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Reservoir Architecture and Tough Gas Reservoir Potential of Fluvial Crevasse-splay Deposits

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SUMMARY

Unconventional tough gas reservoirs in low-net-to-gross fluvial stratigraphic intervals may constitute a secondary source of fossil energy to prolong the gas supply in the future. To date, however, production from these thin-bedded, fine-grained reservoirs has been hampered by the economic risks associated with the uncertainties in their geometry, spatial distribution and reservoir properties. This study aims to provide a better insight into the reservoir architecture and tough gas reservoir potential of stacked and interconnected crevasse splays in a fluvial floodplain stratigraphy. Despite their thickness not exceeding decimetre scale, the surface area of individual crevasse splays may be up to several square kilometres and intervals of stacked and interconnected crevasse splays range up to several metres in thickness. Through incision of consecutive crevasse splays into underlying lobes and the channel fill of cut-through avulsed channels, sand-on-sand contact is established, effectively connecting individual splays. The net reservoir volume of single crevasse splays ranges up to several hundred thousand cubic metres, yielding GIIP estimations in the order of several million cubic metres. For intervals of stacked and interconnected crevasse splays, these figures are up to one order of magnitude higher, making them suitable as a secondary reservoir capacity.

Introduction

The Northwest European gas province is a mature area in which the production of natural gas from conventional reservoirs is declining. Unconventional tough gas reservoirs in low-net-to-gross fluvial stratigraphic intervals may constitute a secondary source of fossil energy to prolong the gas supply in the future. To date, however, production from these thin-bedded, fine-grained reservoirs has been hampered by the economic risks associated with the uncertainties in their geometry, spatial distribution and reservoir properties.

As the reservoir potential of fluvial floodplain intervals has been under-acknowledged in conventional hydrocarbon exploration, there is scant published research on the deposition of overbank crevasse splays and their resulting reservoir architecture and quality. Donselaar et al. (2013) and Li et al. (2014) presented studies on the fluvial processes and deposition of sheet sands in a contemporary semi-arid low-stand basin setting. Fisher et al. (2007), Hampton and Horton (2007), Jones and Hajek (2007) and Nichols and Fisher (2007) described and analysed outcrop analogues exposing longer periods of floodplain aggradation, channel avulsions and overbank deposition in similar settings. A reconstruction of low-net-to-gross fluvial stratigraphy based on subsurface core and well log data was presented by Donselaar et al. (2011).

This study aims to provide a generic model for the reservoir architecture of stacked and interconnected crevasse-splay deposits in a fluvial floodplain stratigraphy. In this paper, current insights and their implications for reservoir volumes are briefly elucidated.

Data and methods

The approach employed in this study is to integrate data from three complementing settings:

- Modern-day fluvial systems: the medial and distal zones of the Río Colorado fluvial system, Altiplano Basin, Bolivia, provide insights into the sedimentary processes and resulting deposition of crevasse splays in a semi-arid endorheic basin. Fieldwork data include aerial photographs, grain-size samples and differential-GPS measurements.
- Outcrop analogues: outcrops of the Cenozoic Huesca fluvial fan, Ebro Basin, Spain, display floodplain stratigraphy build-up over longer time frames, revealing stacking patterns and long-term trends. Fieldwork data include three-dimensional interpretation panels, lithological logs and grain-size samples
- Subsurface data: core and well log data from the gas-prolific U. Permian and Triassic intervals of the West Netherlands Basin are used to extract the subsurface expressions and petrophysical properties of fluvial crevasse splays under reservoir conditions. The data include well logs, slabbed cores and core plug measurements.

Conceptual static reservoir-architecture models are constructed by the data analysis of sediment body geometries, trends and facies distributions. The acquired data will be used to confine and validate process-based models, which in turn yield generic three-dimensional reservoir models and, ultimately, a predictive modelling approach for the exploration and development of crevasse-splay complexes as tough gas reservoirs.

