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Origin and distribution of the organic matter in the distal lobe of the Congo deep-sea fan – A Rock-Eval survey

François Baudin[a,*], Elsa Stetten[a,b], Johann Schnyder[a], Karine Charlier[c], Philippe Martinez[c], Bernard Dennielou[d], Laurence Droz[e]

[a] Sorbonne-Universités, UPMC-Univ. Paris 06, CNRS, Institut des Sciences de la Terre (ISTeP), UMR 7193, 4 place Jussieu, 75005 Paris, France
[b] Sorbonne-Universités, UPMC-Univ. Paris 06, CNRS, Laboratoire d'Ecogéochimie des Environnements benthiques (LECOB), UMR 8222, Observatoire Océanologique, Banyuls-sur-Mer, France
[c] Université de Bordeaux, CNRS, Environnements et Paléoenvironnements Océaniques et Continentaux (EPOC), UMR 5805, Allée Geoffroy St Hilaire, 33615 Pessac Cedex, France
[d] IFREMER-Département REM, Unité des Géosciences Marines, 29280 Plouzané, France
[e] Université de Bretagne Occidentale - Institut Universitaire Européen de la Mer, CNRS, Laboratoire Domaines Océaniques (LDO), UMR 6538, 29280 Plouzané, France

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ABSTRACT

The Congo River, the second largest river in the world, is a major source of organic matter for the deep Atlantic Ocean because of the connection of its estuary to the deep offshore area by a submarine canyon which feeds a vast deep-sea fan. The lobe zone of this deep-sea fan is the final receptacle of the sedimentary inputs presently channelled by the canyon and covers an area of ~2500 km². The quantity and the source of organic matter preserved in recent turbiditic sediments from the distal lobe of the Congo deep-sea fan were assessed using Rock-Eval pyrolysis analyses. Six sites, located at approximately 5000 m water-depth, were investigated. The mud-rich sediments of the distal lobe contain high amounts of organic matter (~3.5 to 4% Corg), the origin of which is a mixture of terrestrial higher-plant debris, soil organic matter and deeply oxidized phytoplanktonic material. Although the respective contribution of terrestrial and marine sources of organic matter cannot be precisely quantified using Rock-Eval analyses, the terrestrial fraction is dominant according to similar hydrogen and oxygen indices of both suspended and bedload sediments from the Congo River and that deposited in the lobe complex. The Rock-Eval signature supports the 70% to 80% of the terrestrial fraction previously estimated using C/N and $\delta^{13}C_{org}$ data. In the background sediment, the organic matter distribution is homogeneous at different scales, from a single turbiditic event to the entire lobe, and changes in accumulation rates only have a limited effect on the quantity and quality of the preserved organic matter. Peculiar areas with chemosynthetic bivalves and/or bacterial mats, explored using ROV Victor 6000, show a Rock-Eval signature similar to background sediment. This high organic carbon content associated to high sedimentation rates (> 2 to 20 mm.yr^{-1}) in the Congo distal lobe complex implies a high burial rate for organic carbon. Consequently, the Congo deep-sea fan represents an enormous sink of terrestrial organic matter when compared to other turbiditic systems over the world.

1. Introduction

A classic but still relevant question in marine biogeochemistry and marine geology is the understanding of the fate of organic carbon (OC) delivered from the continent to the ocean (Benner, 2004; Blair & Aller, 2012; Hedges and Keil, 1995; Hedges et al., 1997; Goni et al., 1997). Most terrestrial particulate organic carbon (POC) is delivered to the ocean by rivers with an annual total flux estimated between 200 and 500 Tg C.yr^{-1} (Bianchi et al., 2014; Dagg et al., 2004; Degens et al., 1991; Ludwig et al., 1996; Meybeck, 1993, Schlünz and Schneider, 2000). Between 55% and 80% of the exported terrestrial OC is quickly remineralized along the continental margins (Burdige, 2005). The remainder is buried into sediments and mixed with autochthonous marine OC. Much of this preserved terrestrial fraction (40% to 50%) is stored in deltaic environments and the rest is dispersed along continental shelves, margins and deep oceanic settings (Berner, 1982; Burdige, 2005; Hedges and Keil, 1995).

