The Ogooue Fan (Gabon): a modern example of deep-sea fan on a complex slope profile.

All the changes in the manuscripts appear in red.

Review 1

We are thankful to Dr Hogdson for his interest in our paper and for his helpful and constructive comments. We have made efforts to clarify the parts of the manuscript that, in light of the reviewer's comment, needed to be more accurate and more detailed.
Here, we report below the reviewers' comments answers concerning the main issues.

General comments:
The manuscript by Mignard et al. presents recently collected bathymetry, sidescan, and core data from the understudied Ogooue Fan, offshore Gabon. These data permit the authors to present an interesting case study clearly. They demonstrate that changes in seabed topography above a stepped slope, formed by volcanic seamounts and mud diapirs/volcanoes, strongly influence the location of erosion and sediment bypass, and deposition, and therefore the distribution of faices and environments of deposition. There is nothing particularly new here – several modern/recent, ancient subsurface, and exhumed systems have shown similar patterns that indicate how sensitive turbidite systems are to subtle gradient changes. Nonetheless, more case studies will help the community advance understanding of threshold controls (e.g. gradient and confinement).
With that in mind, and given the quality of data, there needs to be much more quantitative information on gradients, gradient changes, and dimensions of the erosional and depositional feature reported. Also, even though this is a case study, it does add to generic aspects of these system types, however the introduction is too parochial in scope. Specific comments:

1. Abstract: there is a random sentence to fix – wrong place? But the abstract can be more – more numbers, and clearer on what is novel here, beyond more knowledge of this particular system. What are the wider implications?
2. The introduction needs a rewrite. This is far too parochial in scope, and focused on the geological setting of the system, rather than providing a context for the analysis of stepped submarine slope systems in general. What is the 'gap' that can be addressed, or at least contribute to? There are several assertions or facts made where supporting references should be cited.
3. Suggest that a wider set of papers that deal with stepped slopes be cited and compared. What are the similarities and differences?

The abstract the introduction and the conclusion have been rewritten in the manuscript. The discussion has been expanded and reorganized and four new figures have been added. As suggested by both reviewers, most information given in the introduction is now placed in the "Context" section, whereas the introduction focuses on the role of complex topographic slopes on depositional processes and fan architecture. More literature concerning this topic is now cited and we are very thankful to the reviewer for providing us references that we could use.

In this context, the study of the Ogooue fan provides a good example of what impacts can very subtle gradient changes have of sedimentary systems construction. Indeed, the gradient change between the "ramps" and the "steps" of the slope found in the distal part of the slope is less than 0.4° (steps : <0.6°, ramps <0.2°). These gradients are very low compared to the ones found in the literature for modern fans (4° and 1° offshore Niger Delta (Barton, (2012)) or ≈1° and ≈0.6° for the Benin minor canyons (Deptuck et al., (2012)). This new data could be useful to study the gradient change threshold that is required to provoke sedimentation or bypass/erosion.

4. Please check for accuracy of use of turbidite (deposit) and turbidity currents (flow). Turbidity current deposit is fine, turbidite flow is not, turbidite deposit is superfluous.

In all the manuscript, we have been more careful about the use of "turbidite" and "turbidity currents". We have removed, wherever they appear, the formulations "turbidite flow" and "turbidite deposit".

5. In several places meandering is used to describe a channel form. You should use sinuous which is descriptive. Meandering is an interpretation, and a controversial one in deep-water, so should be avoided without supporting evidence.

We agree with Dr. Hogdson about our misuse of "meandering" for description of the shape of the channels. This has been corrected in the revised manuscript and "meandering" has been replaced by "sinuous" in the "Results" and "Discussion" sections. The sinuosity of Channel D has also been calculated in order to provide more details about the downslope evolution of channels. Sinuosity was measured at 2 km intervals because this length appeared to be the most adapted to the meanders with short wavelength and short amplitude found along the channel path. The same length has been used in Babonneau et al. (2002) to calculate along the present day Zaire Canyon/Channel.

6. Some numbers are used, but mainly for gradients. Overall, however, I would like to see much more quantitative information stated, with gradients, changes in gradients, widths and depths/thicknesses of erosional and depositional features, sinuosity. This would really help elevate the paper, and allow worker to compare different systems, and consider thresholds etc., and to quantify relatively long, deep, shallow, etc.

We understand the reviewer request and the manuscript now provides much more quantitative information about the Ogooue Fan. All the morphological features referred in the text are described more precisely with numbers (depth, width, length and volume when possible). Moreover, following the request of the second reviewer, three new figures showing details of some morphological features of the system (The Cape Lopez lobe, the canyons ramp and the mid-system area with scours) have been prepared and will allow the reader to have more details on the Ogooue Fan. All the gradients are now expressed in "degree" rather than "in percent" to allow an easier comparison with previously published literature.

Also, on figure 5, we need more methodological information on how the levee height and channel depth (check spelling) are derived. Which levee, as seem asymmetric? How is base levee defined/identified? Using seismic data? Is depth measured from base levee?

Seismic data show that the channels incise the seafloor below the depth of the associated levees which are poorly developed and sometimes asymmetric. These features are similar with the morphology of the recent Congo channel-levee system. On figure 5, a small drawing is added to present the definition of the morphologic parameters measured from bathymetric data.

7. Cape Lopez lobe: This is not really ponded, according to your interpretations, as some of the flows are able to escape the confinement and pass downdip. This is a more confined step – and intraslope or perched basin, similar to several on the African margin (e.g. Jobe et al., 2017, and at outcrop, e.g. Spychala et al., 2015

We agree on our misuse of the expression “ponded lobe” for the Cape Lopez lobe located north of the Mount Loiret. This sediment body with one knickpoint and an exit channel corresponds in fact to an intraslope sandy lobe which has developed on a confined step. This lobe is very similar with the “X fan” described in Jobe et al., (2017) and is in the same size range as the intraslope complexes studied in the Karoo Basin by Spychala et al. (2015): 8 km x 8 km, 76 km² for the X fan (Jobe et al., (2017)), 6 to 10 km wide and 15 to 25 km long for the lobe complexes in the Karoo basin (Spychala et al. (2015)) and 6 km x 16 km, and 106 km² for the Cape Lopez lobe. These morphological details have been added to the manuscript as well as a new figure showing the details of the lobe as requested by the second reviewer.

8. The echofacies interpretations are not done in isolation. You are using the interpretations of other studies, including your groups, which are sometimes calibrated with core. Therefore, need to cite supporting literature of these echofacies interpretation (as with sedimentary and seismic facies).

The previous studies that have been used to calibrate our echofacies when no cores were available have been more carefully cited. Among them, there are the studies of Damuth, (1975 and 1980), Loncke et al. (2009), Praston and Laine (1989), Gaullier and Bellaiche (1998), Piper et al. (1995) and Keynon et al. (1995).

Technical corrections:
Several nomenclatural points to be consistent on: Seabed, seafloor, and sea-floor used. Stick to one.

Only “seafloor” is used in the manuscript in order to remain consistent.

Suggest use external levee, and internal levee or terrace deposit to be clear.

The description of the channel-levees systems has been clarified to be more accurate.

Also, fan, system, apron, are used, with various descriptors, turbidite, deep-sea. Be consistent.

We have removed from our manuscript the expression “deep-sea turbidite system”, “apron” and replaced them by the term “fan”.

Numerous suggested changes in grammar, spelling, and sentence structure are contained on the attached annotated pdf file. Supporting references for terms, such as sediment bypass, lobe complexes, etc.

We are very grateful to Dr Hodgson for its careful and detailed reading of the manuscript. All the changes that are suggested on the annotated pdf file will be found in the revised manuscript.

All the reference cited here can be found in the revised manuscript.

<u>Review 2</u>

We are thankful to Dr Haugton for his interest in our paper and for his helpful and constructive comments. We have made efforts to answer most of his questions in the revised manuscript.
Here, we report below the reviewers' comments answers concerning the main issues.

This paper provides interesting details of a part of the West African margin for which there is limited data currently available in the public domain. It describes a deep-sea fan system related to sediment discharged from the Ogooue River in Gabon (although it is also characterised as an apron on the basis of multiple feeder systems). The area sits between areas where extensive work has already been published so it fills a gap and also demonstrates some features unique to this part of the margin. The focus here on tracing slope canyons and channels down slope across what is a topographically complex slope and basin floor on account of the presence of the Cameroon volcanic line across which the system traverses. The work is based on recent sea floor and shallow echosounder and seismic imaging, as well as an array of shallow cores, some of which have already been published, but not from the perspective of facies distribution and wider system character so there is significant new material here.
What will be of particular interest to the deep-water research community is the complex way in which the system is responding to the changing gradients and variable levels of lateral confinement.

The paper includes some spectacular images of a headless valley system that sits mid-way along the transport path (the term distal valley may be a little misleading particularly as there is another confinement further down slope).

The valley is now termed as "mid-system valley" to avoid any misunderstanding.

Unlike deep-sea fans building into open basins, this one has a series of depocenters separated by bypass sectors where gradients are steeper and where flows become more confined. Deep-water systems commonly traverse irregular sea floor topography related to mobile substrates and active or pre-existing structures so this aspect makes the study more than just of regional interest.
The set-up in the introduction very much focusses on the west Africa margin but it might be useful to cast it more widely in terms of system response to complex topography and to refer to other examples in the literature – for example the late Bill Normark and colleagues work on headless channels in the California borderland. There has been a lot of work done on stepped slopes and the response of gravity currents to topography, so it is important that the more novel aspects of this system are stressed, and previous work referenced as appropriate.

We agree on this remark and a rewrite of the introduction has been done. As suggested by both reviewers, most information given in the introduction has been placed in the "Context" section, whereas the introduction will focus on the role of complex topographic slopes on depositional processes and fan architecture. This study shows that very subtle gradient changes (less than 0.4°) can have a major impact on the fan construction. These gradients are much lower than the ones previously presented in most of the articles concerning stepped slopes. We have also widened our bibliographic research in order to be able to compare our result with other stepped-slope systems.

One issue that is important in looking at interactions of deep sea systems and topography is whether the topographic is static or dynamic. Some more details on the history of the Cameroon volcanoes and sea mounts would be useful. How young are the volcanoes – is activity continuing in the offshore part of the chain?

