Understanding Avulsion Events in a Tropical River - Applications for Fluvial Reservoirs

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Abstract

Improvements in interpretation, characterization and modelling of fluvial reservoirs are needed to unlock the vast amounts of hydrocarbons hosted in fluvial reservoirs. The lateral continuity of sand-bodies as well as sandstone and mudstone distributions is often hard to predict, especially when channel bodies are below seismic resolution. In such cases, reliance on depositional models and scaling relationships are essential.

The understanding of avulsion events offers a process-based approach for unraveling controls in facies distribution and stratigraphic architecture in fluvial systems. Here we present the evolution of a 2007 avulsion event that took place in the anabranching reaches of the tropical Magdalena River, Colombia. The investigation of this recent event offers an exceptional opportunity for understanding the formation of avulsion belts and their deposits as well as the relationship between river morphology and grain size at field and reservoir scales. Preservation potential in this basin is high as more than 1000 m of fluvial deposits have been preserved during the last 5 Ma. This analogue is particularly relevant for the fluvial reservoirs of the Mungaroo Formation, which hosts vast resources of hydrocarbons in the North West Shelf of Australia.

Background and Regional Setting

The Magdalena River is a major fluvial system that drains most of the Colombian Andes. It has the highest sediment yield, ~ 850 T/km^2/yr, of all the rivers terminating on the Caribbean Sea (Restrepo and Syvitski, 2006). The Magdalena River has a drainage basin area of 257,438 km^2 and extents for 1612km (Restrepo et al., 2006). It starts at La Magdalena lagoon at an elevation of 3685 m; it then flows along the intermontane basin bounded by the Eastern and Central Cordillera of the Colombian Andes. At the town of El Banco, the Magdalena River intersects the buried end of the Central Cordillera and divides into multiple anabranching channels, this section is known as the Mompox tectonic depression (Smith, 1986; Kettner et al., 2010). Swamps, marshes and lakes are also predominant in this section of the floodplains of the Magdalena River (Fig. 1). The two main branches are the Brazo de Mompox and the Brazo de Loba, the first one used to be the main fluvial route during 1500-1700; whereas today the most transited branch is Brazo de Loba. Historic maps corroborate that the anabranching system in the Mompox tectonic depression has been active for centuries. Additionally, this depocenter has preserved more than 1000 m of fluvial sequences during the last 5 Ma (Potter, 1997). At the end of the Mompox tectonic depression the anabranching channels converge into a single channel and the river planform is meandering until it finally forms a delta and terminates into the Caribbean Sea.

The Magdalena basin is characterized by high precipitation with an average rainfall of 2050 mm/yr for the entire basin (Instituto de Hidrología, Metereología y Estudios Ambientales, IDEAM, 2001). There are two wet and two dry seasons, which generate a bimodal river pattern discharge, with a lower peak in June and a higher peak in November or December. The meridional oscillation of the Intertropical Convergence Zone (ITCZ) controls the annual hydrological cycle and defines these two rainy seasons (Restrepo et al., 2014). The first season extends from May to June, when the ITCZ is migrating from north to south. The second and stronger season lasts occur when the ITCZ shifts northward.

The anabranching reach investigated in this study is located 30 km downstream of El Banco (Fig. 1). In 2007, an avulsion event took place in the location of the field site, generating multiple channels that are now fully established (Fig. 2). Based on discharges recorded at the closest gauging station to the field site, ~ 200 km downstream, high magnitude discharges and associated floods have occurred since 2007. The discharges since 2007 have been the largest of at least a 70-year record. It must be noted that several large tributaries converge between the field site and the gauging station location, but Brazo de Loba is the largest contributor to discharge at the gauging site.

Methods

Satellite image mapping was carried out in ArcGIS to provide a description of the geomorphic elements as well as their dimensions. Topographic transects were surveyed using a Real Time Kinematic GPS to capture changes in elevation along the floodplain and to ground-truth the remote mapping. Sediment samples were collected for quantitative analysis of grain size to record lithological changes. Changes in channel depth and their relation to channel geometry were recorded while conducting a bathymetric survey.

