How to be predictive with low net-to-gross reservoirs: a Triassic case study

Cómo ser predictivo con rocas almacén de baja relación neto a bruto: un ejemplo triásico

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ABSTRACT

The ability to be predictive in exploratory geology (hydrocarbon prospecting or hydrogeology) is very important when dealing with a highly heterogeneous reservoir rock and with a low net-to-gross ratio. A Triassic example is presented in the succession informally known as TIBEM (south central Spain) corresponding to a very distal fluvial flood plain that is studied in outcrop and in cores and well logs of wells made behind the outcrop (OBO characterization, Outcrop / Behind Outcrop). It is shown that there are characteristic patterns of 1D data from gamma ray and distribution of tadpoles acquired in wells that allow as to accurately locate the well within the detail sedimentary model of the ancient floodplain. In this way, from the 1D data, inferences can be made about the 3D disposition of the sandstone sedimentary bodies corresponding to the channel and the crevasse-splay lobes, as well as the interconnectivity between these and their potential permeability barriers and baffles. The usefulness of this workflow when it comes to making robust models is evident.

Keywords: *floodplain, Triassic, reservoir rock, borehole, well logging.*

RESUMEN

La capacidad de ser predictivo en geología exploratoria (prospección de hidrocarburos o hidrogeología) contando exclusivamente con datos de sondeo está muy mermada cuando se trata con una roca almacén altamente heterogénea y con baja proporción de capas porosas frente a impermeables (baja ratio net-to-gross). Se presenta un ejemplo triásico en la sucesión informalmente conocida como TIBEM (sector centro occidental de España) correspondiente a una llanura de inundación fluvial muy distal que se estudia en afloramiento y en testigos de sondeo y diagrafías de pozos realizados detrás del afloramiento (caracterización OBO). Se pone de manifiesto que existen unos patrones característicos de datos 1D de diagrafías de rayos gamma y de distribución de tadpoles adquiridos en pozos que permiten situar con precisión el pozo dentro del modelo sedimentario de detalle de la antigua llanura de inundación. De este modo, a partir del dato puntual se pueden hacer inferencias sobre la disposición en 3D de los cuerpos sedimentarios de arenisca correspondientes al canal y a los lóbulos de derrame, así como la interconectividad entre estos y sus potenciales barreras y deflectores de permeabilidad. La utilidad de este protocolo de trabajo a la hora de confeccionar modelos robustos se pone de manifiesto.

Palabras clave: *llanura de inundación, Triásico, roca almacén, sondeo, diagrafías de pozo.*

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Introduction

The 3D characterization of reservoir rocks from only subsurface data is a difficult process, especially in those very heterogeneous formations with a small proportion of porous beds embedded in sediment of very low permeability (low net-to-gross ratio). Extreme cases of this type of formations are those originated from the sedimentary dynamics of fluvial floodplains in a very distal context (Bridge and Tye, 2000). In this situation, the allogenic processes related to the tectonics, the climate and the frequent modifications of the base level, united and combined with the autocyclic processes that participate in the fluvial dynamics give rise to a very varied possibility of distribution of sandy geobodies embedded in fine sediment.

Thus, when geometrically characterizing a detrital aquifer or a reservoir of hydrocarbons in this type of formations, it becomes very difficult to be predictive in the distribution of sandstone bodies, in their dimensions, their permeability baffles and their interconnectivity. Frequently the available data correspond to few boreholes, assisted by some geophysical information. However, when it is necessary to estimate the volume of accumulated fluids in a sandstone, a substantial amount of quality data is needed to estimate the dimensions and distribution of the heterogeneities.

The integrated study of outcrop and subsurface data, called Outcrop / Behind Outcrop characterization (onwards OBO) (Slatt *et al.*, 2011; Viseras *et al.*, 2018) constitutes a methodology of contrasted results to resolve these uncertainties. Thus, the OBO workflow integrates 2D high resolution outcrop data and 3D outcrop data, development by photogrammetry techniques, with subsurface data behind the outcrop that includes core recovery, Gamma Ray logs and borehole image logs.