All the volcanoes of the Cameroon Volcanic line are more or less of the same age and have been active for at least 65Ma (Lee et al., 1994; Déruelle et al., 2007). Geophysical studies of the line suggest that the volcanic alignment could be related to a deep-mantle hot line (Déruelle et al. 2007). The Bioko island recorded eruption as young as 1923 (Déruelle et al. 1987) whereas Ar/Ar dates realized by Barfod et Fitton (2014) on Sao Tomé volcanic rocks have shown activity as young as 0.036 Ma and proved activity of the volcanic island over much of the Pleistocene. A previous publication from Lee et al. (1994) showed also recent volcanic activity for the Annobon Island (0.2 Ma). This volcanic - and associated seismic- activity could have triggered some down slope processes on the slopes of Sao-Tomé and Annobon. Slump deposits can be seen on the 3.5 kHz seismic lines in the vicinity of these two islands. Unfortunately, we found only limited information in the literature concerning the sea-mounts in our studied area. Emery et al. (1975) described them as part of the basement uplift linked with the Guinea Ridge. Meyers et al. (1998) proposed that these seamounts were primarily composed of old oceanic basement and a thick sediment cover capped with volcanic rocks.

At several points the text mentions mud diapirism – but it is unclear to what extent this is an issue here in terms of sea floor topography. Where are the mud diapirs?

Some mud diapirism appears in the vicinity of Annobon Island. They form small relief on the seafloor (< 20 m high and 100 m of diameter). Their definition is based on morphological characteristics and on the presence of gas in the water column over this structures (Garlan, personal communication). The "small Annobon" is a much larger structure which gathers a large number of smaller mud volcanoes and forms a more than 200 m high and 10 km large mount. Its morphology is very different from the other rocky seamounts of the area which present much steeper slope and a clear pelagic drape.

Given how important pock marks are in the area just to the north, why are these apparently less well developed in the study area? What is different about the Equatorial Guinean margin? Are there any examples of the Jobe et al. depositional canyons and if not why the change along the margin.

According to Pilcher and Argent (2007) who studied the pockmarks in the area north of the Mount Loiret, their presence is due to different processes. Some pockmark trains are related to the presence of abandoned channels buried under hemipelagic sediments (Pilcher and Argent, 2007, Jobe et al., 2010). The pockmarks result from the expulsion of fluid contained the underlying sand after the abandonment of the channel and its filling by fine-grained sediments. This is the case for the pockmark trains located just north of the Cape Lopez lobe that follow the path of buried sinuous channels. The absence of pockmark on the southern part of our studied area where the active channels of the Ogooue fan are settled may be linked with the higher slope gradient that prevents the deposition of thick fine-grained sediments layers.
Following the classification of Jobe et al. (2010), the canyons of the Ogouee fan are of two types, some are clearly of "Type I", they indent the shelf and are pathways for erosive, sand-rich turbidity currents sourced from shallow water. Others are more of "Type II", they head in deeper water and lack access to coarse-grained sediment. According to Jobe et al., erosive turbidity currents are rare and relatively unimportant in these canyons, favoring their infill by hemipelagic sediments and the formation of pockmarks trains. The development of Type I rather than Type II canyons may be linked with local variations in sediment supply.

Parts of the system apparently show extensive scouring and a range of different features are described, but it is a little hard to see these because they are overlain by the interpretation lines. It would be useful to include a few more un-interpreted sea floor images showing features such as the putative mega flutes.

A new figure showing close-ups of deferent bathymetric features presented in the text has been added. We hope that this figure will allow to better support our interpretations.

Figures 5 and 6 work very well showing one of the leveed channels and the valley feature. It would also be good to see more detail on the 'ponded' lobe associated with the northernmost Cape Lopez canyon – it is currently reproduced at very small scale.

A new figure showing the Cape Lopez intraslope lobe has been prepared and added to the manuscript.

The straight to sinuous channels appear erosional and inset with channel floors well beneath the levees - is this similar to Congo fan? Levees seem to be relatively poorly developed – is this the case?

The channels of the system are indeed deeply incised in the seafloor, below the associated levees, when present. This feature is similar to the Zaire Channel (Babonneau et al., 2002). This incision is observed along most of the channel path and is attenuated only in the distal area. This entrenched morphology prevents extensive overflow of turbidity currents and a low development of external levees. For the Zaire channel it has been proposed that the entrenched morphology of the channel confines the flow and keeps the energy high enough to allow a transport of sediment to very distant areas. This morphology is opposed to the morphology of aggrading channels (such as the Amazon Channel) where the thalweg is perched above the base of the levee system (Damuth et al., 1995).

I am not quite sure I know what is meant by a secondary channel.

The term "secondary channel" has been replaced by "subsidiary channel" according to the definition of Masson et al. (1995) "channels with no headward connection with an obvious feeder system"

The core data are a very useful compliment to the sea floor and shallow imaging and the age constraints are important in thinking about depositional rates. Are some of the AMS 14C dates new – some have been published already but if the others are new should be properly tabulated with analytical details.

A new table has been added giving details about the new AMS 14C dates, specifying the age reservoir and the calibration curve used.

Only the MIS1/2 boundary is indicated on the core correlation in Fig. 3 but reading Mignard et al (2017) the case is made for penultimate glacial sections as well as last glacial in some of the cores of the basis of stable isotope profiling. It would be useful to indicate this on Fig. 3 where the lower part of KC10 is interpreted previously as MIS6.

We initially didn't add the older ages for KC 10 to Fig. 3 as only MIS1/2 boundary is discussed in the text. But we understand the reviewer request and the limits of MIS 1 to 6 have been drawn for KC10 on figure 3.

The mid-system incision and valley is a very interesting feature of this system and impressively wide at 15 km, presumably as it collected a number channels. A large volume of sediment has been removed and translated down slope (can you estimate how much?). A significant part of the lower fan system must come from erosion of this valley.

According to our bathymetric data, the volume of sediment removed from the mid-system valley is between 8 to 10 km3. We agree that this important volume of sediments has, in all likelihood, been transported downstream to the most distal lobe. We assumed that these sediments may be preferentially found in the most distal and muddier part of the system. According to the mineralogical composition of the turbidites found in the distal lobe just at the outlet of the valley (KC11) showed that the main source for the sediments in the sandy distal lobe are coming from the Ogooue delta (high density of fresh plant debris).

Channels feeding to it seem better resolved to the north. Presumably during the Holocene (and earlier) transgression, precursors of Manji island may have migrated eastwards, sequentially feeding the various slope canyons ending up at Cape Lopez canyon today.

The development of the Mandji Island started 3,000 years ago (Lebigre, 1883, Giresse, 1975, 1977). The reconstruction of the past positions of the spit showed that it grew north with several successive steps. However, its southern most limit has never changed. It seems thus difficult for us to link its evolution with the feeding of the different canyons of the slope. Nonetheless, it is highly probable that its position change has influenced the feeding of the northernmost canyons. Some of them are currently being infilled with hemipelagic sediment and might have been abandoned due to the growth of the Manji Island.

The shelf/coastal set up is unusual with longshore drift maintaining supply to deep water – comparisons are made with longshore drift in the California margin where longshore drift feeds sand to La Jolla canyon, but the kink in the Ogooue coast sets up a rather different geometry where sand is able to spill downslope at the shelf edge without the need for a canyon to cut back to the modern shoreline.

Currently, most of the canyons are not fed with sand supply, except for the Cape Lopez canyon. The canyons heads are too far from the coastline to be fed by the littoral drift. The only turbidite recorded during the Holocene highstand (in core KC13) might result from the destabilization of the pre-Holocene sandy deposits found on the continental shelf (Giresse and Kouyoumontzakis, 1973).

One wonders also given the coastal and shelf geometry whether this type of system is partitioned into a contemporaneous sandy supply from the outboard littoral cell (in what is otherwise a sand deficient system) and contemporary mud supply from the extensive bay head delta behind it feeding north towards the Equatorial Guinea margin with its pockmarks and muddy depositional canyons.

The contemporary muddy supply linked with the Ogooue discharge is concentrated north of the Mandji Island. Most of it remains in a mud zone at the mouth of the Ogooue River (Giresse and Odin, 1977). Farther from the shoreline, relict deposit consisting of shelly sand compose the seafloor.

Is that a previous highstand strand plain sitting inboard of the modern bay head delta on Google Earth?

On Google earth the post-Holocene transgression coastline position is clearly visible. It is marked by North-South lineation on the satellite images (Lebigre, 1983).

Specific points lied to line numbers.

Most of these points have been directly corrected in the manuscript. Here are some more specific answers:

Line 23: 'The most distal depocenters receive only the upper parts of the flows, which are composed of fine-grained sediments'. Why uppermost – does this component not escape to the levees?

The entrenched morphology of the channels prevent an important development of the levees. This feature allow the distal transport of the fine-grained sediments.

Line 25: evidence that the system is active during highstand?

Biscara et al., (2011) showed that the Cape Lopez lobe has recorded recent turbidity currents in the Cape Lopez Canyon proving its current activity.

Line 67: Seems odd Angola Basin lies to north of ridge.

Right, this is a mistake, we were referring to the Guinea Basin, not the Angola Basin.

Line 98: Show backscatter classes on separate figure showing examples.

A new figure has been created to better show the backscatter classes

Line 128: Why no MIS1/2 boundary in KC21 in terms of facies/carbonate content?

Sedimentological study of core KC21 indicates that there has been no important sedimentation change at the MIS1/2 transition. This is in agreement with our scheme of continuous activity of the northern Lobe.

Line 177: source of mass transport deposits – do they have volcanic sand grains or not?

Volcanic sand grains have been found only in core KC01, this is specified in the "sedimentary facies" section of the manuscript.

Line 189: What is a thin incision? Some of detail here hard to see given small scale of seafloor maps – include a blow up?

A new figure has been added and a more precise description of the different canyons is now given in the text.

Line 205: Channel seems to change direction before seamount – why is this? What is bathymetry like between San Tome and seamount? Is there a ridge here?

There is actually a ridge between Sao Tomé and the seamount, this is now better illustrated in Figure 1. We have added some isobaths.

Line 226: How does lobe pass to channels? Provide a more detailed image.

A figure illustrating this part of the system has been added to the manuscript.

Line 248: Any potential for bed waves/cyclical steps?

Some bed waves are seen north of mount Loiret. They are localized on a high gradient part of the slope.

Line 297: is it all delta fed? Components supplied by alongshore transport?

Giresse and Kouyoumontzakis (1973) showed that the Gabon shelf presents a high sandy quartz content due to the successive deposition of the Holocene transgression sediments. These relict sandy deposits might compose some of the turbidite. However, the alongshore drift is localized really close to the coastline creating the sandy spits. This current seems unable to feed the canyons which heads are localized more than 50 km away from the shoreline.

