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Bankfull discharge as a key control on submarine channel morphology and architecture: Case study from the Rio Muni Basin, West Africa

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ABSTRACT

Bankfull discharges play a pivotal but underappreciated role in determining submarine channel morphometrics and architecture. This hypothesis is suggested by the power law relationship between channel morphometrics and discharge and the logarithmic relationship between channel architecture and discharge. We apply this relationship to the Rio Muni deep-water channels of Equatorial Guinea in three ways. Firstly, relatively dilute turbidity currents with a relatively low discharge of *ca.*1.1 × 10^4 to 6.9 × 10^4 m^3/s tended to enhance channel confinement and thalweg deposition, but to discourage lateral spreading of the flow. This, in turn, reduced depth and sinuosity (*SI*) of the channel form as the fill aggraded, as previously reported for younger channels on this slope. These vertically aggraded channel belts [represented by relative angles of channel trajectories (T_c) ranging from 47.2° to 81.0°] are narrower (averaging 634 m), thinner (averaging 23 m), and straighter (mean value of *SI* = 1.17) than their laterally migrated counterparts. Secondly, turbidity flows with a relatively high discharge of *ca.*4.1 × 10^4 to 15.8 × 10^4 m^3/s appear to have reduced channel confinement, but to promote thalweg erosion and lateral spreading of the flow. This, in turn, increased depth and sinuosity of the channel form as it laterally migrated, forming laterally migrated channel belts (represented by a relatively low T_c of 21.8° to 49.0°) that are wider (1.5×), thicker (2×), and more sinuous (1.2×) than their vertically aggraded counterparts. Thirdly, a gradual decrease of discharge through time likely drove an architectural transition from lateral migration to vertical aggradation and associated migrating-to-aggrading channel trajectories.

1. Introduction

Submarine canyons or channels, first highlighted by Shepard (1936), have long been a focus of deep-water sedimentology and stratigraphy (Wynn et al., 2007; Peakall and Sumner, 2015; de Leeuw et al., 2016). This is because they: (i) act as the main conduits for sediment transport across ocean floors, giving rise to the largest sedimentary accumulations on the planet (Posamentier and Walker, 2006; Peakall and Sumner, 2015; de Leeuw et al., 2016); (ii) are repositories for economically important hydrocarbon reservoirs (Mayall et al., 2006; Janocko et al., 2013a); (iii) preserve critical paleoclimatic and paleoceanographic signals from their neighboring regions (Gingele et al., 2004; Gong et al., 2016); (iv) are important conveyers of nutrients and carbon into the deep ocean (Galy et al., 2007; de Leeuw et al., 2016; Reimchen et al., 2016). Despite their significance and many years of study, our understanding of deep-water channels is still relatively poor, and comparison is still frequently made with their much better documented terrestrial counterparts (*i.e.*, rivers) (Peakall et al., 2012; Jobe et al., 2016). Deep-water channels are a consequence of the dynamic interplay of turbidity currents and the evolving seafloor (de Leeuw et al., 2016). However, it remains elusive that how bankfull discharge (*Q*) of turbidity currents controlled channel morphometrics and architecture. The present study utilizes three-dimensional (3D) seismic data from the Rio Muni Basin of Equatorial Guinea, West Africa to: (i) investigate kinematics and their corresponding architectural styles and morphometric properties of the studied deep-water channels and (ii) to address how turbidity current discharge can determine morphology and architecture of submarine channels with migrating-to-aggrading channel trajectories. Results from this study contribute to an improved understanding of the role of sediment discharges in determining kinematics and stratigraphic architecture of deep-water channels.

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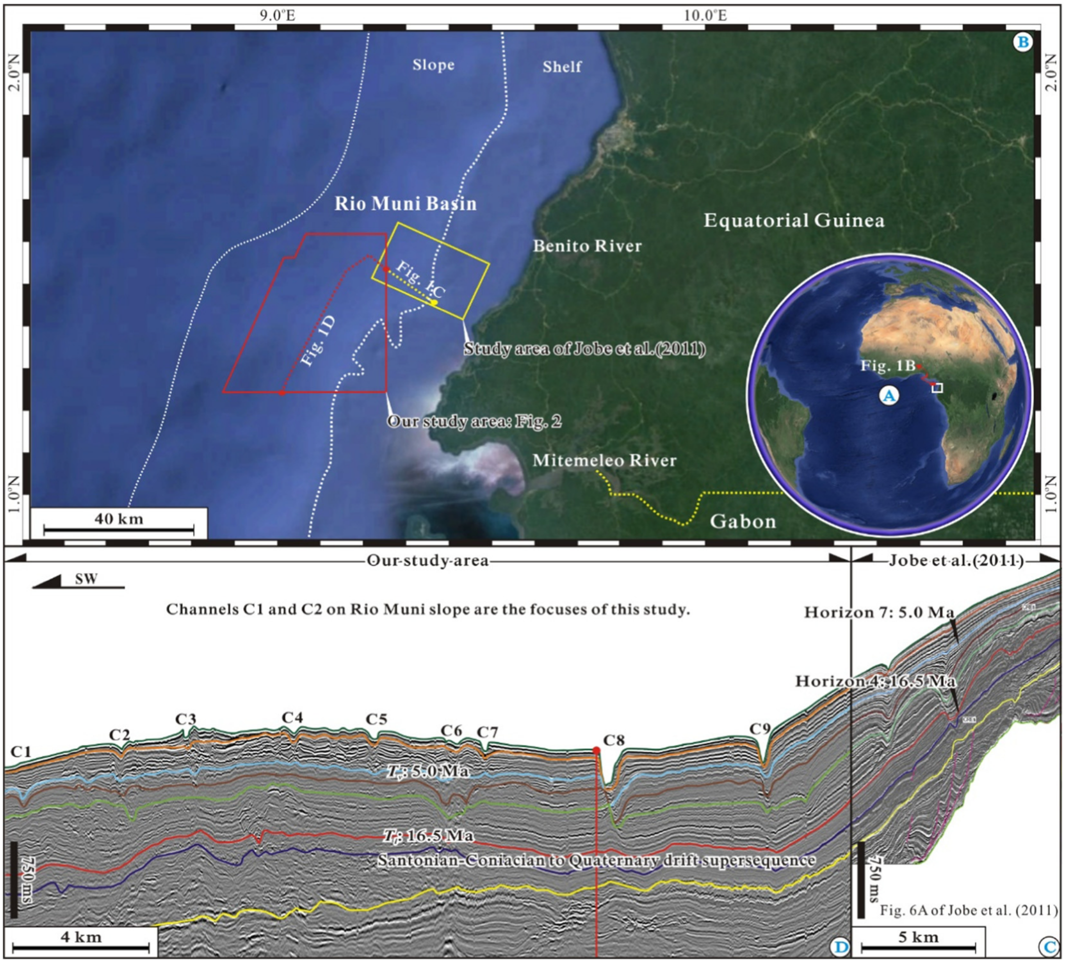