Results and Discussion

Our results suggest that thalweg location plays a role in the location of the avulsion node (Fig. 3). The occurrence of the avulsion event is likely due to high discharge magnitudes in 2007 and frequent floods afterwards (e.g. 2010). The frequent floods during 2007-2010 enabled the erosion and maintenance of the newly formed channels. These frequent floods are the result of high rainfall episodes associated with La Niña events. The open question is whether the newly formed channels will continue to erode, whether they are presently stable, or whether they will infill; each channel may evolve differently with time. It is possible that, over time, one of these channels will become dominant and increase in size while the other channels will infill.

The difference in width and depth between the newly formed channels and the main channel highlights the fact that these datasets have to be put in context. At first, the data seems to show a wide range of values but when considering the timing of their formation, patterns can be extracted. For example, the main channel is wider and deeper than the newly formed channels. Width and depth decrease in the newly formed channels as the number of channels increase. This trend can be explained by a decrease in flow competence as the discharge is divided into multiple channels. Understanding the controls and factors governing the change in channel dimensions has relevant implications for petroleum reservoir characterization and reservoir modeling.

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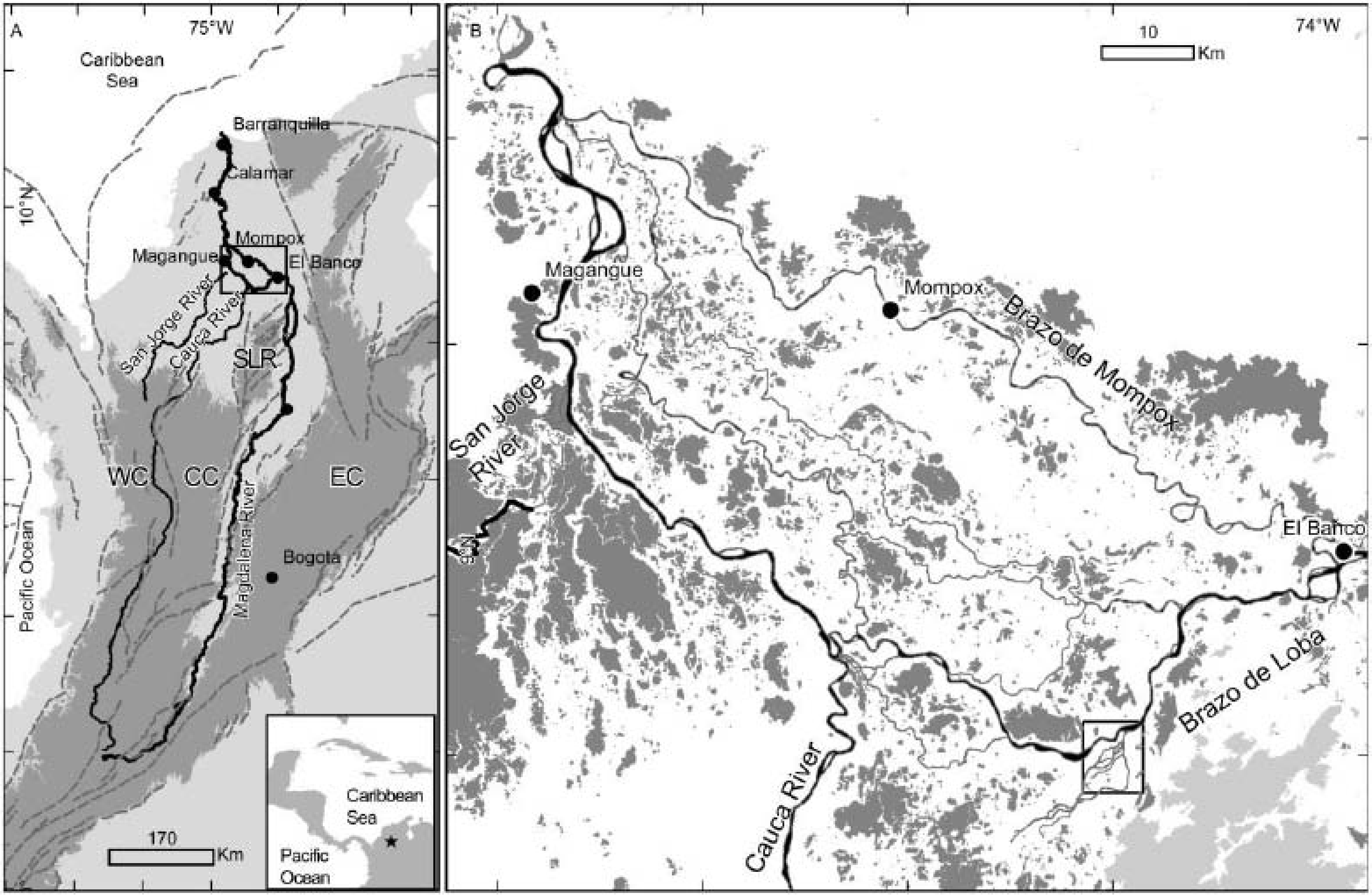