Line 321: Geometry of various scour features are not that well illustrated.

A new figure has been added to the manuscript revised manuscript.

Line 369: Mud volcanoes? Where are these?

We were referring about the “Small Annobon” structure.

All the reference cited here can be found in the revised manuscript

Abstract. The effects of important changes in slope gradient on turbidity currents velocity have been investigated in different deep-sea systems both in modern and ancient environments. However, the impact of subtle gradient changes (<0.5°) on sedimentary processes along deep-sea fans still needs to be clarified. The Ogooue Fan, located in the northeastern part of the Gulf of Guinea, extends over more than 550 km westwards of the Gabonese shelf and passes through the Cameroun Volcanic Line. Here, we present the first study of acoustic data (multibeam echosounder and 3.5 kHz, very-high resolution seismic data) and piston cores covering the deep-sea part of this West African system. This study documents the architecture and sedimentary facies distribution along the fan. Detailed mapping and near-seafloor seismic dataset reveal the influence of subtle slope gradient changes (< 0.2°) along the fan morphology. The overall system corresponds to a well-developed deep-sea fan, fed by the Ogooue River ‘sedimentary load, with tributary canyons, distributary channel-levee complexes and lobes elements. However, variations in the slope gradient due to inherited salt-related

structures and the presence of several seamounts, including volcanic islands, result in a more complex fan architecture and sedimentary facies distribution. In particular, turbidity currents derived from the Gabonese shelf deposit across several interconnected intraslope basins located on the low gradient segments of the margin (<0.3°). The repeated spill-overs of the most energetic turbidity currents have notably led to the incision of a large mid-system valley on a higher gradient segment of the slope (0.6°) connecting an intermediate sedimentary basin to the more distal lobe area.
Distribution and thickness of turbidite sand beds is highly variable along the system, however, turbidite sands preferentially deposit on the floor of the channel and the most proximal depositional areas. The most distal depocenters receive only the upper parts of the flows, mainly composed of fine-grained sediments. The Ogooue deep-sea fan is predominantly active during periods of low sea-level because the canyon heads are separated from terrestrial sediment sources by the broad continental shelf. However, the northern part of this system appears active during sea-level highstands. This feature is due to one deeply incised canyon, the Cape Lopez Canyon located on a narrower part of the continental shelf, which receives sediments transported by the longshore drift.

Keywords: Ogooue Fan, Gulf of Guinea, complex slope profile, turbidity currents, stepped slope

1 Introduction

Deep-sea fans are depositional sinks that host stratigraphic archives of Earth history and environmental changes (Clift and Gaedicke, 2002; Fildani and Normark, 2004; Covault et al., 2010, 2011), and are also important reservoirs of natural resources (Pettingill and Weimer, 2002). Therefore, considerable attention has been given to the problems of predicting architectures and patterns of sedimentary facies distribution in submarine fans. First models concerning the morphologies of these systems described submarine fans as cone-liked depositional areas across unconfined basin floors of low relief and gentle slope gradient (Shepard and Emery, 1941; Shepard, 1951; Dill et al., 1954;

Menard, 1955; Heezen et al., 1959). However, the development of numerous studies realized on both fossil and modern fans showed that topographic complexity across the receiving basin can strongly influence the organization of architectural elements of submarines fans (Normark et al., 1983; Piper and Normark, 2009). A wide range of geometries and architectural features due to topographic obstacles has been described in the literature. Among these features are ponded and intra-slope mini-basin due to three-dimensional confinement (Prather, 2003; Prather et al., 2012, 2017; Sylvester et al., 2015) or tortuous corridors created by topographic barriers (Smith, 2004; Hay, 2012). Spatial changes in slope gradients are also important as they cause gravity flows to accelerate or decelerate along the slope (Normark and Piper, 1991; Mulder and Alexander, 2001) allowing the construction of successive depocenters and sediment bypass areas (Smith, 2004; Deptuck, 2012; Hay, 2012). These stepped-slopes have been described along modern systems such as the Niger Delta (Jobe et al., 2017), the Gulf of Mexico (Prather et al., 1998, 2017) or offshore Angola (Hay, 2012), but also in ancient systems such as the Annot Sandstone Formation (Amy et al., 2007; Salles et al., 2014), the Karoo Basin (Spychala et al., 2015; Brooks et al., 2018) or the Lower Congo basin (Ferry et al., 2005).

On stepped-slopes where structural deformation is very slow, sediment erosion and deposition are the dominant processes that control the short-term evolution of slope. In these systems, the slope gradient variations play a key role and studies have shown that subtle gradient changes can have an important impact on flow velocity and consequently deep-sea fans organization (e.g. Kneller, 1995; Kane et al., 2010; Stevenson et al., 2013). However, despite the growing numbers of studies describing these systems, the impact of subtle changes in slope gradient on deep-sea fans organization still needs to be better apprehended.

The modern Ogooue Fan provides a new large-scale example of the influence of subtle gradient changes on deep-sea sediment routing. This system, which results from the sediment discharge of the Ogooue River, is the third largest system of the Gulf of Guinea after the Congo and the Niger fans (Séranne and Anka, 2005). However, in contrast to these two systems that have been the focus of many studies (Droz et al., 1996, 2003; Babonneau et al., 2002; Deptuck et al., 2003, 2007), the Quaternary sediments of the Gabon passive margin have been relatively poorly studied, especially in its deepest parts (Bourgoin et al., 1963; Giresse, 1969; Giresse and Odin, 1973). The regional survey of the area by the SHOM (Service Hydrographique et Océanographique de la Marine) in 2005 and 2010, during the OpticCongo and MOCOSED cruises, provided the first extensive dataset on the Ogooue deep-sea fan, from the continental shelf to the abyssal plain.

The objective of this paper is to document the overall fan morphology, and to link its evolution with the local changes in slope gradients or topographic obstacles present in the depositional area. This study contributes to the understanding of the impact of subtle slope gradient changes on deep-water systems and can be used to develop predictive models for systems located on stepped-slope with low to very low gradient changes (< 1°).

2 Geological setting

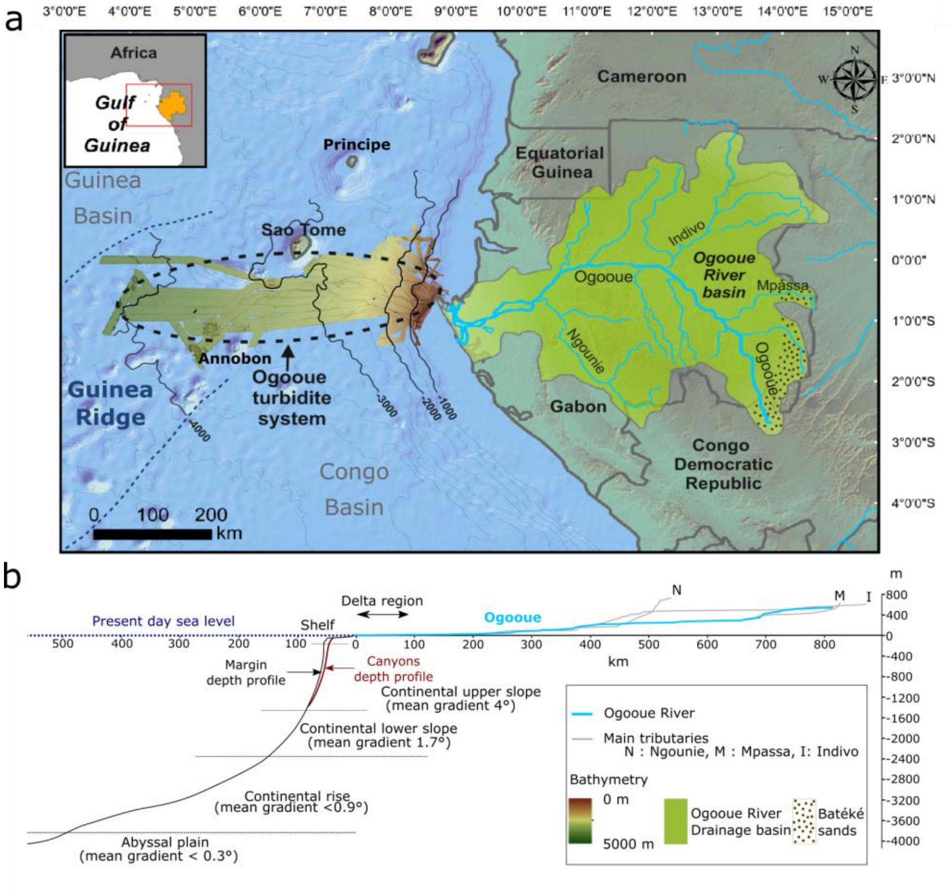

Figure 1: a) The Ogooue sedimentary system from source (river and drainage basin) to sink (Quaternary turbidite fan). b) Channel depth profile of the Ogooue River (blue) and its main tributaries (grey) and mean depth profile along the Gabonese margin.

The continental margin of the Gulf of Guinea formed during the rifting that occurred within Gondwana craton in Neocomian to lower Aptian times. Syn-rift deposits are buried by mid-late Cretaceous transgressive sediments consisting initially of evaporites, which have created salt-related deformations of the margin sediments, followed by platform carbonates (Cameron and White, 1999; Mougamba, 1999; Wonham et al., 2000; Séranne and Anka, 2005). Since the Late Cretaceous, the West African margin has recorded clastic sedimentation fed by the denudation of the African continent (Séranne and Anka, 2005). Different periods of major uplift and canyons incision occurred from Eocene to Lower Miocene times (Rasmussen, 1996; Wonham et al., 2000; Séranne and Anka, 2005). The sediments depocenters were located basinward of the main rivers, such as the Niger, Congo, Ogooue or Orange River forming vast and thick deep-sea fans (Mougamba, 1999; Séranne and Anka, 2005; Anka et al., 2009).

The Ogooue Fan is located in the northeastern part of the Gulf of Guinea on the Gabonese continental slope. The fan develops on the Guinea Ridge, which separates the two deep Congo and Guinea basins. This region is notably characterized by the presence of several volcanic islands belonging to the Cameroon Volcanic Line (CVL) associated with rocky seamounts (Figure 1a). Geophysical studies of the volcanic line suggest that the volcanic alignment is related to a deep-mantle hot line (Déruelle et al., 2007). All the volcanoes of the CVL have been active for at least 65 Ma (Lee et al., 1994; Déruelle et al., 2007). Ar/Ar dates realized on Sao Tomé and Annobon volcanic rocks evidenced the activity of theses volcanic island over much of the Pleistocene (Lee et al., 1994; Barfod and Fitton, 2014). The MOCOSED 2010 cruise revealed that numerous mud volcanoes where associated with the toe of the slopes of the volcanic islands (Garlan et al., 2010). They form small topographic highs on the seafloor (< 20 m high and 100 m in diameter) and show active gas venting (Garlan et al., 2010).