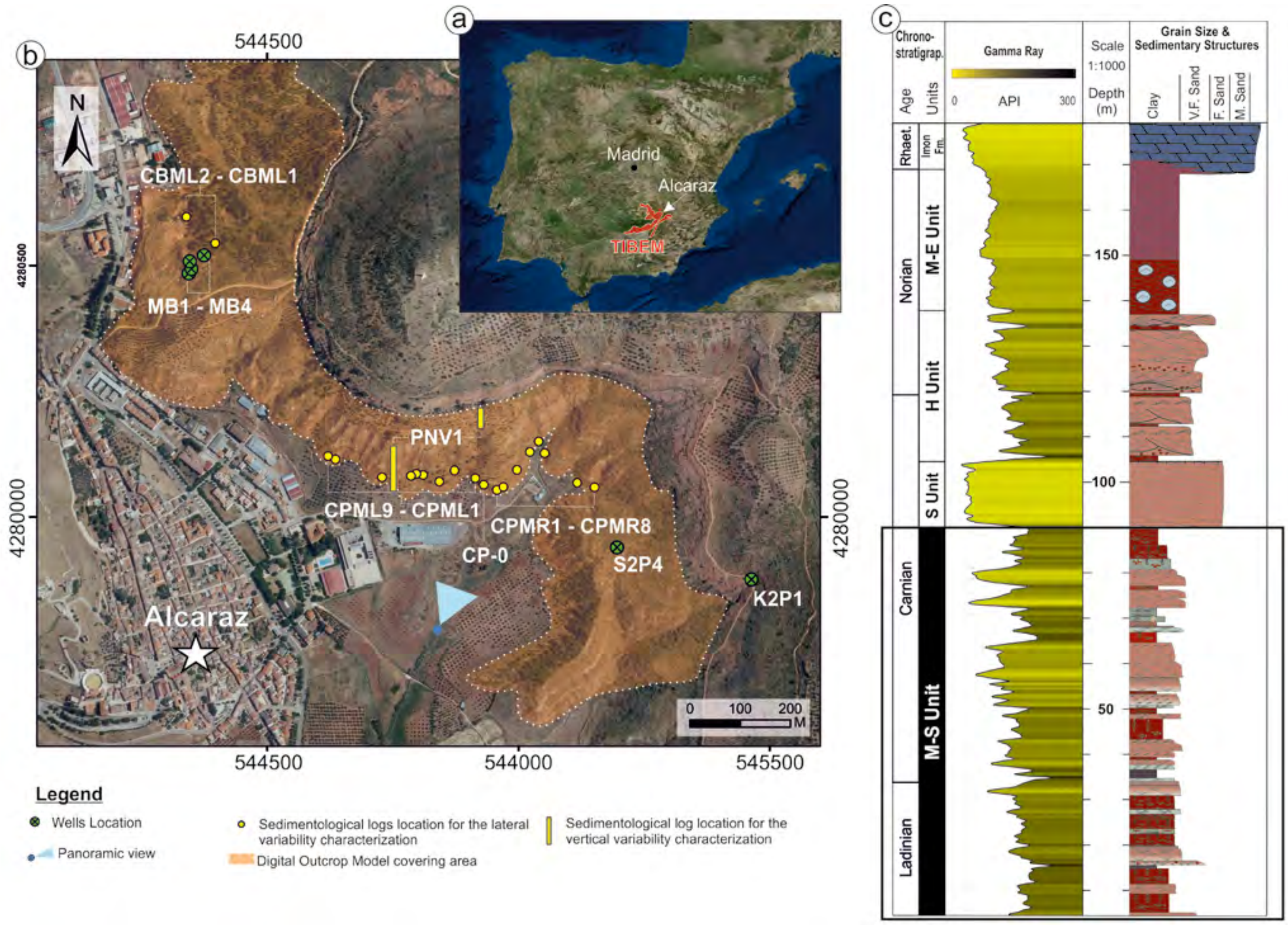

Fig. 1.- A) Location of the TIBEM sucession in south central Spain. B) Close-up view of the location of the studied outcrops. C) Simplified TIBEM stratigraphy and lithological succession in the Alcaraz area based on the gamma ray log. The lower part of the succession stands out, which corresponds to the mudstone-sandstone unit (M-S), on which the detailed observations are made. S, H, M-E, sandstone, heterolithic and mudstone-evaporitic Units. See color figure in the web.

