

On the origin of crevasse-splay amalgamation in the Huesca fluvial fan (Ebro Basin, Spain): Implications for connectivity in low net-to-gross fluvial deposits



K.A. van Toorenburg^{a,*}, M.E. Donselaar^a, N.A. Noordijk^{a,1}, G.J. Weltje^b

^a Department of Geoscience and Engineering, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands

^b Department of Earth and Environmental Sciences, University of Leuven, P.O. Box 2410, 3001 Leuven, Belgium

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ABSTRACT

Floodplain deposits are abundant in low-gradient dryland river systems, but their contribution to connected reservoir volumes has not yet been fully acknowledged due to their poor detectability with typical wireline log suites and relatively-lower reservoir quality. This study presents an analysis of stacked crevasse splays in the distal part of the Miocene Huesca fluvial fan (Ebro Basin, Spain). Vertical stacking of crevasse splays implies local aggradation of the active channel belt. Lateral amalgamation of crevasse splays created an elevated rim around their feeder channel, raising its bankfull height. Subsequent crevasse splays were deposited on top of their predecessors, creating sand-on-sand contact through incision and further raising the active channel belt. This process of channel-belt super-elevation repeated until an upstream avulsion occurred. Amalgamated crevasse splays constitute connected reservoir volumes up to $\sim 10^7$ m³. Despite their lower reservoir quality, they effectively connect channel deposits in low net-to-gross fluvial stratigraphy, and hence, their contribution to producible volumes should be considered. Unswept intervals of amalgamated crevasse splays may constitute a secondary source of natural gas. Their interval thickness can serve as a proxy for feeder-channel dimensions, which can in turn be used to estimate the degree of stratigraphic connectivity.

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1. Introduction

Floodplain deposits in low net-to-gross fluvial stratigraphy contain fine-grained reservoir bodies (e.g., Donselaar et al., 2011; McKie, 2011a; Ford and Pyles, 2014). These sub-seismic-resolution deposits are difficult to distinguish on well logs (e.g., Passey et al., 2004; Bridge, 2006) and are thought to represent a relatively small proportion of overall sandstone volumes with a reservoir quality that is generally lower than that of coarser-grained fluvial facies (e.g., Pranter et al., 2008). As a result, intervals of floodplain deposits have been discarded as ‘waste zones’ in conventional reservoir development (Donselaar et al., 2011) and published research on their accumulation and reservoir architecture is limited (Bridge, 2006). Smith et al. (1989); van Gelder et al. (1994); Tooth (2005); Donselaar et al. (2013), and Li et al. (2014) have studied the deposition of crevasse splays in active river systems through field work and time-lapse satellite data analysis. Fisher et al. (2007); Hampton and Horton (2007); Jones and Hajek (2007);

Nichols and Fisher (2007), and Gulliford et al. (2014) have provided qualitative characterisations of ancient fluvial floodplain deposits exposed in outcrop and proposed and/or applied conceptual models for their stratigraphic evolution. Jordan and Pryor (1992); Pranter et al. (2008, 2009); McKie (2011a), and Ford and Pyles (2014) have presented quantitative reservoir-architecture studies of heterogeneous fluvial intervals based on outcrop and subsurface data. These authors have acknowledged the contribution of crevasse-splay sheet sands to connected reservoir volumes, but focussed on channel and bar deposits which constitute the highest-quality reservoir sandstones. A dedicated study of overbank splay geometries has been conducted by Mjøs et al. (1993), who established geometric ratios and rudimentary volume estimates based on outcrop analogues. A more in-depth examination is needed to better assess the (secondary) reservoir potential of crevasse splays and their impact on reservoir connectivity.

