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Research paper

Sedimentology and alluvial architecture of the Bajo Barreal Formation (Upper Cretaceous) in the Golfo San Jorge Basin: Outcrop analogues of the richest oil-bearing fluvial succession in Argentina

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A B S T R A C T

This study addresses the sedimentology, architecture and dimensions of fluvial deposits in the Bajo Barreal Formation (Upper Cretaceous) in the Codo del Senguerr anticline, Golfo San Jorge Basin, Argentina. The stratigraphic framework of the 450–650 m thick alluvial succession was carried out through description and interpretation using 18 detailed sedimentary logs along a 4.5 km wide exposure, where 314 fluvial channels were analysed. The Bajo Barreal Formation is a high-accommodation fluvial succession, dominated by fine-grained floodplain deposits, with isolated-to-vertically stacked, sheet-like, low-sinuosity or braided fluvial channels of limited lateral mobility clustered in several coeval channel belts, in which fluvial channels were relocated by avulsion. The Lower Member consists of reworked ash-fall materials preserved in floodplain areas (78%), floodplain sandstones (4%) and fluvial channels (18%). The mean thickness of sandbodies is 2.96 m (n = 118) and mean true width is 112 m (mean W:T = 43), with thicker and wider sandbodies in upper levels of the Member. The Upper Member consists of grey siltstones and mudstones preserved in extensive lowland areas (78%) and fluvial channels (19%), with scarce preservation of sandstones in the proximal floodplain (3%). Fluvial channels are narrow low-sinuosity sheets with comparable thickness (mean = 3.21 m, n = 196), but greater width than those of the Lower Member (mean width = 147 m, mean W:T = 50). Paleoflow data from 298 fluvial sandbodies indicates a paleoflow direction toward the SE (Az. 112°). Rivers flowed parallel to inherited early Cretaceous normal faults and are oriented to high-angle (>70°) to the current axis of the Codo del Senguerr anticline, suggesting that the uplift of the anticline occurred after the deposition of the formation. The variation in geometry of fluvial channels in both Members of the Bajo Barreal Formation could help in planning and developing primary and/or enhanced oil recovery projects in nearby oilfields, and provide data necessary for modelling the subsurface connectivity of hydrocarbon reservoirs.

1. Introduction

Fluvial systems are heterogeneous on a variety of scales, from microscopic to megascopic (Weber and van Geuns, 1990; Ambrose et al., 1991; Jordan and Pryor, 1992; Miall, 1996; Lynds and Hajek, 2006; Bridge, 2003, 2006), as documented in a wealth of sedimentary studies of outcrops and modern systems. Coarse-grained components of ancient fluvial systems contain more of the 20% of the remaining reserves of hydrocarbon in the world, and are an important reservoir type for the petroleum industry. Their importance has resulted in research focused on understanding the internal and external complexity of reservoir types (Miall, 1996; Bridge and Tye, 2000; Bridge, 2003; Labourdette, 2011), modelling of their behaviour (Bridge and Leeder, 1979; Karssenberg et al., 2001; Keogh et al., 2007), and recovery of hydrocarbons (Tye, 1991; MacDonald and Halland, 1993; Hamilton et al., 1998; Root et al., 2005; Kjemperud et al., 2008).

The Golfo San Jorge Basin in central Patagonia (Fig. 1A) provides 47% of the liquid hydrocarbons in Argentina. About 90% of this hydrocarbon comes from fluvial channels in the Upper Cretaceous Bajo Barreal Formation. The remaining production is obtained from the Albian Castillo Formation, with minor production from the underlying Pozo D-129 Formation. Because of its prolific

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hydrocarbon production and remaining potential, the Bajo Barreal Formation has been extensively studied since the middle of the past century (Feruglio, 1949a,b; Lesta and Ferello, 1972; Lesta et al., 1980). The analysis of outcrop exposures in the San Bernardo Fold Belt (Fig. 1B) (Sciutto, 1981; Meconi, 1990; Figari et al., 1990; Legarreta et al., 1993; Hechem et al., 1990; Hechem, 1994, 1997; Bridge et al., 2000; Bellosi et al., 2002; Umazano et al., 2008, 2009, 2012) have shown large variability in facies and environment along the exposures, and variable importance of volcaniclastic materials in different areas of the basin. A huge amount of subsurface information including seismic surveys, wireline logs and cores (Brown et al., 1982; Clavijo, 1986; Barcat et al., 1989; Fitzgerald et al., 1990; Figari et al., 1999; Uliana and Legarreta, 1999; Sylwan, 2001; Rodriguez and Littke, 2001; Hechem and Strelkov, 2002; Sylwan et al., 2008) have been used to reconstruct the tectono-stratigraphic evolution of the basin, and to define the extension of hydrocarbon reservoirs. In the last 30 years, most of the subsurface research has been conducted correlating and mapping multiple, thin, isolated and discontinuous fluvial channels, which constitute the main hydrocarbon reservoirs (Sanagua et al., 2002; Rodriguez and Aguirre, 2015; Giampaoli, 2015). Although considerable research has been conducted on the sedimentology of the unit, little data has been published on the large-scale variability of the fluvial systems, or on the changes in its sandstone-body dimensions at outcrops. Exceptions include the detailed measurements on photomosaics of Bridge et al. (2000) and Umazano et al. (2012). In this paper, we present sandstone-body dimensions measured with GPS of 312 fluvial channels in both Members of the Bajo Barreal Formation in an area close to some of the main oilfields in the basin (Fig. 1B).

