

Fluvial sedimentary bodies in the Guadix Basin: analysis of their geometry for their potential use as outcrop analogues for hydrocarbon reservoirs

Cuerpos sedimentarios aluviales y fluviales en la Cuenca de Guadix: análisis de su geometría para su potencial uso como análogos aflorantes de almacenes de hidrocarburos

Sila Pla-Pueyo^{1,2}, César Viseras^{2,3}, Saturnina Henares^{2,3} and Luis M. Yeste^{2,3}

¹Institute of Petroleum Engineering. Heriot-Watt University, Edinburgh. EH14 4AS, United Kingdom. sila.pla@gmail.com

²Sedimentary Reservoir Workgroup (SEDREGROUP). <http://www.sedregroup.com>

³Departamento de Estratigrafía y Paleontología. Facultad de Ciencias, Universidad de Granada. Av/ Fuentenueva, s/n. 18002. Granada, Spain. viseras@ugr.es, shenares@ugr.es, luismiyeste@gmail.com

ABSTRACT

The Guadix Basin (Betic Cordillera, S. Spain) presents high quality outcrops of alluvial and fluvial sediments, deposited in an endorheic basin developed throughout the Pliocene and Pleistocene. In the present study, we analyse a selection of seven architectural elements (3D sedimentary bodies) representing three different drainage systems: an axial fluvial system, and two transverse alluvial fan systems. After their description, the sedimentary bodies are classified (in qualitative terms) according to their potential quality as hydrocarbon reservoirs. The aim of this work is to identify the best examples of potential reservoirs in alluvial and fluvial facies in the Guadix Basin, in order to target them in future studies as outcropping analogues. As a final conclusion, three architectural elements, two from the Axial System and one from the Internal Transverse System are suggested as future targets.

Key-words: Alluvial, fluvial, geometry, outcropping analogue, reservoir.

RESUMEN

La Cuenca de Guadix (Cordillera Bética, Sur de España) presenta afloramientos de excepcional calidad de sedimentos aluviales y fluviales, depositados en una depresión endorreica durante el Plioceno y Pleistoceno. En el presente trabajo analizamos una selección de siete elementos arquitectónicos (cuerpos sedimentarios 3D) que representan tres sistemas de drenaje diferentes: un sistema fluvial axial y dos sistemas transversales de abanicos aluviales. Una vez descritos, los cuerpos sedimentarios se han clasificado cualitativamente en función de su potencial calidad como rocas almacén de hidrocarburos. El objetivo de este trabajo es identificar los mejores ejemplos de potenciales reservorios de hidrocarburos en facies aluviales y fluviales en la Cuenca de Guadix para utilizarlos como análogos aflorantes. La conclusión final de este trabajo es que se proponen tres elementos arquitectónicos, dos del Sistema Axial y uno del Sistema Transversal Interno, como objetivo de futuros estudios.

Palabras clave: Aluvial, almacén, análogo aflorante, fluvial, geometría.

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Introduction

The study of outcrop analogues for hydrocarbon reservoirs that are currently being exploited facilitates the exploration and allows the inference of petrophysical properties of the reservoir that may be crucial to characterise the quality of the reservoir (Lunt *et al.*, 2013). The aim of this study is to assess, for the first time, if the Pliocene-Pleistocene siliciclastic deposits of the Guadix Basin may be a useful analogue for hydrocarbon reservoirs in alluvial and fluvial sediments. For that purpose, alluvial and fluvial sedimentary bodies (formed by sands or

coarser sediments) in the basin have been selected and described in this article. The final objective is to identify the most promising sedimentary bodies that may be good analogues, to target them in future studies.

Geological context

The Guadix Basin, located in the centre of the Betic Cordillera (southern Spain), lies on the ancient contact between the External and the Internal Zones of the mountain range (Fig. 1). Its continental filling (Upper Tortonian - Upper Pleistocene) comprises three of the six genetic units in which the

sedimentary infill of the basin is divided (Viseras *et al.*, 2005). Of these three units, so called IV, V and VI, only units V and VI (Pliocene-Pleistocene) crop out in the central sector of the Guadix Basin.