* Corresponding author.
E-mail address: francois.baudin@upmc.fr (F. Baudin).

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Today, because of a high sea-level stand, the major world rivers deposit their sediments –including the OC fraction– mainly on the continental shelves. By contrast, during sea-level falls related to glacial periods, most of the world rivers delivered their sediments into the deep ocean by the means of turbidite systems. Thus, globally, at the scale of glacial-interglacial cycles, the depocenter of the terrestrial OC flux into the oceans moved from proximal shallow marine (deltaic) to more distal deep marine (deep-sea fan) environments and *vice versa*. Only rivers directly connected to the deep ocean by a canyon can maintain an active turbidite system during high sea-level stands.

This is the case of the Congo River which drains the second largest watershed of the world (3.7 10^6 km^2) and concentrates about 38% of the yearly run-off from Africa (Laraque et al., 2009; N'kounkou and Probst, 1987). Therefore, the Congo River system is a channelized continuum, from the watershed to the deepest distal zones of the deep-sea fan, via a single erosional canyon that penetrates into the estuary. Indeed, the Congo deep-sea fan receives continuous sedimentary inputs via turbidity currents (Heezen et al., 1964; Khripounoff et al., 2003; Vangriesheim et al., 2009) and remained permanently active during the Quaternary, regardless of sea level fluctuations (Droz et al., 1996, 2003; Marsset et al., 2009; Picot et al., 2016; van Weering & van Iperen, 1984). The modern active turbidite system is restricted to a channel-levee-lobe that extends 760 km westward off the Congo-Angola margin (Savoye et al., 2000, 2009; Fig. 1A), but more than 80 inactive paleo-channels have been identified (Marsset et al., 2009).

For 30 years, substantial efforts have been made to study the terrestrial OC flux at the Congo River mouth (Cadée, 1984; Coynel et al., 2005; Kinga-Mouzéo, 1986; Mariotti et al., 1991; Spencer et al., 2012, 2014). The Congo River delivers yearly ~5.5 10^7 t of sediment (Wetzel, 1993) and presents a high POC/suspended material ratio of 1/25. Therefore the Congo ranks fifth in term of annual POC flux to the oceans with an export reaching 2 Tg $C.yr^{-1}$ (Coynel et al., 2005). With a dissolved organic carbon (DOC) estimated to 12.4 Tg $C.yr^{-1}$, the Congo River is the second major exporter of terrestrial OC to the ocean after the Amazon River. At the Kinshasa-Brazzaville station, the %POC is typically 6–7.5% of the suspended sediment (Spencer et al., 2012) and the %DOC of total OC ranges from 80–90% (Coynel et al., 2005; Kinga-Mouzéo, 1986; Spencer et al., 2012). When suspended sediment is separated into coarse (> 63 µm) and fine (0.7–63 µm) fractions, the POC ranges 5.7 to 11.8% in coarse fraction to 7.0–8.8% in the fine one (Spencer et al., 2012). Congo POC predominantly originates from C3 vascular plant vegetation and soil inputs as evidenced by elemental, isotopic and lignin phenol data (Mariotti et al., 1991; Spencer et al., 2012). The POC from the fine fraction shows an older ^{14}C signature (~550 yr BP) than POC from the coarse fraction, suggesting a more abundant contribution of soil OC in the fine fraction (Spencer et al., 2012). These authors observed little modification of organic matter concentrations and geochemical signatures between the Kinshasa-Brazzaville station and the mouth of the Congo River (~350 km downstream), suggesting that the Kinshasa-Brazzaville station is a suitable reference point for constraining the Congo export of terrestrial OC to the Atlantic Ocean.