The Quaternary Ogooue Fan extends westwards over 550 km through the CVL. Overall, the modern slope profile is concave upward, similar to that of many other passive margins. The mean slope gradient shallows from 7° on the very upper slope to < 0.3° in the abyssal plain (Figure 1b). The Gabonese continental shelf, which is relatively narrow, can be divided into two sub-parts: the south Gabon margin presenting a SE-NW orientation and the north Gabon margin presenting a SW-NE orientation. The southern part of the margin is characterized by the presence of numerous parallel straight gullies oriented perpendicular to the slope (Séranne and Nzé Abeigne, 1999; Lonergan et al., 2013). On the north Gabon margin, the area located between 1°00 S and the Mandji Island is incised by several canyons that belong to the modern Ogooue Fan (Figure 2a).

North of the Mandji Island, the seafloor reveals numerous isolated pockmarks as well as sinuous trains of pockmarks. These features are interpreted as the results of fluid migration from shallow buried channels (Gay et al., 2003; Pilcher and Argent, 2007).
The Ogooue Fan is supplied by the sedimentary load of the Ogooue River, which is third largest African freshwater source in the Atlantic Ocean (Mahé et al., 1990). Despite the relatively small size of the Ogooue River basin (215,000 km^2), the river mean annual discharge reaches 4,700 m^3/s due to the wet equatorial climate (Lerique et al., 1983; Mahé et al., 1990). The Ogooue River flows on a low slope gradient in a drainage basin covered essentially with thick lateritic soils that developed over the Congo craton and Proterozoic formations related to Precambrian orogenic belts (Séranne et al., 2008). The estuary area includes several lakes (Figure 1b) (Lerique et al., 1983) that contribute to the dominant muddy composition of the particle load of the Ogooue River that is estimated between 1 and 10 M t/yr. (Syvitski et al., 2005). The limited portion of sand particles in the river originates mainly from the erosion of the poorly lithified Batéké Sands located on a 550-750 m high perched plateau that forms the easternmost boundary of the Ogooue watershed (Séranne et al., 2008) (Figure 1a). On the shelf, recent fluviatile deposits consist of fine-grained sediments deposited at the mouth of the Ogooue River (Giresse and Odin, 1973). The wave regime along the Gabonese coast causes sediments to be transported northward. Sedimentary transport linked to longshore drift ranges between 300,000 m^3/yr. and 400,000 m^3/yr. (Bourgoin et al., 1963) and is responsible for the formation of the Mandji Island, a sandy spit of 50 km long located on the northern end of the Ogooue Delta (Figure 3). Except for the Cape Lopez Canyon, located just west of the Mandji Island with the canyon head in only 5 m water depth (Biscara et al., 2013), the Ogooue Fan is disconnected from the Ogooue Delta during the present-day high sea-level (Figure 3).

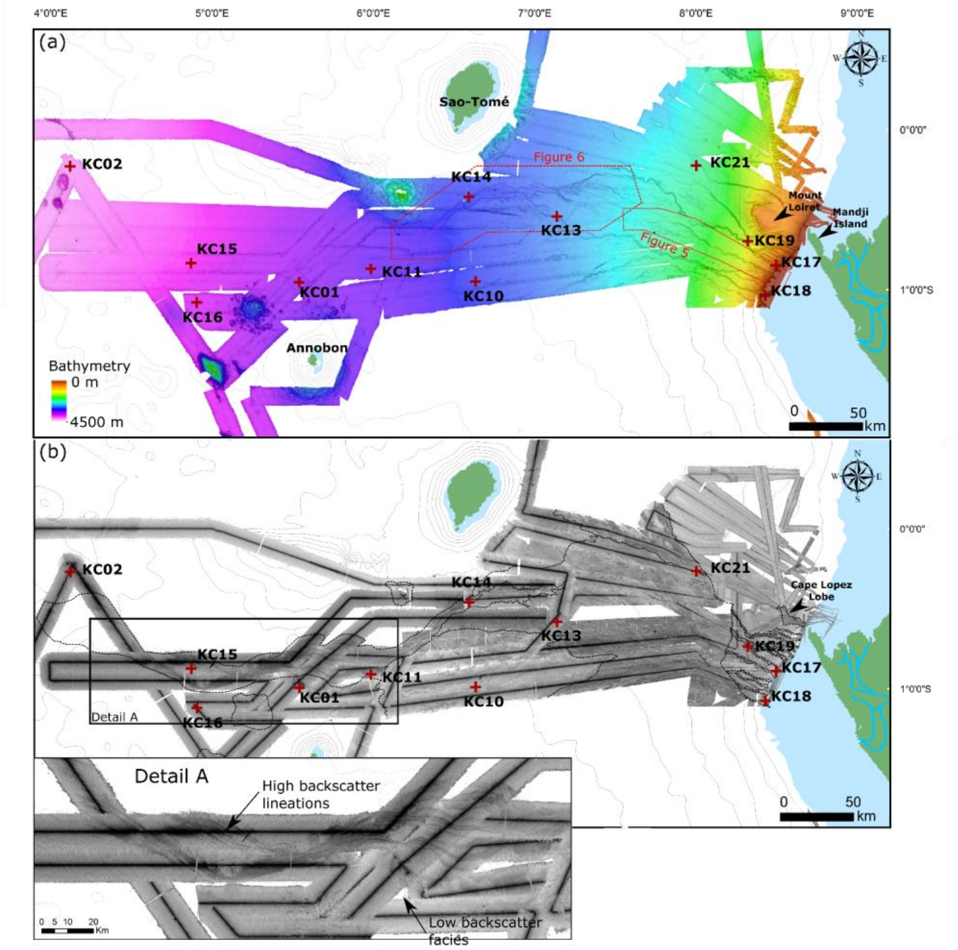

Figure 2: (a) Detailed bathymetric map of the Ogooue Fan, based on the multibeam echosounder data of the Optic Congo2005 and MOCOSED2010 surveys. (b) Acoustic imagery of the Ogooue Fan (high backscatter: dark tones; low backscatter: light tones). Detail A: close-up of the deepest part of the Ogooue Fan. Red crosses: location of the studied cores.

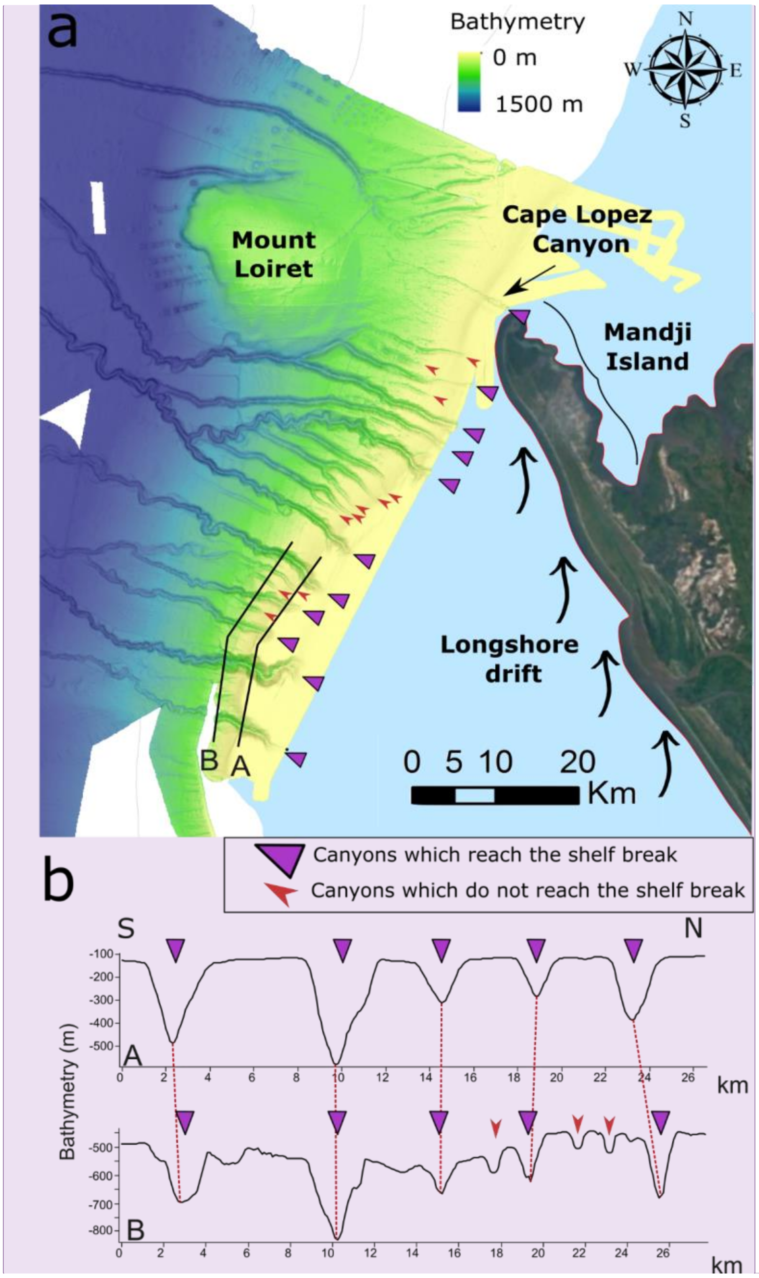

Figure 3: a) Close-up view of the Gabon shelf and canyons ramp. Bathymetry is from the Optic Congo2005 and MOCOSED2010 surveys, satellite view is from Google Earth. b) Two bathymetric profiles across the canyons showing the two types of canyons which are present along the Gabonese slope.

