facies were identified and grouped into three main facies categories (B, S, and L) related with specific sedimentary processes. B facies are the most prospective zones and include coarse-grained sandstones and fine-grained conglomerates with abundant sandstone matrix. The main facies types of this category are massive, low-angle crossbedded, and roughly laminated coarse-grained deposits, commonly composed of thick beds showing gradual and recurrent facies changes. Petrophysically, B facies are characterized by clean sands as shown by spectroscopy and gamma ray shows. The water saturation is low in this facies. Regarding the reservoir characteristics, pretest results show pressure connectivity and the same pressure formation tendency across the B facies.

This paper proves how the interpretation of high-resolution borehole electrical images improved the sedimentological models developed for each reservoir sand, in terms of depositional environments, paleocurrent determinations, and sand-body orientations within the Merecure Formation.

A new sedimentological characterization can be improved by using an image log in combination with the openhole conventional and advanced logs. These technologies offer a powerful technique to accurately mark the lithology unit boundaries; diagnose the mineralogical rock type; and identify the facies and facies associations, fluid type, and fluid properties.

The proposed hyperpycnal depositional model provides the answers to the operational problems encountered in this field, being a modern and more realistic depositional model that matches very well with the reservoir geology.

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