Geometry of individual and amalgamated crevasse splays

Individual crevasse splays form lobate sand beds with surface areas up to several square kilometres, originating from a point source (a breach point in the levee of the main channel). The thickness of these lobes ranges from centimetres to decimetres, decreasing from proximal to distal along the main current direction and laterally, perpendicular to the lobe axis. Dendritic distributary crevasse-splay channels build up levees and may have an erosional base near the splay apex due to high current velocities and back-stepping reflux erosion.

Crevasse splays fill up the accommodation space by compensational stacking, resulting in amalgamation with adjacent crevasse splays (Li et al., 2014). When the increase in accommodation rate exceeds sediment supply, crevasse splays originating from a single levee breach point may stack vertically. Typically, the bottom-most crevasse splay conformably overlies a well-developed paleosol, signifying the end of a period of non-deposition (Kraus, 2002). Subsequent splays incise into the underlying elevated topography in the proximal part (Figure 1) and build out further onto the floodplain, detaching and fingering out laterally away from their apex. Intervals of stacked crevasse splays reach up to several metres in thickness and seem to occur periodically in floodplain stratigraphy.

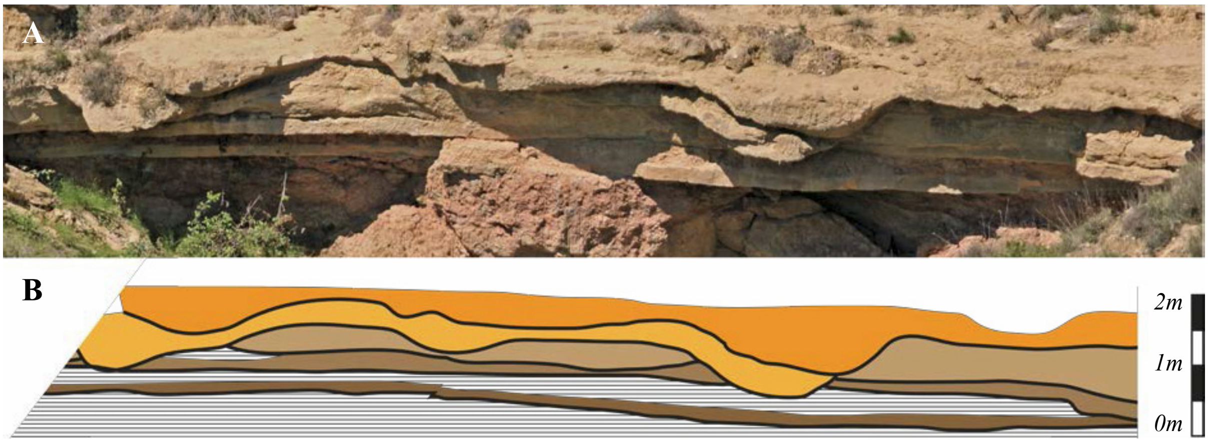

Figure 1 *Stacked crevasse splays overlying a well-developed paleosol and incising underlying deposits (view perpendicular to paleoflow).* ***A)*** *Photo panel.* ***B)*** *Interpretation indicating consecutive deposits in different colours.*

Crevasse splays and crevasse-splay complexes may be incised by the main fluvial channel after a successful avulsion. As the depth of incision can exceed the thickness of an interval of stacked crevasse splays, it is significant in assessing connectivity.

Grain-size distribution

The grain-size distribution in crevasse splays is composed of two main fractions with different modes of deposition. The coarser fraction (generally up to very-fine sand) is deposited during peak runoff as high-density suspended load breaks out of the main channel confines and becomes subject to a waning flow regime, often manifested by climbing ripples. The mean grain size of this fraction seems to decrease away from the splay apex and with increasing distance from the distributary crevasse splay channels. The finer fraction settles out of suspension at a later stage from a body of (near) standing water, expressed in horizontal laminae.

Where stacked crevasse splays incise into underlying deposits, sand-on-sand contact is established, effectively connecting the coarser-grained fractions of individual crevasse splays. The consecutive deposits form a coarsening-upward succession (Figure 2), resembling that of prograding deltaic deposits.