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3 Material and method

The bathymetry and acoustic imagery of the studied area result from the multibeam echosounder (Seabat 7150) surveys conducted onboard the R/V "*Pourquoi Pas?*" and "*Beautemps-Beaupré*" during the MOCOSED 2010 and OpticCongo 2005 cruises (Mouscardes, 2005; Guillou, 2010) (Figure 2). The multibeam backscatter data (Figure 2b) have been used to characterize the distribution of sedimentary facies along the margin. Changes in the backscatter values correspond to variations in the nature, the texture and the state of sediments and/or the seafloor morphology (Unterseh, 1999; Hanquiez et al., 2007). On the multibeam echosounder images, lighter areas indicate low acoustic backscatter and darker areas indicate high backscatter. Five main backscatter types are identified on the basis of backscatter values and homogeneity (Figure 4). Facies A is a homogeneous low backscatter facies, Facies B is a low backscatter heterogeneous facies, and Facies C is a medium backscatter facies characterized by the presence of numerous higher backscatter patches. Facies D and E are high and very high backscatter facies, respectively. High backscatter lineations are present within Facies D.

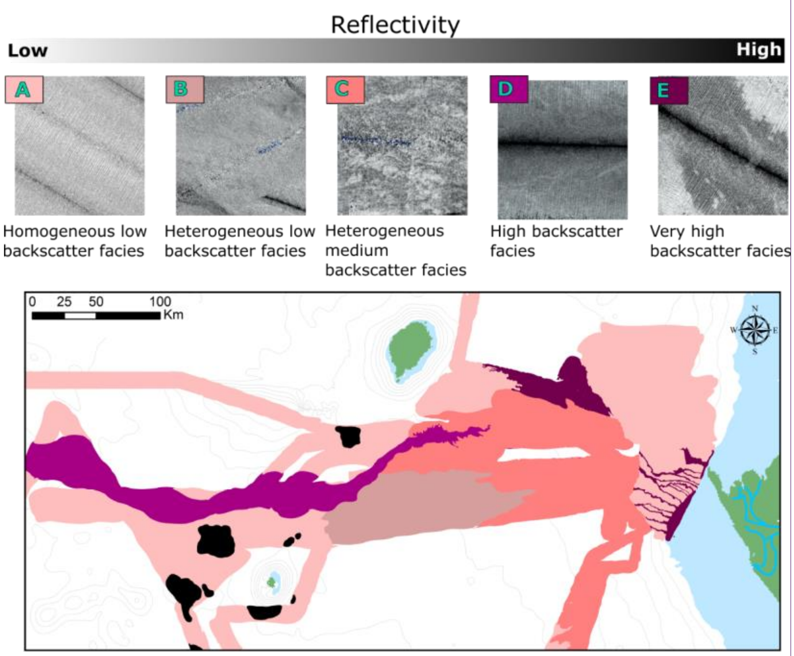

Figure 4: Reflectivity facies map of the Ogooue Fan showing the five main backscatter facies.

A total of four thousand five hundred km of 3.5 kHz seismic lines were collected in the area of the Ogooue Fan during the MOCOSED 2010 cruise and 470 km during the Optic Congo 2005 cruise (iXblue ECHOES 3500 T7). These data were used to analyze the near-surface deposits. The dataset covers the shelf edge, the slope and the abyssal plain. In this study, the 3.5 kHz echofacies has been classified according to Damuth's methodology (Damuth, 1975, 1980a; Damuth and Hayes, 1977) based on acoustic penetration and continuity of bottom and sub-bottom reflection horizons, micro-topography of the seafloor and presence of internal structures.

The twelve Küllenberg cores presented here were collected during the cruise MOCOSED 2010. Five of these cores have already been presented in Mignard et al. (2017) (Table 1). Visual descriptions of the cores distinguished the dominant grain size (clay, silty clay, silt, and fine sand) and vertical successions of sedimentary facies. Thin slabs were collected for each split core section and X-ray radiographed using a SCOPIX

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digital X-ray imaging system (Migeon et al., 1998). Subsamples were regularly taken in order to measure carbonate content using a gasometric calcimeter and grain size using a Malvern Mastersizer S. The stratigraphic framework is based on the previous work of Mignard et al., (2017), new AMS ^{14}C dating (Table 1) done on core KC21 and KC18 and facies correlation to determine the boundary between Marine Isotopic Stage 1 (MIS1) and Marine Isotopic Stage 2 (MIS2). Indeed, the transition from MIS2 to MIS1 in the south-west Atlantic is marked by an abrupt increase in carbonate content (Volat et al., 1980; Jansen et al., 1984; Olausson, 1984; Zachariasse et al., 1984). This feature is recorded in all the cores of this study collected in the medium and distal part of the system (Figure 5). The new AMS ^{14}C datings were realized on a mixture of different planktonic foraminifer species living in the uppermost water column. Radiocarbon dates have been calibrated using MARINE13 curve (Reimer, 2013) and using a standard reservoir age of 400 years (Table 2; Mignard et al, 2017).

Table 1: Characteristics of the twelve studied cores (MOCOSED 2010 cruise).

Core	Depth (m)	Latitude	Longitude	Length (m)
KC01	3504	00°57,010’ S	005°31,806’ E	12,96
KC02	4109	00°13,525’ S	004°07,620’ E	12,76
KC10	3148	00°56,666’ S	006°39,809’ E	11,54
KC11	3372	00°52,008’ S	006°00,008’ E	9,92
KC13	2852	00°32,508’ S	007°08,589’ E	7,62
KC14	3140	00°25,010’ S	006°36,006’ E	11,34
KC15	3850	00°49,996’ S	004°50,009’ E	12,01
KC16	3738	01°05,003’ S	004°52,010’ E	11,48
KC17	565	00°51,188’ S	008°29,377’ E	8,20
KC18	366	01°01,940’ S	008°25,409’ E	7,99
KC19	1610	00°41,593’ S	008°18,592’ E	10,03
KC21	2347	00°13,004’ S	008°00,011’ E	11,81

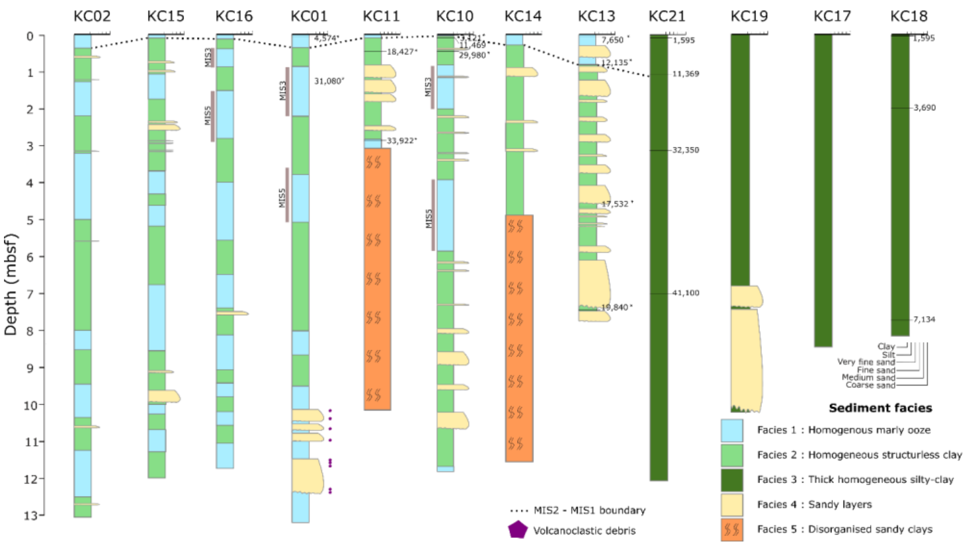

Figure 5: Sedimentological core logs from the Ogooue Fan, showing grain-size variation, lithology and bed thickness (locations of cores are presented in Figure 2). Ages are from ^{14}C dating (dates with a star are from Mignard et al. (2017), grey bars show MIS3 and 5 sediments for KC16, KC01 and KC10 (Mignard et al., 2017).

Table 2: AMS ^{14}C ages with calendar age correspondences realized for this study (Reimer, 2013).

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Core number	Sample depth	Conventional age (reservoir correction) BP	Calendar age cal. BP
KC18	7	1,523 ±30	1,780
KC18	197	3,671±30	3,690
KC18	787	7056±40	7,134
KC21	12	1532±30	1,595
KC21	115	10,654±80	11,369
KC21	327	30,569±90	32,350
KC21	700	39,732±120	41,100

4 Results

4.1 Sedimentary facies

The classification in five sedimentary facies used here is based on photography and X-ray imagery, grain size analyses and $CaCO_3$ content (Figure 5). Interpretation of these facies is based on the comparison with previous sedimentary facies classifications such as Stow and Piper, (1984); Pickering et al., (1986) and Normark and Damuth, (1997).

Facies 1: Homogenous, structureless marly ooze. This facies is composed of structureless, light beige marly ooze with relatively high concentration of planktonic foraminifers. The mean grain size is around 15 µm and the $CaCO_3$ content ranges between 40 and 60%. This facies is interpreted as a pelagic drape deposit; it forms the modern seafloor of the deepest part of the Ogooue Fan and is observed in most of the core tops corresponding to the MIS 1 interval.

Facies 2: Homogenous, structureless clay: Facies 2 consists of dark brown clay. The mean grain size is less than 15 µm and the $CaCO_3$ content is less than 30%. This facies has been interpreted as hemipelagic drape deposits.

Facies 3: Thick, homogeneous silty-clay: Facies 3 consists of very thick homogeneous dark silt-clay layers containing less than 10% of $CaCO_3$. This facies contains numerous quartz and mica grains and plant debris indicating a continental origin of the sediments. It results from the deposition of the fine-grained suspended load coming from the Ogooue River and flowing down the slope or belonging to the flow tops of the turbidity currents.

Facies 4: Silty to sandy layers: Facies 4 consists of fine- to medium-grained sand beds with a thickness up to several meters. They are either normally-graded or massive and display a variety of bedding structures: ripple cross laminations, parallel laminations. The composition varies from terrigenous (quartz and mica) to biogenic (foraminifers), some sand beds are highly enriched in organic debris (Mignard et al., 2017). They are interpreted as being deposited by turbidity currents initiated on the Gabonese continental shelf. Four beds sampled at the base of core KC01 present a high concentration of volcaniclastic debris, such particles are completely absent in all the other sandy beds (Figure 5) sandy beds. This specific composition and the particular location of the core both suggest that these sequences originate from the nearby Annobon volcanic island.

Facies 5: Disorganized sandy clays: Facies 5 consists of thick intervals of deformed or chaotic clay with deformed or folded silty to sandy layers containing mainly quartz grains and rare plant debris. This facies is interpreted as a slump deposit or debrite.

