The Congo deep-sea fan: how far and for how long?

A basin-wide view of the interaction between a giant submarine fan
and a mature passive margin

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1.- Introduction

The Congo deep-sea fan is one of the largest submarine fan systems in the world and one of the most important depocentres in the eastern south Atlantic. The present-day fan extends over 1000 km offshore the Congo-Angola continental margin and it is sourced by the Congo River, whose continental drainage area is the second largest in the world (3.7 106 km²) (Droz et al., 1996) (Fig.1). There is a direct connexion between the river’s drainage basin and the deep basin through an impressive submarine canyon, which cuts down about 950 m at the shelf-break and more than 1300 m at 100 km offshore the coastline (Babonneau et al., 2002). Hence, the direct transfer of terrigenous material onto the abyssal plain takes place through the canyon, by-passing the shelf and upper slope. The submarine fan covers a surface of about 300,000 km² and contains at least 0.7 Mkm³ of Tertiary sediments (Anka and Séranne, 2004; Droz et al., 2003; Savoye et al., 2000).

The analysis of thousands of km of 2D seismic-reflection profiles from the ZaiAngo project across the Congo-Angola passive margin allowed us the integration of the relatively-unknown depocenters located beyond the Continent-Ocean boundary (COB) of the Congo basin with the better constrained successions on the shelf and upper slope.

This contribution complements previous work done on the Lower Congo basin and addresses questions regarding the sediment partitioning between the deep-sea fan and the continental margin, its timing and controlling factors. We focus on analysing how different processes known to affect the margin, such as submarine erosions, salt tectonics, basin filling, and continental uplift, are recorded in the distal deposits of the lower slope and abyssal plain, and to what extent they control the submarine fan deposits. This has lead to a re-interpretation of the post-rift history of sediment supply in the basin and a reconsideration of the long-term stability of the Congo River as a long-term sediment supplier.

Results from this work yield a contribution to better understanding the signature in the ultra-deep accumulations of geological processes acting on the continental margin and the resulting partitioning of sediment transport in areas of high river input.

2.- Data and methodology

We analysed a unique dataset of more than 20,000 km 2-D time-migrated multi-channel seismic reflection profiles from the ZaiAngo Project, interwoven on a grid spacing of 6 to 25 km and covering an area of 200,000 km² from the slope to the abyssal plain (Fig.1). With a recording two-way travel time (TWT) of more than 10 s, these profiles allow to visualize the oceanic basement at about 8 s (TWT).

The seismic interpretation was carried out using Sismage Research™ software developed by the oil company Total. We followed a conventional 2D interpretation methodology of delimitation of high amplitude reflectors, unconformities, and onlap/downlap surfaces, generation of surface-depth and isopach maps, and well-to-seismic ties.

We focused our analysis on the distal units deposited basinwards of the salt limit, which is located roughly near the COB, as the seismic dataset allowed for the first time to image in detail these deep and distal areas of the basin. Due to the absence of wells in the abyssal plain, the ages of the seismic reflectors were determined by correlation to well tops located on the northern upper-slope, landwards of the COB. Thus, the age control relies on: (1) long-distance correlation of the distal seismic reflectors identified in the abyssal plain with more proximal and better age-constrained reflectors in the slope, (2) north-eastern extended correlation towards the south Gabon basin where seismic markers are already dated from previous works, and (3) seismic tie to stratigraphic well tops on the shelf.

Since a direct tie between the seismic facies and lithology data was not possible due to the absence of boreholes in the abyssal plain, we used the seismic signature of the sedimentary facies in
the present-day submarine fan and, by analogy, identified the distal seismic facies and interpreted their possible depositional environments.

3.- Main results & discussion

Fig. 2 depicts the general distribution of the main seismic units and markers identified at the Continent-Ocean transition, which roughly coincides with the limit of the Aptian evaporite level represented in the northern slope (Congo) by a thrusting and on the southern slope (Angola) by large salt walls and the Angola escarpment (Fig. 1).

**A1 Albian-Turonian:** Aptian salt / oceanic crust overlaying unit

The thickness of the Albo-Turonian unit remains almost constant along the upper and lower slope across the Congo margin, whilst it decreases towards the base of the southern slope in the Angolan margin. This is consistent with the aggrading ramp-profiled shelf morphology described by other authors in the Angolan upper slope (Anderson et al., 2000; Lavier et al., 2001; Massala, 1993). In contrast, the distal age-equivalent deposits on the abyssal plain present thickness up to 2500 m and contain a minimum estimated volume of about 0.2 Mio km³, representing average sedimentation rates of about 75 m/My (Fig. 3). The isopach map of the distal deposits depicts a wide radial fan-shaped depocentre aligned on the present Congo River's outlet-submarine canyon axis, which suggests that the unit could have been fed by a paleo-Congo River whose outlet was located nearby the present-day one (Fig. 4). Should this be the case, the Atlantic sedimentary system related to the Congo River is much older than previously thought (Anka et al. 2009).

Moreover, the existence of this thick basal unit overlying the oceanic crust rules out widespread ideas, which propose that the main Albian- Upper Cretaceous depocentres on the Gulf of Guinea were located to the north and south, but not in the Congo-Angola basin (i.e. Leturmy et al., 2003; Lucazeau et al., 2003).