The aim of this study is to document the spatial and temporal variation in the sedimentology and alluvial architecture of the Bajo Barreal Formation along a 4500 m wide exposure in the eastern limb of the Codo del Senguerr anticline, to assess its potential as an analogue of hydrocarbon reservoirs in nearby oilfields. The specific objectives of this study are (1) to analyse the alluvial sedimentology and architecture of the Lower and Upper Members, (2) to quantify the dimensions (true width/thickness) of fluvial channels of both Members, (3) to provide useful information for primary and/or enhanced oil recovery practices, and (4) to analyse the coeval tectonic scenario based in the evolution of fluvial systems and paleoflow data. The sedimentological and tectonic implications of the approach followed in this study can be of interest to geologists working in fluvial successions in other geological settings. We hope the data will be also useful to geoscientists and engineers as they consider subsurface fluid flow problems in fluvial successions.

2. Geological framework

The Golfo San Jorge basin is a dominantly extensional basin superimposed on Paleozoic continental crust formed as a response to the break-up of the Gondwana supercontinent during the Jurassic and Early Cretaceous (Barcat et al., 1989). The infill of the basin started during the Middle to Upper Jurassic (Fig. 2), with deposition of a thick succession dominated by basalts, rhyolites and ignimbrites known as the Lonco Trapial or Bahía Laura Groups (Lesta and Ferello, 1972), representing the climax of the rift event that led to the fragmentation of Gondwana in southern South America. A second extensional event took place in the uppermost Jurassic and Early Cretaceous, with the development of E–W, NNW–SSE or NE–SW striking half-grabens, filled by black shales and wedge-shaped, sandstone bodies of lacustrine origin (Figari et al., 1999). These strata composed the Las Heras Group, and are only preserved in the subsurface.

The Barremian Patagonidic tectonic phase (compressional) in the Andean Ranges resulted in an eastward shifting of the main depocentres of the basin over a regional unconformity, and the incorporation of large volumes of pyroclastic detritus. At the same time, the generation of new WNW–ESE to E–W striking normal faults (Uliana et al., 1989; Paredes et al., 2013; Ramos, 2015) resulted in the creation of accommodation space for the deposition of the Chubut Group (Barremian to Campanian?) in fluvial and lacustrine environments (Hechem et al., 1990; Hechem and Strelkov, 2002). The Chubut Group mainly crops out in the San Bernardo Fold Belt, which was formed as a result of the tectonic inversion of extensional depocentres during the Cenozoic (Peroni et al., 1995; Homovc et al., 1995), although more recent studies (Navarrete et al., 2015; Gianni et al., 2015a,b) have suggested that the uplift of the San Bernardo Fold Belt started during the deposition of the Castillo Formation (Albian).

The Chubut Group is mape up of six continental formations: Pozo D-129, Matasiete, Castillo, Bajo Barreal, Laguna Palacios and Lago Colhué Huapi formations (Fig. 2). Initial sedimentation occurred in a widely distributed lacustrine unit (Pozo D-129 Formation - Barremian to Aptian) which was sourced from the north by fluvial systems within the Matasiete Formation (Sciutto, 1981; Paredes et al., 2007). Both units are overlain by the Castillo Formation (Albian), equivalent to the Mina del Carmen Formation in the subsurface (Lesta, 1968), which contains a large proportion of

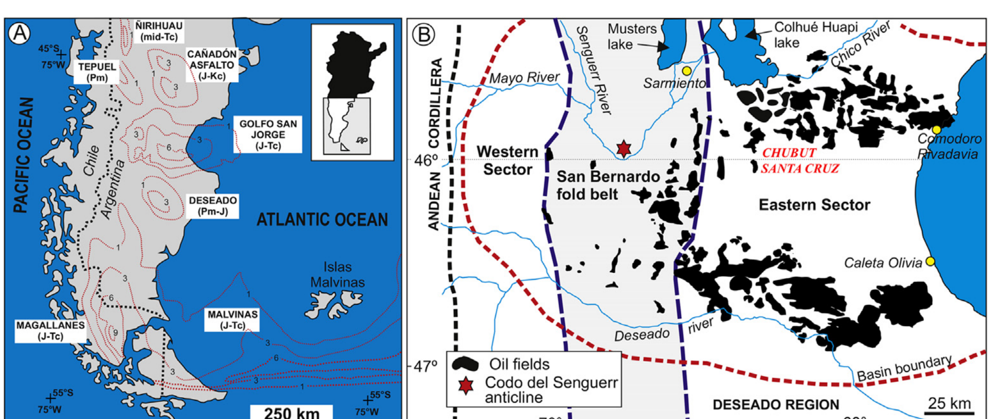

Fig. 1. **(A)** Location map of the Golfo San Jorge Basin and nearby basins in central Patagonia, Argentina. **(B)** Main structural regions of the Golfo San Jorge basin and boundaries of the basin, with indication of main localities. The major oilfields in the basin are indicated in relation to the location of the Codo del Senguerr anticline (star).