4.2 Fan morphology

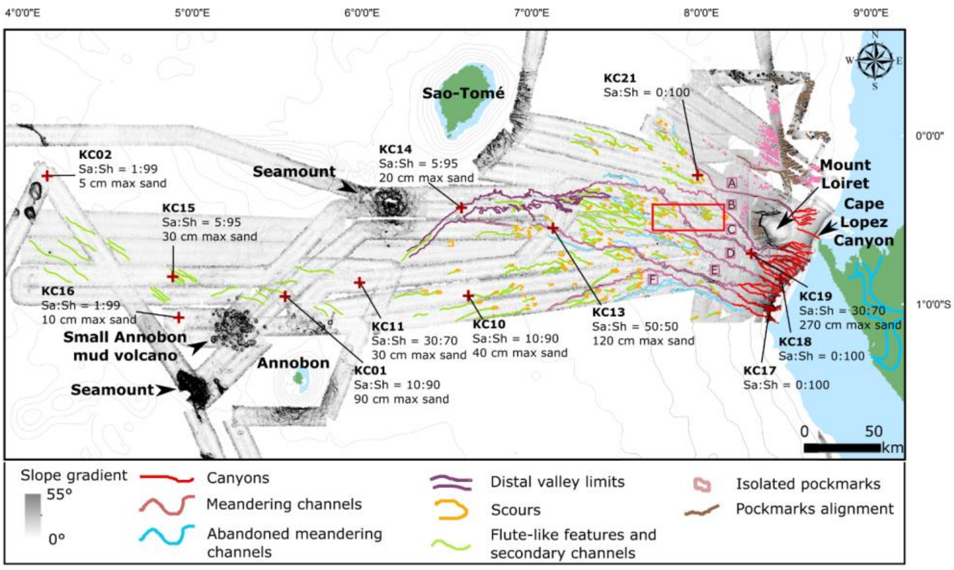

Figure 6: Interpreted gradient-shaded map of the Ogooue Fan showing the main features of the fan. A, B, C, D, E and F are the six main channels discussed in the text. The sand/shale ratio of the cores are shown (Sa:Sh) as well as the maximum sand-bed thickness in each core (max sand). A close-up view of the red rectangle is presented in Figure 8.

Analysis of the seafloor data (bathymetry and acoustic imagery) reveals the different domains of the Ogooue sedimentary system and the different architectural features of the Ogooue Fan (Figure 6).

The Gabon continental shelf is relatively narrow, decreasing in width from 60 to 5 km toward the Mandji Island (Figure 3). The slope is characterized by two main topographic features: (1) the Mount Loiret, a guyot located just west of the Manji Island, which forms a bathymetric obstacle on the upper slope and (2) a ramp of several tributary canyons located south of the Mount Loiret (Figure 3). This ramp is composed of several wide and deep canyons (several hundreds of meters deep and 2-3 km wide near the canyons head), with a "V-shape" morphology and which heads reach the shelf break. Several thinner and shallower incisions are located between these deep canyons. They are less than 100 m deep and 1 km wide and their heads are located between 200 and 400 m water depth (Figure 3). The continental shelf and the slope present low backscatter values except for the canyons, that correspond to very high backscatter value (Figure 4).

The transition between the continental slope and the continental rise, between 1,200 and 1,500 m water depth, is marked by a decrease in the slope gradient from a mean value of 2.3° to 0.9°. At this water depth, several canyons merge to form five sinuous channels (B to F in Figure 6). These channels appear with higher backscatter value than the surrounding seafloor (Figure 4). These sinuous subparallel channel-levees complexes extend down to 2,200 m water depth with a general course oriented toward the north-west (Figure 6 and 7). At 2,200 m water depth, the southernmost channel (channel F in Figure 6) deviates its path toward the south-west.

The sinuosity of these channels decreases Westward. Channel D sinuosity has been calculated over 2 km long segments (Figure 7C). It is less than 1.1 along the first 13 km corresponding to the canyon part. From 13 to 40 km from the head the mean sinuosity is 1.4 and then decreases to less than 1.2 between 40 to 90 km from the head. Finally, the most distal part of the channel, from 90 km from the head, is very straight with a sinuosity index lower than 1.1 (Figure 7C).

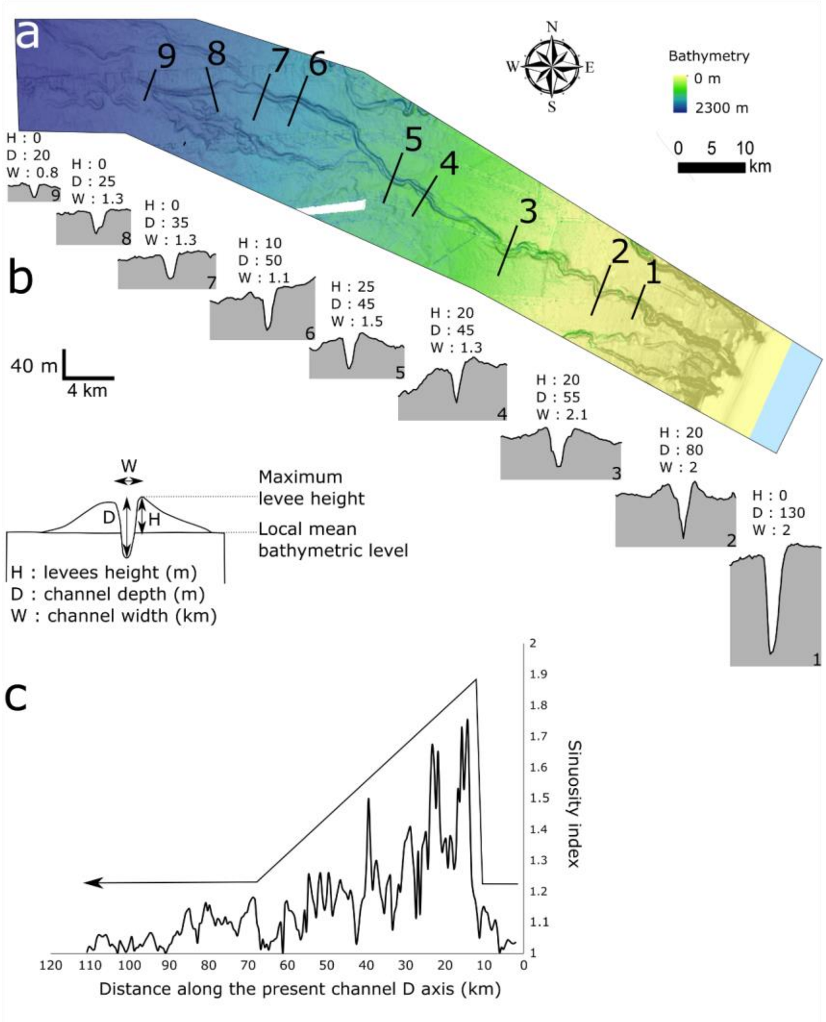

Figure 7: a) Detailed bathymetric map of channel D (location in Figure 2) b) serial bathymetric profiles showing the evolution of the channel-levees along the slope and c) sinuosity down the channel D measured along 2 km channel segments.

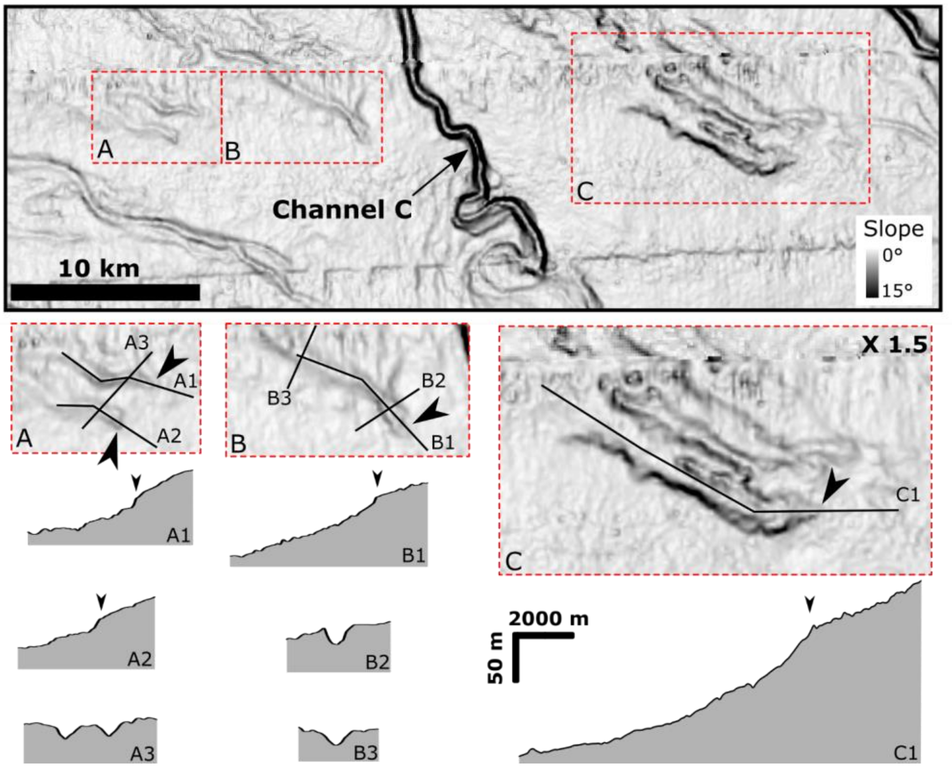

Figure 8: Close-up view of the gradient-shaded map showing erosional lineations (A and B) and amalgamated scours (C) in the central part of the system (location in Figure 6).

Downslope, in the central part of the system, the seafloor located between 2,200 m and 2,500 m water depth, presents numerous erosional features including scours, lineations and smaller, subsidiary channels, corresponding to channels with no headward connection with an obvious feeder system according to Masson et al. (1995) (Figure 8). These erosional features appear on a very gentle slope area (0.3°) characterized by a heterogeneous medium backscatter facies (Figure 4). At 2,500 m water depth, just south of the Sao-Tomé Island, the head of a large, 100 km long, mid-system valley appears (Figure 9). This valley can be subdivided in two parts of approximately equal length with two different orientations. The upper part of the valley is oriented E-W, whereas the lower part is oriented NE-SW. This direction change is due to the presence of a rocky seamount located north of the valley and which deflects its course. The upper part

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of the valley is up to 15 km wide with numerous erosional scars and terraces on its flanks. The valley bottom is characterized by very high backscatter value and small internal erosion channels. Downstream, the valley becomes narrower with a "U" shape (Figure 9, profile 5). Its flanks appear regular with no scar of down-flank mass deposits. The depth of the valley decreases from 60 m in its central part to only 10 m near its mouth. The area located south of the mid-system valley is characterized by a heterogeneous low-backscatter facies. Some erosional features and subsidiary channels are present but scarce.