The palaeogeography of the Guadix Basin during the Pliocene and Pleistocene was characterised by three drainage systems (Viseras, 1991; Fernández *et al.*, 1996). The axis of the valley was occupied by an axial fluvial system (from now on AS) that in the study area was dominated by high sinuosity sandy channels, floodplain fine-grained deposits and palustrine carbonate related to wetlands (much more

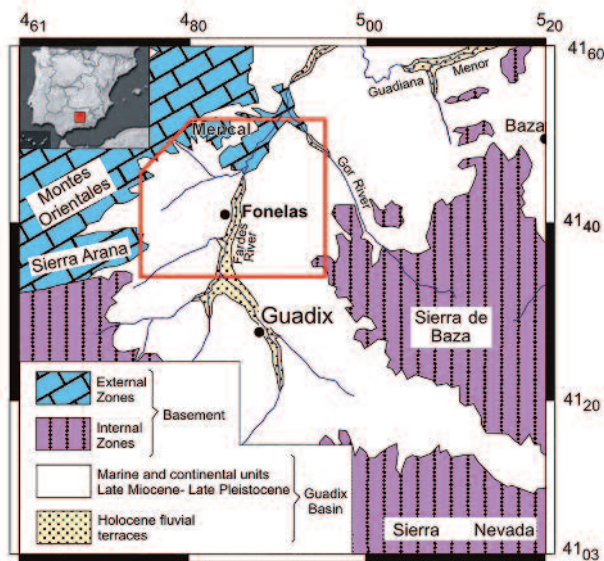


Fig. 1.- Location of the Guadix Basin in the Betic Cordillera (S. Spain). A square delimits the study area.

Fig. 1.- Localización de la Cuenca de Guadix en la Cordillera Bética (Sur de España). Área de estudio delimitada por un cuadrado.

predominant in unit VI) (Pla-Pueyo *et al.*, 2009). The AS was fed laterally by two different systems of alluvial fans. The External Transverse System (from now on ETS) was formed by small and isolated alluvial fans with their source area on the External Zones of the Betic Cordillera (Viseras, 1991; Fernández *et al.*, 1993). The Internal Transverse System (ITS from now on) consisted of large and coalescent alluvial fans coming from the Internal Zones of the Betic Cordillera (Viseras, 1991; Viseras and Fernández, 1992, 1994, 1995). The differences in lithology and tectonism of their source area resulted in very different sedimentary body geometries in each of the transverse alluvial systems.

Geometries of sedimentary bodies

A selection of the architectural elements observed in the study area is presented in this article, focusing only in those bodies that could be good analogues for hydrocarbon reservoirs in alluvial and fluvial facies (sand bodies with different degrees of lateral connectivity and different estimated porosity).

A detailed description of the selected 3rd order architectural elements (in this case referred to 3D sedimentary bodies) that have been identified in each of the three drainage systems is given in table I.

At this stage, we will only describe the selected sedimentary bodies, without discussing the net to gross in the outcrops or the influence of the fine grain sediments in the reservoir quality of these potential ana-

logues. This will be the aim of further studies on targeted bodies.

Axial System

The Axial System bears a range of 3rd order architectural elements, including gravel and/or sand ribbon-like channels, multistorey-multilateral channels, floodplain silty-clay sheet beds and several types of carbonate bodies (e.g., tufas and palustrine beds). The most interesting elements from the point of view of the present study are the channels.

Gravel-sand channels

This high sinuosity channels have been described in previous works (Viseras *et al.*, 2006; Pla-Pueyo *et al.*, 2009), and are characterised by the presence of mostly gravel and sand lithofacies, showing epsilon, trough and planar cross-bedding (Table I). The aspect ratio of these channels varies between 1:3 and 1:4, so they are considered narrow ribbon channels if we follow the classification by Gibling (2006). The proportion of silt and clay lithofacies within the channels is negligible and the sorting is good, so lithologically, these channels would have a relatively high porosity. However, the connectivity between the different pod-shape deposits of channels would need to be studied in detail.

Sand channels

These sedimentary bodies, named "sand bodies" when they were published before (Pla-Pueyo *et al.*, 2009), show a higher pro-

portion of fine-grained sediments and are mostly sandy lithofacies, interspersed with silty layers (Table I). The most predominant sedimentary features are lateral accretion surfaces. The aspect ratio of these channels ranges between 1:3 and 1:10, although it tends to be closer to 1:5. Therefore, they are considered narrow ribbons.

Their sandy nature would give the channels high values of porosity, although the frequent intercalation of silty-clay thin beds would surely affect the connection between the different porous areas in the channel, acting as barriers to the flow. Moreover, the channels do not present in general long periods of lateral accretion, meaning lower lateral extension of the channels. The connectivity among different pods of the sinuous system would need further study. It might be bad in those channels that have higher proportions of fine grained sediments in the bottom of the accretion units, and much better in those dominated by sands at the bottom (Miall, 1996) and it could also affect the quality of these potential reservoirs.

Amalgamated channels

The amalgamated channels, which have been identified only in Unit VI, are described here as a variation of the gravel-sandy channels described in previous publications (Pla-Pueyo *et al.*, 2009). They present multistorey, multilateral channels with an aspect ratio reaching 1:15, so they have certain characteristics that makes them different from the gravel-sand channels described above and that will affect their quality as potential reservoirs (Table I).