Floodplain deposits are abundant in the distal part of low-gradient dryland river systems fringing endorheic basins, such as the Huesca fluvial fan, Ebro Basin, Spain (e.g., Nichols and Fisher, 2007). The distal part of the fluvial system is characterised by one single active channel with a downstream-decreasing bankfull capacity (Tooth, 2000, 2005; Nichols and Fisher, 2007; Weissmann et al., 2010; Donselaar et al., 2013; Li and Bristow, 2015). This has been attributed to: (1) a gradient-induced loss in flow energy, and (2) a transmission loss due to high

* Corresponding author.

E-mail addresses: k.a.vantoorenburg@tudelft.nl (K.A. van Toorenburg), m.e.donselaar@tudelft.nl (M.E. Donselaar), niels.noordijk@vanoord.com (N.A. Noordijk), gertjan.weltje@kuleuven.be (G.J. Weltje).

¹ Present address: Van Oord B.V., P.O. Box 8574, 3009 AN Rotterdam, The Netherlands.

percolation and evapo-transpiration rates. The downstream decrease in cross-sectional area makes the channel prone to extensive overbank deposition during short episodes of peak discharge (Donselaar et al., 2013). Similar depositional and climatological conditions characterised Permo-Triassic basins throughout the Central and North Atlantic margins (Williams and McKie, 2009; McKie, 2011b), including now gas-prolific plays in Northwest Europe (e.g., Geluk, 2007a, 2007b; Donselaar et al., 2011).

In this study, an analysis is presented of thin-bedded floodplain deposits in the distal part of the Huesca fluvial fan. Depositional mechanisms explaining the occurrence of intervals of stacked crevasse splays will be proposed. Understanding these processes and their preserved sedimentary architecture improves connectivity estimations of subsurface floodplain reservoirs and aids the interpretation of low net-to-gross fluvial stratigraphy.

2. Geological setting

The Huesca fluvial fan is located on the northern fringe of the Ebro Foreland Basin in northeast Spain (Fig. 1A). The basin formed during the Cenozoic in the Pyrenean Phase of the Alpine Orogeny. It is bounded by the Sierras Marginales thrust front to the north and the Iberian and Catalan coastal ranges to its SW and SE, respectively. From the late Oligocene to the late Miocene, the centre of the basin was occupied by a lake undergoing cycles of water-level fluctuations, which caused km-scale migrations of the shoreline over a low-gradient coastal plain. Alternations of lacustrine clastic sequences with carbonates and evaporites led Arenas and Pardo (1999) to associate high lake levels with a relatively humid paleoclimate, whereas low lake levels were linked to a more arid playa-lake environment.

The Huesca fluvial system derived its sediment from the high Pyrenees as well as the uplifted South Pyrenean Foreland Basin to its north. Sediments of the Huesca fluvial system entered the Ebro Basin through a 15–20 km wide gap formed by a fractured zone in the Sierras Marginales thrust sheet, which acted as its line source (Donselaar and

Schmidt, 2005). The fan has a ~60 km radius and shows a change in fluvial style from amalgamated braided streams in its proximal reaches to meandering channels and eventually unconfined terminal lobes towards its distal fringe (Nichols and Fisher, 2007; Fisher et al., 2007) (Fig. 1A).

Low net-to-gross floodplain deposits are abundant in the distal part of the fluvial system (Nichols and Fisher, 2007). Here, channel deposits comprise <10% of the overall stratigraphy (Hirst, 1991). Their low-sinuuous ribbon geometry (width-to-thickness ratio <15) has been attributed to a limited longevity, as channels avulsed prior to any substantial lateral migration (e.g., Friend et al., 1979; Hirst, 1991; Nichols and Fisher, 2007). Thin-bedded sandstone sheets are common and frequently extend from the top of channel deposits as ‘wings’, continuing into the channel-fill sandstone (Friend et al., 1986; Hirst, 1991; Nichols and Fisher, 2007; Fisher et al., 2007). These laterally-extensive sandstone bodies have been interpreted as the result of unconfined sheet flow (Friend et al., 1986), i.e., overbank levees and crevasse splays (Hirst, 1991; Fisher et al., 2007).