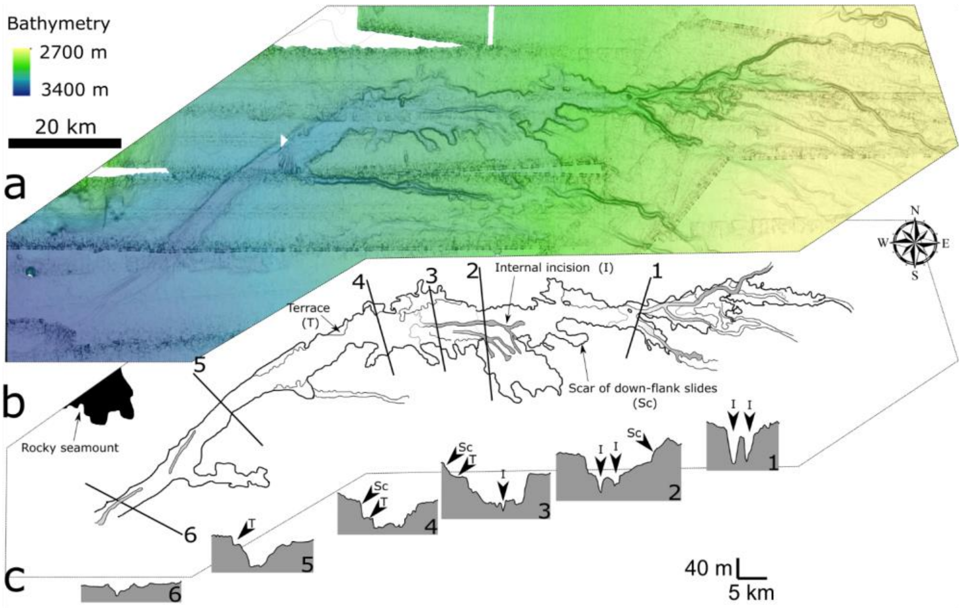

Figure 9: (a) Detailed bathymetric map of the mid-system valley of the Ogooue Fan between 2,700 and 3,400 m water depth; b) Interpretation of the main morphological features of the valley; c) Six transverse profiles of the mid-system valley extracted from the bathymetry data (Sc: scar of down-flank slides, I: internal incision, T; Terrace).

West of the mid-system valley outlet, the seafloor is very flat and shows only subtle morphological variations except for local seamounts. Few channel-like, narrow elongated depressions (maximum 10 m deep) presenting high backscatter values can be identified. These lineations are restricted to a long tongue of high backscatter at the mouth of the valley (Figure 2b, Detail A). This tongue is globally oriented E-W at the exit of the mid-system valley and then deflects toward the NW at 3,700 m water depth, following the steepest slope.

North of Mount Loiret, the upper slope presents a lower slope gradient compared to the south part and is characterized by the presence of numerous linear pockmark trains on the upper part and pockmarks fields on the lower part. This whole area has a very low and homogeneous reflectivity. Trace of active sedimentation on this part of the margin is only visible in association with the Cape Lopez Canyon, which is the only canyon located north of the Mount Loiret (Figure 3). This canyon is associated with a small intraslope lobe located just north-east of the Mount Loiret and referred as the Cape Lopez Lobe (Figure 10) (Biscara et al., 2011). This northern system continues basinward with Channel A, the head of which is located in the vicinity of the Cape Lopez Lobe. At 2,200 m water depth, Channel A ends and its mouth is associated on the backscatter map with a fan-shaped area of very-high reflectivity, which is associated with some subsidiary channels and erosional marks (Figure 4).

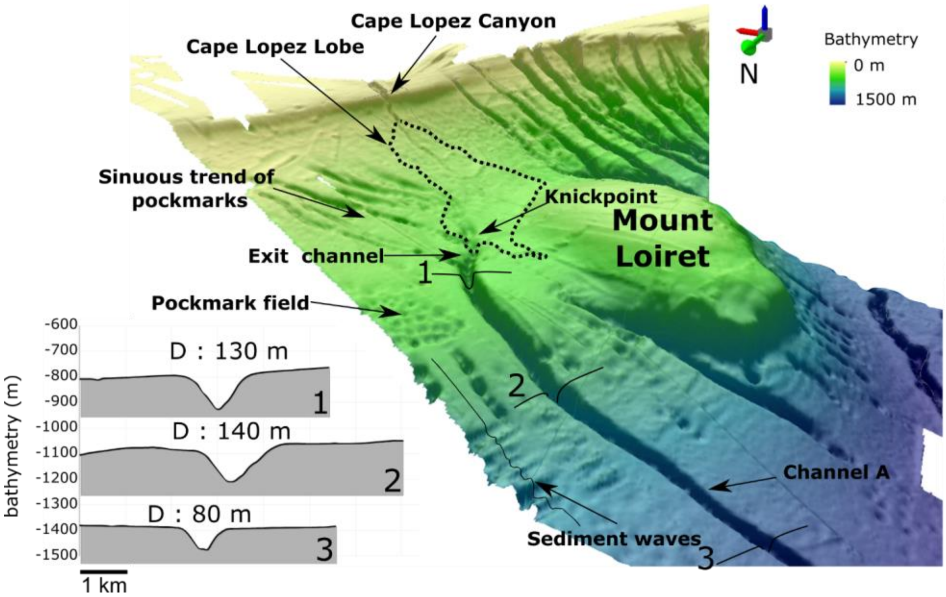

Figure 10: a) Three-dimensional representation of the Cape Lopez, Canyon, Cape Lopez Lobe and Channel A, b) three transverse profiles of Channel A.

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4.3 Echofacies analysis and distribution

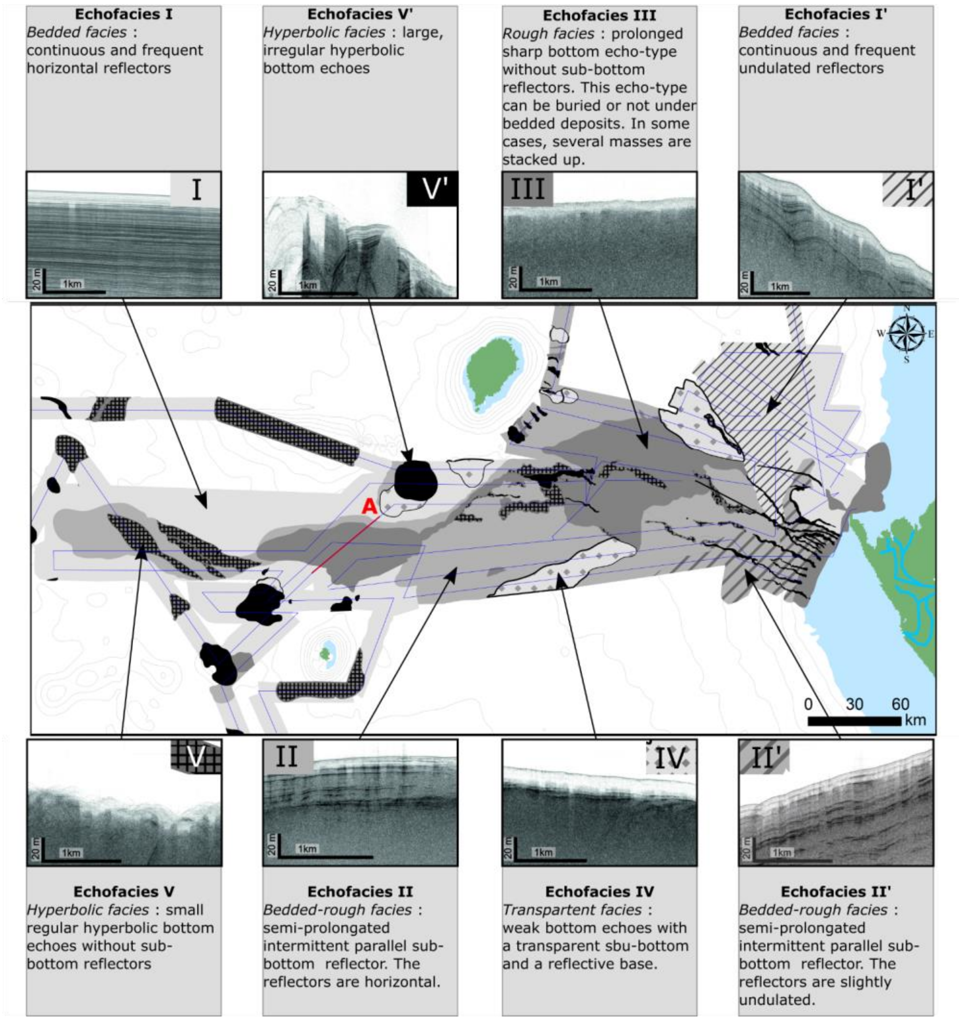

Figure 11: Echofacies map of the Ogooue Fan. Eight shades of grey represent the specific echofacies.

The main echofacies have been discriminated on the profiles based on amplitude, frequency and geometry of the reflections (Figure 11). They have been grouped into five main classes: (I) bedded, (II) bedded-rough, (III) rough, (IV) transparent and (V) hyperbolic. Most transitions between echofacies are gradual.

The echofacies of the edge of the Gabonese shelf consists of rough echofacies III (Figure 11). Core KC18 indicates that this area is dominated by fine-grained, structureless, terrigenous sedimentation.

North of the Mount Loiret, the continental slope presents bedded echofacies I, which evolves into echofacies I' down isobath 1,500 m which corresponds to an increase in the slope gradient. Previous studies have shown that bedded echofacies are commonly associated with alternating sandy and silty beds (Damuth, 1975, 1980a; Pratson and Laine, 1989; Pratson and Coakley, 1996; Loncke et al., 2009) or with hemipelagic sedimentation (Gaullier and Bellaiche, 1998). The very low reflectivity of the area and the absence of any channel suggest that only hemipelagic sedimentation occurs in this area. The wavy aspect of echofacies I' is certainly due to the post-deposition deformation of the hemipelagic sediments (Bouma and Treadwell, 1975; Jacobi, 1976; Damuth and Embley, 1979; Damuth, 1980b).