They show mostly well sorted gravel and sandy lithofacies, but they do not present lateral accretion. They mostly present trough cross-bedding, and their aspect ratio is much higher than for the other type of channels, so they could be considered as sheet deposits. They also show almost no content in silts or clays, so their porosity would be high. Their lateral extension is over 30 m, so laterally they would be very continuous bodies, and the connectivity within them would be good.

Internal Transverse System

The geometry of the Internal Transverse System sedimentary bodies varies a lot depending on their proximity.

In the study area, the medial-distal facies of the alluvial fans have been identified (Pla-Pueyo, 2009; Pla-Pueyo *et al.*, 2011), which means a predominance of fine-grained facies over the coarse ones. However, as a result of a more distal position, the coarse facies in the study area are better sorted, so this could be an advantage instead of an issue.

There are mainly two types of channels identified in the study area as belonging to the Internal Transverse System fans: ribbon channels and the so-called pseudotabular complexes.

Ribbon channels

The ribbon channels (Table I) coincide mostly with the description of the gravel-sandy channels of the Axial System, so they will present a relatively high porosity and an aspect ratio between 1:3 and 1:10.

However, these ribbon channels are slightly different in the ITS and the AS in their overall geometry. In the ITS, a pendular behaviour has been described for the channels (Viseras and Fernández, 1995), so after a certain lateral migration period (usually not long), the channel would suffer avulsion upstream and change not only its location, but also the direction of its lateral accretion. This means that the lateral continuity of the meandering belts is low and the

connectivity between different pods would be bad to medium, depending, as in the sand channels of the AS, on the proportion of sands at the bottom of the channels.

Pseudotabular complexes

The pseudotabular complexes, described in previous works (Viseras, 1991; Viseras and Fernández, 1992, 1994, 1995) are formed by braided channels developed in the medial-distal part of an alluvial fan. The predominant lithofacies are gravels, and there are sandy facies as well, but not significant presence of silt or clay.

The individual channels have a low aspect ratio, but they appear as part of sheet-like bodies (aspect ratio up to 1:100) comprising several channels. This lateral amalgamation of channels, together with the predominant grain size and the almost absence of silts and clays makes these bodies very good potential reservoirs, with high porosity and high lateral connectivity among the channels.

External Transverse System

The External Transverse System alluvial fans have a particularity that will affect the quality of any potential reservoir rock in them. In the case of the ITS and AS bodies, the lithology is metamorphic in origin

(quartz, schists) and only in the ITS some carbonate grains appear, formed by dolomite coming from the Internal Zones (Viseras, 1991; Pla-Pueyo *et al.*, 2009). However, most of the facies of the ETS are detrital carbonate. The carbonate clasts come from the marine Mesozoic beds in the External Zones and were redeposited in the alluvial fans. Similar facies but siliciclastic in nature have been identified in other basins (e.g., Alonso-Zarza, 2003; Luzón *et al.*, 2011). Due to their provenance the matrix and the clasts of the ETS sediments are mostly carbonate (with the exception of some chert clasts), and it means that its facies are prone to carbonate cementation during diagenesis. Therefore, from the three drainage systems, they actually will be the most affected by diagenetic processes that may reduce porosity.

The most likely bodies to be used as analogues for hydrocarbon reservoirs in the ETS are V-shaped channels, tabular bodies and breccia beds, and the breccias beds can be discarded due to their strong degree of cementation, which has reduced their porosity to practically none.

V-shaped channels

This type of channels were first described in the area by Fernández *et al.* (1993). They are dominated by clast-sup-

Reservoir quality	Architectural element (drainage system)	Aspect ratio (thickness: lateral extension)	Geometry	Lithofacies associations	Interpretation	Relative porosity of beds	Connectivity among beds
1	Pseudotabular channel complexes (ITS)	Up to 1:100	Wide sheet	Gla, Gcm/Gh, Gp/Sp, Gt/St *Gi	Medial fan channels moving laterally in a pendular way	High	Good
2	Multistorey, multilateral channels (AS)	Around 1:15	Wide ribbon-narrow sheet	Gt/St	Shallow channels dominated by small dunes (centre of AS)	High	Good
3	Gravel-sand channels (AS)	1:3-1:4	Narrow ribbon	Gla/Sla, Gt/St, Gp/Sp, Sr, Sh, Fl, Fo	Large meandering channels (centre of AS)	High	Medium
4	Tabular bodies (ETS)	1:20-1:100	Narrow sheet-wide sheet	Gcm, Gh *Gos	Small mouthbar of channel into lake (ETS)	Medium	Medium
5	Sand channels (AS)	1:3-1:10	Narrow ribbon	Sla-St/Sr-Sh-So/Fo-Fl Gcm, Gt, Gp	Small meandering channels in floodplain (margin)	High	Medium-bad
5	Ribbon bodies (ITS)	1:3-1:10	Narrow ribbon	Sla-St/Sr-Sh-So/Fo-Fl Gcm, Gt, Gp	Small meandering channels in distal alluvial fan (margin)	High	Medium-bad
6	V-shaped channels (ETS)	1:2-1:4 (in really entrenched channels 2:1)	Stepped V with lateral wings (narrow ribbon)	Gcm, Gh *Gi	Entrenched channel in distal floodplain (Fan fringe)	Low	Bad