3. Methodology

The study area is located to the northeast of Huesca and comprises two outcrop localities spaced approximately 1.6 km apart (Fig. 1B). Natural cliff faces at 1.3 km to the NNW of the *Castillo de Montearagón* fortress (Fig. 1D) cover an approximately 35 m thick interval (Fig. 2A) over an area of 0.2 km². The western cut slope of the *Presa de Montearagón* reservoir dam (Fig. 1C) exposes a 52 m thick succession (Fig. 2B) over a length of 550 m.

The local structural dip was reconstructed in order to accurately correlate data between outcrop localities. A well-developed paleosol at the base of the succession was chosen as a reference horizon, based on the assumption that it developed on a near-horizontal floodplain during a sustained period of inactivity (Kraus, 2002). Sixteen point locations were measured along this horizon with sub-centimetre accuracy using a Trimble R7 differential-GPS (dGPS) set (Parkinson and Enge, 1996).

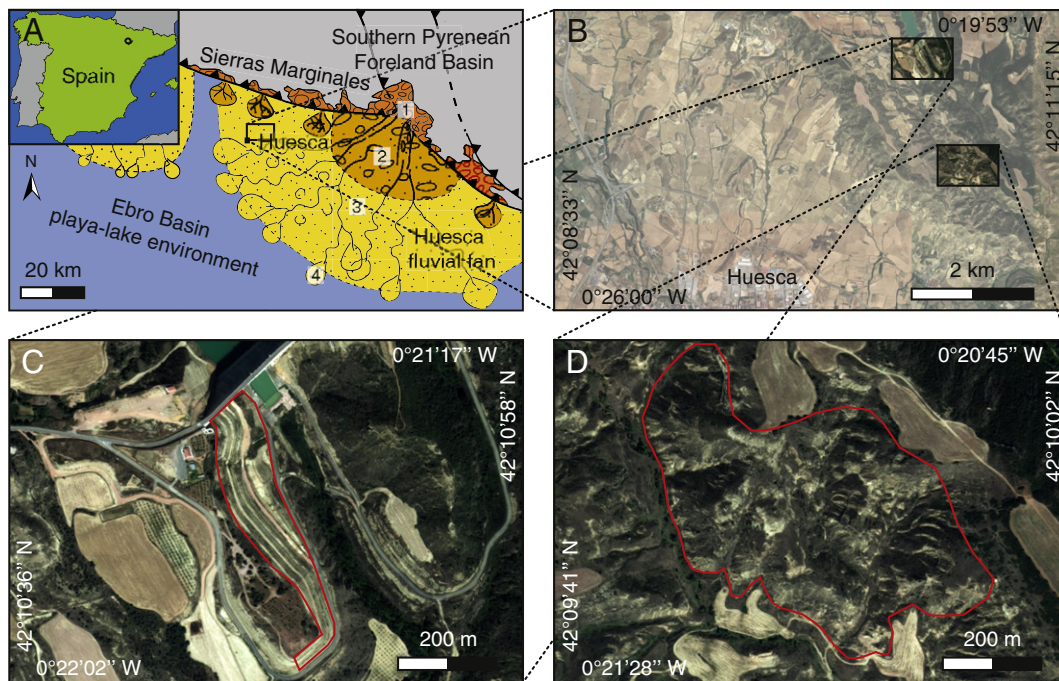


Fig. 1. Study area. (A) Miocene paleogeography of the Huesca fluvial fan showing its line source (1), proximal braid plain (2), distal meandering channels (3), and terminal lobes at the fan fringe (4) (modified from Donselaar and Schmidt (2005)). Inset: map of Spain; black circle indicates location of paleogeographic map. (B) Overview map of outcrop localities NE of Huesca, indicated by boxes (Google Earth Pro). (C) Satellite image of the *Presa de Montearagón* outcrop locality, with the western cut slope encircled in red (Google Earth Pro). (D) Satellite image of the *Castillo de Montearagón* outcrop locality, with the studied cliff faces encircled in red (Google Earth Pro).

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