**A2 Post-Turonian – Eocene:** Basinward-thinning unit

This unit gradually thins out basinwards indicating a probable pinch-out against underlying unit A1 at about 250 km from the salt limit. Thus, conspicuous double seismic marker “TC” – top of A1 would represent either a sedimentary hiatus or a condensed section on the abyssal plain. Additionally, well logs on the Congo margin register a maximum deepening of the shelf during the Palaeocene-Eocene, which is contemporaneous with very low sedimentation rates in the upper slope (Anderson et al., 2000; Valle et al., 2001). Hence, A2 is the distal-most expression of this event and represents a long period of basin starvation in the abyssal plain. Nevertheless, north-south correlations using strike seismic lines indicate that a lateral-equivalent unit is present to the south, on the Angolan slope, with a thickness up to 500 m.

**A3 Oligocene-Miocene:** Basinward-thickening wedge

A3 represents the Tertiary Congo deep-sea fan, whose onset is identified to take place during the Early Oligocene. On the seismic it looks as a basinward-diverging wedge whose thickness increases dramatically, from about 0.5 s TWT in the lower slope to more than 1.5 s TWT beyond its base. It contains at least 0.7 Mio km³ and represents average sedimentation rates of about 80 m/My (Fig. 3).

The basal boundary “BO” is the distal correlative surface of a major regional unconformity, the “Oligocene unconformity”, identified throughout the west African margin (e.g. McGinnis et al., 1993; Nzé Abeigne, 1997; Séranne and Nzé Abeigne, 1999; Séranne et al., 1992). In the upper slope, these deposits are onlapping this unconformity. The onset of the giant Congo deep-sea fan in early Oligocene follows the basin starvation event represented by A2 and reactivates the abyssal plain as the main depocentre of the basin.

**A4 Pliocene-Recent:** Upward & basinward facies change

This unit consists of a package, about 0.8 s TWT thick, of highly continuous, parallel, low-to-moderate amplitude reflectors that cover most of the present-day northern slope. The unit can be traced landwards where ODP Leg 175, site 1077, recovered hemipelagic deposits composed of diatom and nannofossil-rich clays (Shipboard-Scientific-Party, 1998). At about 200 km offshore, there is a pronounced variation of the internal reflection pattern suggesting a modification on the depositional environment. Not only the thickness increases twofold basinwards, but also the hemipelagics-facies continuous-parallel reflectors switch to stacked-onlapping channel-like geometry, which indicates a general progradation of the turbidite-channel facies of the fan (Fig. 5). This basinward shift of the turbidite deposits is probably driven by the cutting of the Congo canyon, which would canalise the turbidite flows through the slope so larger grain-size sediments would end up on the abyssal plain. Decrease of accommodation space due to both the structural growth of rising salt
diapirs and seaward tilting of the margin would have driven the onset of this canyon (Anka et al., 2008).

4.- Conclusions

1) This study clearly shows the existence of a thick formerly-unknown, Albian-Turonian unit underlying the Cenozoic Congo submarine fan that extends across the Continent-Ocean boundary on the Congo-Angola basin and probably represents a submarine fan fed by a Cretaceous paleo-Congo river.

2) Very low sediment rates during Coniacian-Eocene, associated to a deepening of the shelf, are recorded in the abyssal plain as a double and strong seismic marker representing a long-period of post-Turonian to Eocene condensed sedimentation and distal basin starvation.

3) The onset of the giant Tertiary Congo-deep-sea fan in early Oligocene resulted by an abrupt increase in sediment supply following the basin starvation period. Continuous and increasing sediment influx, in addition to a westward-tilting of the margin, drives the growth of the massive salt diapirs and walls of the Angola escarpment, which in turn leads the northwestern migration of the sediment transfer zones during late Miocene. It followed a general basinward progradation of the fan during the Pliocene until the Present due to the incision of the Congo submarine canyon by the end of Miocene- early Pliocene (Fig. 6a,b,c).

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REFERENCES


Fig. 1. Continental drainage basin, Congo River, submarine canyon, and deep-sea fan system (SL: salt limit, CVL: Cameroon volcanic line, EAR: East Africa Rift, KN: Kouiloi-Niari Rivers, Kw: Kwanza River, Og: Ogoué River). Grey lines represent the 2D ZaiAngo Seismic grid analysed during this study.

Fig. 2. General distribution of the main seismic units and reflectors identified at the base of the present-day northern slope (Congo). TC: top Turonian, BO: base of Oligocene, R: boundary Miocene-Pliocene.
Fig 3. Comparison between the compacted deposited volume and the average sedimentation rates of A1 and the Tertiary fan deposits on the lower lope and the rise/abyssal plain.

Fig 4. Isopach map of A1 depicting a fan-shaped depocentre aligned on the present-day Congo canyon - River outlet axis.
Fig. 5. Basinward shift of the turbidite-channel seismic facies suggesting a general progradation of the fan deposits since early Pliocene.

Fig 6a,b,c. Block diagram showing the proposed interaction of the tertiary Congo submarine fan with the development of the Angola escarpment, the submarine canyon incision, and depocentre migration.
The long-term evolution of the Congo deep-sea fan: a basin-wide view of the interaction between a giant submarine fan and a mature passive margin