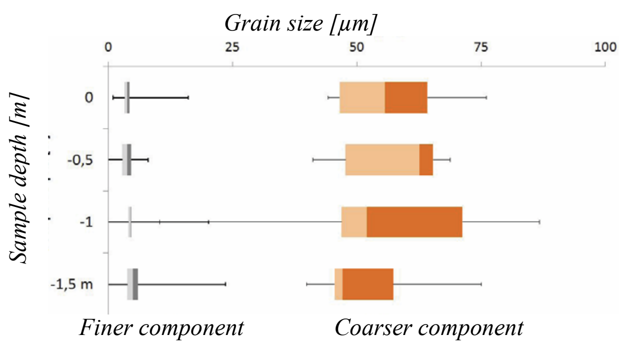

Figure 2 *Vertical median grain-size distribution in an interval of stacked crevasse splays (n = 20).*

Avulsed channels cutting through underlying crevasse-splay deposits contain a channel lag of bed-load sediment, comprising the coarsest available grain sizes. After abandonment, the channel is filled with floodplain fines. However, as the remaining channel topography significantly decelerates overbank flow, coarser crevasse-splay sediments may also be trapped in its depression. The grain-size composition of channel-fill deposits can therefore be heterogeneous and enhance the connectivity of crevasse-splay deposits.

Reservoir volume estimates

Despite its small thickness, the net reservoir volume of a single crevasse splay ranges up to several hundred thousand cubic metres. For an interval of stacked crevasse-splay deposits, the volume of interconnected reservoir can range up to several million cubic metres.

Taking conservative averages for the petrophysical properties from available core plug measurements (Table 1), estimations for the gas initially in place (GIIP) at hypothetical reservoir conditions can be made (Equation 1). For individual crevasse splays, the GIIP may be up to several million cubic metres. The GIIP in an interval of stacked and interconnected crevasse splays can range up to several tens of millions of cubic metres. A floodplain stratigraphy may comprise multiple of these intervals.

Table 1 *Petrophysical properties at hypothetical reservoir conditions used for GIIP estimation.*

Property	**Value at hypothetical reservoir conditions (~3 km depth)**	
	Single crevasse splay	Interval
Net reservoir volume (*NRV*)	$\sim 2 \cdot 10^5\ m^3$	$\sim 2 \cdot 10^6\ m^3$
Porosity (φ)	~ 0.05	~ 0.05
Gas saturation (S_g)	~ 0.8	~ 0.8
Gas formation volume factor (B_{gi})	$\sim 2.7 \cdot 10^2$	$\sim 2.7 \cdot 10^2$
Gas initially in place (*GIIP*)	$\sim 2 \cdot 10^6\ m^3$	$\sim 2 \cdot 10^7\ m^3$

$$GIIP = NRV \cdot \varphi \cdot S_g \cdot B_{gi} \qquad \textbf{\textit{Equation 1}}$$

The recovery factor and the production mechanisms for this type of tough gas reservoir are the subject of ongoing research. GIIP volumes of crevasse-splay reservoirs alone are insufficient to be developed economically. However, they may be viewed as a secondary reservoir capacity and, as such, be developed at a low investment cost.

Conclusions

Through this study, new insights have been obtained regarding the reservoir architecture of interconnected crevasse-splay deposits and its impact on reservoir potential. Despite their thickness not exceeding decimetre scale, the surface area of individual crevasse splays may be up to several square kilometres and intervals of stacked and interconnected crevasse splays range up to several metres in thickness. Through incision of consecutive crevasse splays into underlying lobes and the channel fill of cut-through avulsed channels, sand-on-sand contact is established, effectively connecting the coarser grain-size fraction in individual splays. The net reservoir volume of single crevasse splays ranges up to several hundred thousand cubic metres, yielding GIIP estimations in the order of several million cubic metres. For intervals of stacked and interconnected crevasse splays, these figures are up to one order of magnitude higher.

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