Fig. 2.- A) Localización de la sucesión TIBEM. B) Vista aérea de la zona que contiene a los afloramientos estudiados. C) Estratigrafía simplificada del TIBEM y sucesión litológica en el área de Alcaraz basada en la diagrafía de rayos gamma. Se destaca la parte inferior de la sucesión, que corresponde a la unidad Areniscoso-Pelítica (M-S), sobre la que se han hecho las observaciones de detalle. S, H, M-E, unidades Areniscosa, Heterolítica y Pelítico-Evaporítica. Ver figura en color en la web.

Geological Setting and Stratigraphy

The stratigraphic succession of the TIBEM (Triassic Red Beds of the Iberian Meseta, Viseras *et al.*, 2011, 2018; Henares *et al.*, 2014, 2016) in the study area comprises fluvial to coastal deposits within a linked stratigraphic framework and accumulated during the Tethyan rifting process (Late Permian-Upper Triassic; Sánchez-Moya *et al.*, 2004). In the area selected for this study (Fig. 1A, B), the *ca.* 160 m-thick sedimentary succession (Ladinian-Norian) is divided into four sequences on the basis of the predominant lithology and depositional environments (Fig. 1C). From base to top, they are: (i) a mudstone-sandstone unit (M-S Unit), that includes both a meandering channel system and overbank sandstone deposits embedded in distal floodplain mudstones; (ii) a sandstone unit (S Unit) corresponding to a braided system; (iii) a heterolithic unit (H Unit) comprising alternating sandstone and mudstone layers deposited in a fluvial-tidal transition zone; and (iv) a mudstone-evaporitic unit M-E Unit) composed of silt-rich coastal plain facies and intertidal sabkha evaporites.

The deposits described in this paper correspond to a 90 m-thick heterolithic section of mudstone and sandstone, the M-S Unit (Yeste *et al.*, 2018; Fig. 2) or Sequence II of Fernández and Dabrio (1985) and Unit K1 of Arche and López-Gómez (2014).

Distribution of sedimentary bodies and sub-environments in the modeled area

The exceptional outcropping characteristics in the area allow us to establish the architectural elements of the study unit, which are the characteristics of a distal fluvial floodplain furrowed by high sinuosity fluvial channels (Viseras and Fernández, 2010). From this we see that the basal main channel and point bar deposits pass laterally into floodplain and swamp deposits interbedded with the crevasse-splay complex deposits (Fig. 2).

In this outcrop, amalgamated crevasse-splay deposits occur throughout but are clearly more frequent toward the eastern edge of the outcrop though still interbedded with an abundance of floodplain and swamp deposits. Toward the western part of the outcrop, the corresponding main channel and point bar deposits occur.

Finally, toward the top of this key outcrop, main channel and point bar deposits occur and grade laterally into the crevasse-splay deposits to the E of the outcrop (Fig. 2).

Fig. 2.- Panoramic view of the study area with the distribution of the main sub-environments characteristic of a distal flood plain in the M-S unit: channels and crevasse-splay lobes. Notice the serrated pattern of the Gamma Ray (GR) signal for this unit highlighting the alternation of sandstone and mudstone beds. See color figure in the web.

Fig. 2.- Vista panorámica de la zona de estudio con la distribución de los principales subambientes característicos de una llanura de inundación distal en la unidad M-S: canales y lóbulos de derrame. Nótese el patrón serrado de la señal de Rayos Gamma (GR) para esta unidad poniendo en evidencia la alternancia de capas de arenisca y argilita. Ver figura en color en la web.

Conceptual model: outcrop and subsurface information

The exceptional quality of the outcrops and the possibility of laterally following each stratigraphic horizon through a Digital Outcrop Model (DOM) and a series of 6 boreholes have allowed us to elaborate a conceptual model that includes a series of facies associations distributed in bands around the main element from which the sediment comes, that is, the fluvial channel (Fig. 3).

Thus, the main channel, with approximate dimensions of 40 m in width and 3 m thick, in its accretion inner margin grades into point bar deposits, which may have two features at the top: scroll bars and locally chute channels. The scroll bar grades into distal floodplain deposits. On the erosive or inner margin of the channel there is a crevasse splay complex that can be partially eroded locally by a crevasse channel. The distal floodplain environment is located up to 300 m from the main channel and locally can intersperse swamp deposits.