Fig. 1. (A) Geographical context of the study area of the Rio Muni Basin along the West African Margin. Location of map shown in (B) is labeled. (B) Map of the West African margin showing the geological context of the study area (red box), the location of the study area of Jobe et al. (2011), and regional plan-view locations of seismic lines shown in Fig. 1C and D. (C and D) Regional arbitrary seismic lines (line locations shown in panel B) illustrating stratigraphic architecture of the Rio Muni margin. The arbitrary seismic lines of Fig. 1C and D correlate unconformities of T_v and T_l to Horizon 4 (16.5 Ma) and Horizon 7 (5.0 Ma) of Jobe et al. (2011). Seismic line of Fig. 1C is compiled from Jobe et al. (2011), respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Geological context and the study area

Our study area is located in the Rio Muni Basin of Equatorial Guinea, West Africa, with current water depth ranging from 50 to 2000 m, and is adjacent to the study area of Jobe et al. (2011) (Fig. 1A and B). However, Jobe et al. (2011) considered canyon development from Cretaceous to present on this margin, but focused on the modern Rio Benito Canyon system. The Equatorial Guinea margin has an average shelf width of *ca.* 18 km, with the modern slope break located in the water depth of *ca.* 100 m (Fig. 2) (Jobe et al., 2011). The modern Equatorial Guinea slope is fairly steep, with the average slope gradient of up to 2.5° (Fig. 2) (Pratson and Haxby, 1996). The present study area of the Rio Muni Basin is currently not linked updip to the major fluvial drainage systems on the West African continent, such as Mitemeleo and Benito Rivers shown in Fig. 1 (see also Jobe et al., 2011).

Rio Muni Basin shows a complex tectonostratigraphy, and experienced three main stages of tectonic-stratigraphic evolution, namely a rift stage from 117 to 106 Ma, a rift-drift transitional stage from 106 to 89 Ma, and a drift stage from 89 Ma to present (Turner, 1995; Meyers et al., 1996; Jobe et al., 2011). Accordingly, the infill of the Rio Muni Basin can be divided into three main supersequences; an Aptian to mid-Albian synrift supersequence, a late Albian to Turonian rift-drift transitional supersequence, and a Santonian-Coniacian to Quaternary drift supersequence (Turner, 1995; Meyers et al., 1996; Jobe et al., 2011). Rifting of the Rio Muni Basin was initiated in the Aptian at about 117 Ma, and this was accompanied by deposition of sapropelic lacustrine source rocks and evaporite deposits (Lehner and De Ruiter, 1977). The rift-drift transitional stage began in the late Albian at about 106 Ma, but was completed by end Turonian (89 Ma), during which shallow-marine carbonate and clastic units were well developed (Lehner and De Ruiter, 1977). The Rio Muni Basin has subsequently evolved as a mature passive margin from the Santonian-Coniacian to Quaternary, during which "typical" deep-water and coeval shallow-water systems became prevalent (Lehner and De Ruiter, 1977; Jobe et al., 2011). Deep-water channels, such as channels C1 through C9 as evident on bathymetric map of the modern seafloor of the study area (Fig. 2) and on seismic sections (Figs. 1B, 3A and B), were well developed within the Santonian-Coniacian to Quaternary drift supersequence. Rio Muni channels C1 through C9 display "classical" V- or U-shaped channel cross-sections in cross-sectional view (Figs. 1D, 3, and 4B), and are seen as single, narrow, west-easting trending, sinuous high or low RMS-attribute bands in plan view (Figs. 4A and 5). Only two of them (*i.e.*, submarine channels C1 and C2) are seen in the released seismic database, and are, thus, the focus of the present study (Figs. 2 and 3).