Table I.- Selected architectural elements ordered in a qualitative way (1 = the best quality as potential reservoir, 6 = the worst). The description and interpretation of each element is provided in the table. The porosity is estimated from the lithology, texture and fabric of the sediments in each sedimentary body, and expressed in a qualitative way as high, medium or low. The connectivity among the lithofacies within each architectural element is also expressed in a qualitative way as good, medium or bad. The asterisk represents occasional presence of the lithofacies.

Tabla I.- Selección de elementos arquitectónicos ordenados de forma cualitativa (1 = la mejor calidad como potencial almacén, 6 = la peor). La descripción e interpretación de cada elemento se proporciona también en la table. La porosidad se ha estimado a partir de la litología, la textura y la fábrica de los sedimentos en cada cuerpo sedimentario, y se expresa cualitativamente como alta, media o baja. La conectividad entre litofacies dentro de cada cuerpo sedimentario también se expresa de forma cualitativa como buena, media o mala. El asterisco representa la presencia ocasional de la litofacies.

ported gravels/conglomerates showing no structure or planar bedding (Table I). The matrix between the gravel clasts tends to be very fine, so the sorting of this facies is not very good. In general, they present a low porosity regarding their texture and fabric. Their aspect ratio may be misleading if the lateral "wings" developed by the channel are taken into account, but the general shape of these channels tends to be ribbon-like, and a realistic aspect ratio for them would be around 1:3.

These channels appear isolated in the mudflat so the connection between bodies is low, and no sandy tabular beds have been found connecting them, as it happens sometimes with the crevasse splays or over-bank coarser sediments in other cases (Donselaar and Overeem, 2008). As a whole, these channels do not seem to be good potential reservoirs.

Tabular bodies

The tabular bodies found in the ETS facies in the Guadix Basin were previously described by Fernández *et al.* (1993) as part of a general rising-level sequence in the alluvial plain. The V-shaped channels would represent an initial fall of the base level, and an increasing base level up to the top of the channel. The tabular bodies would form when the base level is so high that the sediments organise themselves in sheet-like bodies with an aspect ratio of up to 1:100.

The lithology of these bodies is formed by clast-supported gravels showing a massive structure, in some cases horizontal bedding, and occasionally imbrication of clasts (Table I). Sometimes, at the top of these bodies we can observe an open fabric bed, formed by clast-supported gravels with no matrix. The porosity of the beds within these bodies would be medium to high.

The lithology may seem promising in terms of porosity of the bodies, but it is common to find beds of marls intercalated vertically and laterally with the gravel beds. Therefore, the lenses of gravels/conglomerates alternate with lenses of marls within the tabular bodies. This means that, although the lateral continuity of these bodies (up to 250 m) and their thickness (up to 5 m) are considerable, the connectivity

within the different porous facies within them will not be necessarily good.

Discussion and conclusions

A selection of sedimentary bodies of the Guadix Basin has been described and assessed from the point of view of their potential as outcropping analogues for alluvial and fluvial hydrocarbon reservoirs.

As a result, a table is presented, in which the different bodies are ordered from those which have better quality as reservoirs to those which are not so good, using a qualitative approach.

The first two elements represented in Table I are clearly the best, and the V-shaped channels clearly the worst in terms of reservoir quality. However, the three intermediate elements were more difficult to assess. The sand channels (AS) and the ribbon channels (ITS) would have similar quality, so more detailed studies would be required to assess whether ones are better than the others. In the case of the tabular bodies (ETS), they may have slightly lower porosity than the channels above, but they do present a very high lateral extension, so in terms of reservoir quality, their geometry would be an advantage over the ribbon channels.

After the description made for every sedimentary body, and its classification after its reservoir quality, the most interesting architectural elements detected in the study area that will be targeted for future studies belong to the Internal Transverse System alluvial fans (pseudotabular complexes) and the Axial System fluvial sediments (gravel-sand channels and amalgamated channels). A more detailed description of the targeted architectural elements and more information about the potential seals, potential connections with other bodies in their surroundings and any other information affecting their use as outcropping analogues for alluvial and fluvial reservoirs is therefore needed.

The rest of the analysed bodies would require a deeper knowledge of their properties to confirm their low quality as reservoirs.

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