By contrast, little is known on the fate of OC after its entrance into the Atlantic Ocean. The incision of the canyon head enables normal marine waters to penetrate deep into the estuary (Cadée, 1984; Eisma and Kalf, 1984). A thin layer (~10 m) of fresh-water overflows this saline incursion. This surface layer, rich in fine sediment, POC and DOC, travels westwards and extend as a plume, up to 800 km from the coast. Except for some local areas of new production, supported by nutrient inputs from river-driven upwellings, OC concentration decreases gradually until the plume is no longer discernible (Cadée, 1984). All over the expansion of the plume, POC settles towards the seafloor, but this contribution is thought to be limited and does not represent an important sink of OC (see discussion in Section 5.1). The

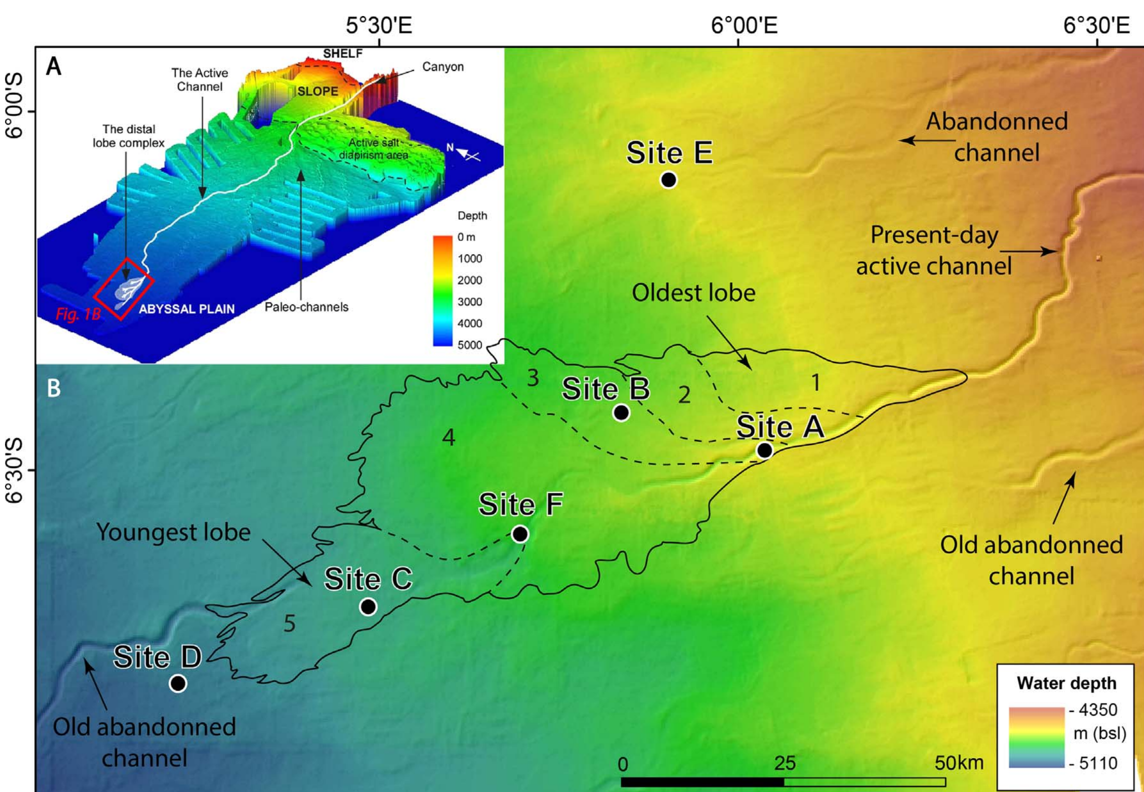

Fig. 1. A) 3D view of the bathymetric map off the Congo River mouth showing the deep-sea fan turbidite system with the present-day unique active channel which ends as a distal lobe complex (reprint from Savoye et al., 2009). B) General bathymetric map of the distal lobe complex of the Congo turbidite system with location of the 6 sites explored during WACS and Congolobe campaigns. The lobe complex shows a series of lobes (labelled 1 to 5 from the oldest to the youngest) having a grape-like prograding downstream organization. Boundaries of the lobe complex and its subdivision are simplified from Babonneau (2002).