The analysis of the well logs from 6 boreholes (Fig. 1) that cut the studied unit shows that there are characteristic patterns of each of the sub-environments distinguished in outcrop. Thus, channel bodies are characterized by a bell-shape profile of the Gamma Ray (GR) log, random azimuth and low to high angles of tadpole patterns (Fig. 3). On the other hand, the crevasse-splay bodies characteristically show a funnel-shape GR log, unidirectional azimuths and low dip angles of tadpole patterns, as well as synsedimentary deformation in their lower part (especially frequent in the medial crevasse, Fig. 3). Finally floodplain deposits are represented in well logs by a serrated-shape of GR log, unidirectional azimuths and very low angles of tadpole patterns.

Conclusions

The integrated analysis of outcrop and subsurface (OBO characterization)

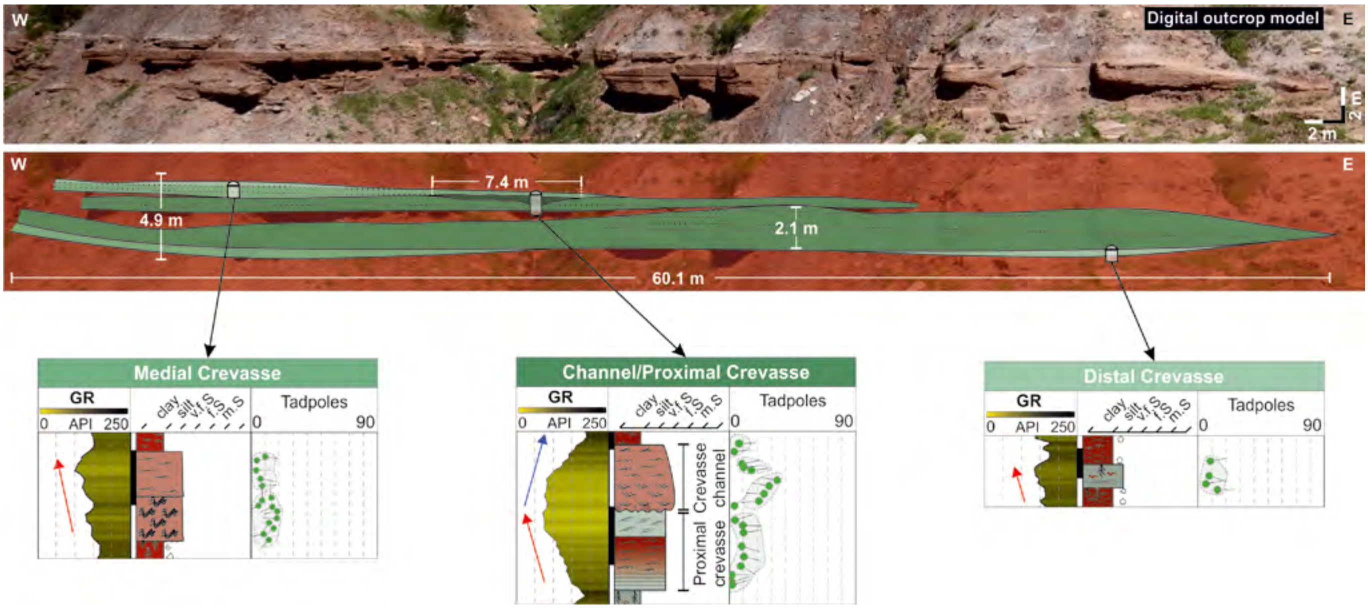

Fig. 3.- Sequences, patterns of Gamma Ray (GR) and tadpole characteristic of different parts of a crevasse-splay lobe geobody. See color figure in the web.

Fig. 3.- Sucesiones, patrones de Rayos Gamma (GR) y de tadpole característicos de distintas partes de un geocuerpo de lóbulo de derrame. Ver figura en color en la web.

of a Triassic unit of low net-to-gross ratio originated from the sedimentary dynamics of a fluvial distal floodplain has allowed us to conclude that:

1. There are characteristic lithofacies, GR logs and tadpole patterns for each of the sub-environments that can be established in the floodplain.
2. The width of the bands of lithofacies has values that are related to the size of the channel from which the sediment comes.
3. Inferences can be made from 1D data obtained in well on the position and dimensions in the space of the main sandstone architectural elements (main channel, point bar, crevasse splay).
4. The correct application of this workflow allows reducing uncertainty in the location of sand-on-sand contacts, advancing lateral amalgamation patterns and vertical stacking of sandstone geobodies.

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