Figure 1. A) Location map showing the Magdalena River and the Colombian Andes. The Magdalena River is depicted by the black thick line and its major tributaries by the thinner black lines; major faults are shown in dashed dark grey lines, the black rectangle displays the area of the image presented in Figure 1B.WC= Western Cordillera, CC= Central Cordillera, EC= Eastern Cordillera. Star on inset shows the location of the field site within South America. Elevation data from shuttle radar topography mission (USGS, 2006). B) Map showing the distribution of major active channels, lakes and marshes (dark grey). Minor channels outside of the area enclosed by the Brazo de Loba and Brazo de Mompox and outside of the study area have not been included on the figure for simplicity. The rectangle depicts the main study area, which is presented in Figure 2.

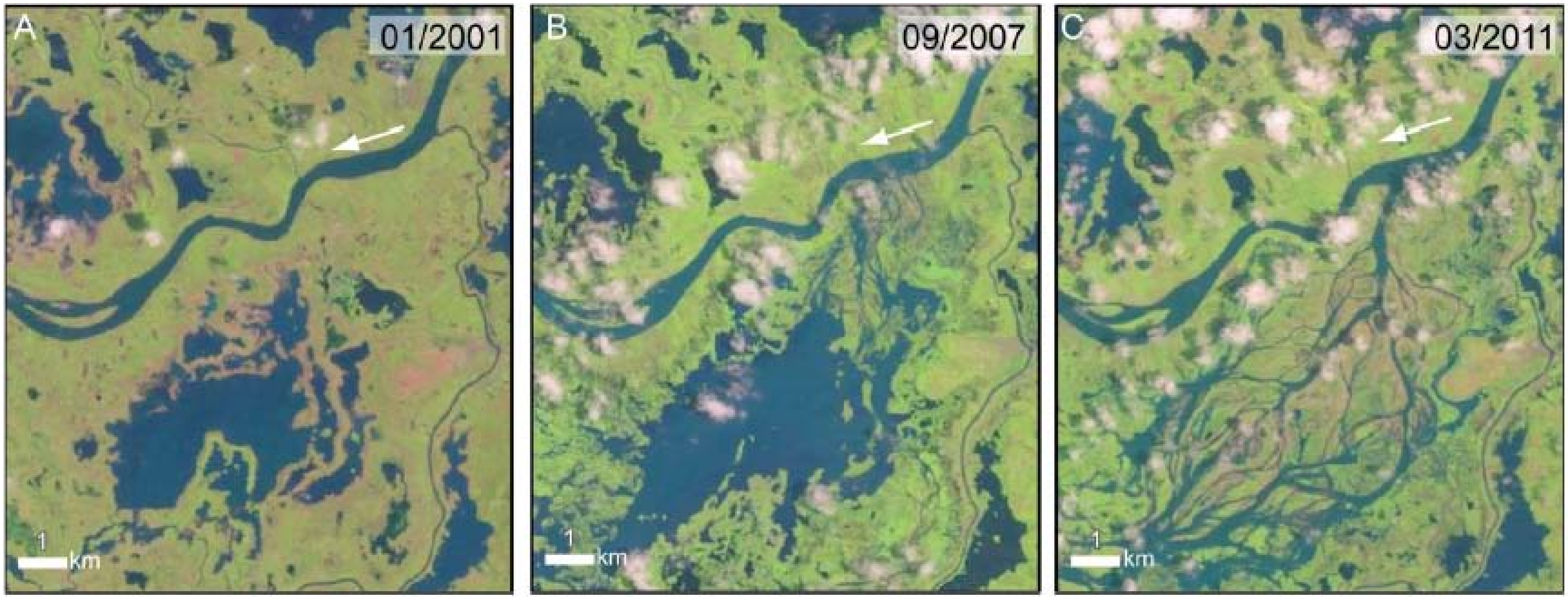

Figure 2. Satellite image of the field site from A) 2001, B) 2007 and C) 2011; notice the presence of multiple channels. Arrow in all the figures shows flow direction.

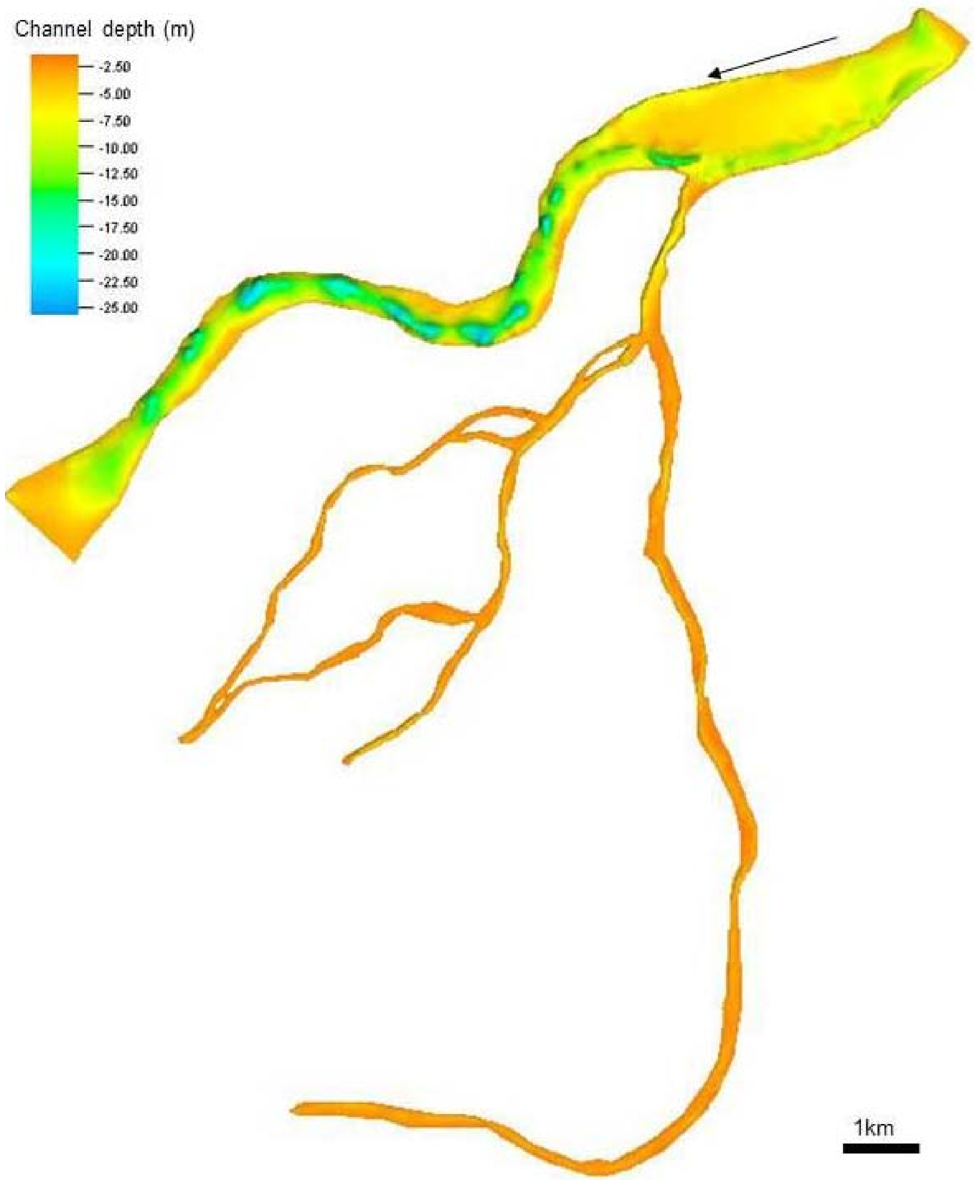

Figure 3. Interpolated bathymetry of the study site. A forced elevation of 3 and 1.7 was added to the channel boundary of the trunk and the secondary anabranches respectively. The channel depth is relative to the enforced bank height. Arrow shows flow direction.