South of Mount Loiret, echofacies II and II' dominate on the continental slope. Despite the lack of sampling, the presence of discontinuous seismic reflectors can indicate the presence of coarse-grained sediment interpreted as turbidites (Damuth, 1975; Damuth and Hayes, 1977). The echo-mapping of the continental rise reveals the presence of different facies. The central part, just upstream of the mid-system valley, is characterized by rough echofacies III that suggests the presence of a high proportion of coarse-grained sediments. Some large channels are marked by hyperbolic facies certainly due to the irregular and steep seafloor. South of the mid-system valley, facies II dominates. Core KC10, collected in this area, indicates the alternation of clayey and sandy layers but with a predominance of fine-grained sediments (Figure 5). Echofacies IV is present in two main areas on the continental rise where they respectively form two lobe-shaped zones: one on the northern part, following the limits of the high-reflectivity area located at the mouth of channel A; the second in the southern part of the system in association with channel F. This echo-facies commonly corresponds to structureless deposits without internal organization due to mass-flow processes (Embley, 1976; Jacobi, 1976; Damuth, 1980a, 1980b, 1994) but it can also characterize basal fine-grained turbidites (Cita et al., 1984; Tripsanas et al., 2002). Core KC21, collected in the northern area indicates homogeneous silty-clay sediments with numerous detrital debris similar to those collected near the continental shelf.

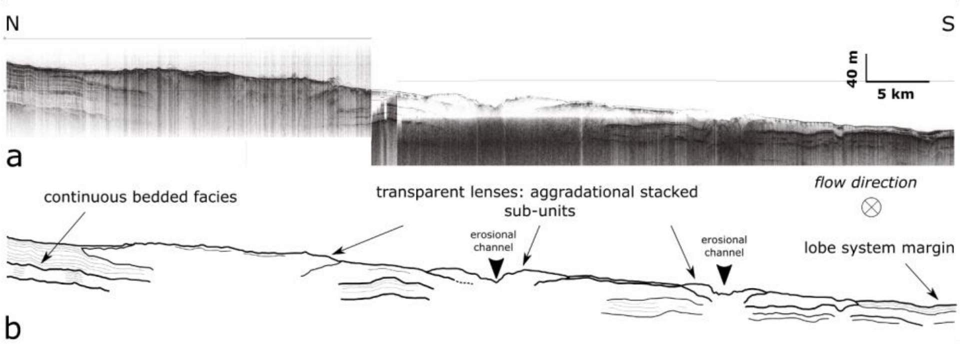

Figure 12: a) Transverse 3.5 kHz very-high resolution seismic line and b) line drawing in the upper distal lobe area, see Figure 11for location of the line.

In the abyssal plain, the area of the elongated tongue noticeable on the backscatter data presents different echofacies. Based on the 3.5 kHz profiles, it can be subdivided into two main domains. The upstream part, at the outlet of the mid-system valley, is characterized by rough echo character but with a specific organization: multiple aggradational stacked transparent sub-units from 10 to 30 meters thick are visible on the seismic lines (Figure 12). This organization is characteristic of sandy lobes deposits (Kenyon et al., 1995; Piper and Normark, 2001). Core KC11, collected in this environment, presents several decimeters-thick sandy layers and a several meter-thick disorganized sandy-clay units interpreted as a slump. The downstream part presents bedded-rough echofacies (II) associated with hyperbolic echofacies (V). Core KC15 intersected fine-grained sediments and several silty layers corresponding to the distalmost turbidites.

On the edge of this tongue, high-penetration bedded facies (I) is dominant. The highly continuous parallel bedding indicates hemipelagic sedimentation with no coarse-grained fraction, which is confirmed by core KC16 and core KC02 both composed of alternating carbonate-rich and carbonate-poor clay sediments. Facies V’ forms some patches on the seafloor and correspond to seafloor mounts. The hyperbolic facies is due to the steep slopes and the irregular topography.

Facies V and IV are also present and form lenses around the island of Sao-Tomé and Annobon. These features indicate some downslope sedimentary transfer from these islands. The limited area covered by these facies suggests short transport by sliding.

5 Interpretation and discussion

5.1 Sedimentary processes along the fan

The Ogooue Fan is a delta-fed passive margin deep-sea mud/sand-rich submarine fan according to the classification of Reading and Richards (1994). However, analysis of sub-surface data (bathymetry, acoustic imagery and 3.5 kHz echo-characters) reveals a great variability of sediment processes in the different domains of the margin, controlled by variations in slope gradient and the presence of seamounts (Figure13a).

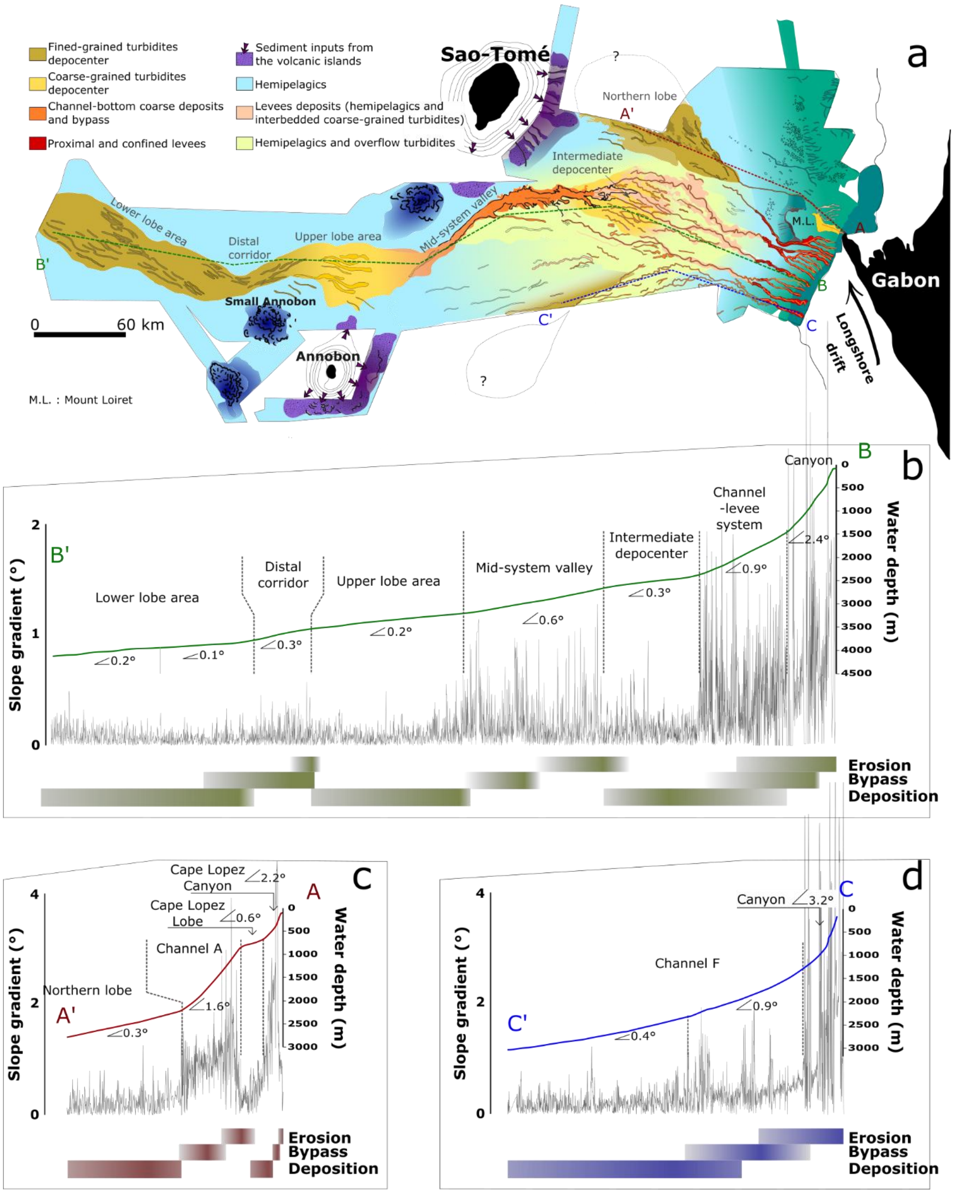

Figure 13: a) Synthetic map showing the architecture and the recent sedimentary processes of the Ogooue Fan determined by imagery and echofacies mapping; b) c) and d) Longitudinal profiles from the bathymetric data along the central, northern and southern part of the Ogooue Fan and slope gradient (in degree, measured every 100m).

The differences in slope gradient along the transects are associated with the main sedimentary processes encountered along the slope.

5.1.1 Canyons system

Erosional processes predominate on the upper part of the slope as indicated by the presence of numerous tributary canyons (Figure 3). Based on the comparison of the canyon depths, widths and head positions, we observe the existence of two types of canyons as described in Jobe et al. (2011) along the Equatorial Guinea margin. The canyons presenting a deep (> hundreds of meters deep) "V" shape and which indent the shelf edge are type I canyons (*sensu* Jobe et al., 2011), whereas the shallower canyons (<100 m deep) with a "U" shape and which do not indent the shelf are type II canyons (*sensu* Jobe et al., 2011). The difference between these two types of canyons indicates different initiation and depositional processes. Type I are commonly associated with high sediment supply and the canyons initiation and morphology are controlled by sand-rich erosive turbidity currents and mass-wasting processes (Field and Gardner, 1990; Pratson et al., 1994; Pratson and Coakley, 1996; Weaver et al., 2000; Bertoni and Cartwright, 2005; Jobe et al., 2011). In contrast, Type II canyons are found in areas of low sediment supply. Their initiation is attributed to retrogressive sediment failures and subsequent headward erosion (Shepard, 1981; Twichell and Roberts, 1982; Stanley and Moore, 1983). Their evolution is controlled by depositional processes involving fine-grained sediments - hemipelagic deposition and dilute turbidity currents - that can be carried over the shelf and upper slope into the canyon heads but without significant erosion (Thornton, 1984). North of the Mount Loiret, the fine-grained sedimentation has completely infilled several type II canyons creating sinuous trains of pockmarks. These pockmarks have been previously described in Pilcher and Argent (2007). Variations in the localisation of coarse-grained sediment supplies play a key role on the development of the two types of canyons. Along the central Gabonese shelf, the very recent development of the Mandji Island 3,000 years BP (Giresse and Odin, 1973; Lebigre, 1983) favoured the construction of the Cape Lopez Type I canyon, which is presently active (Biscara et al., 2013).

5.1.2 Channels system

The transition from canyons to sinuous channels with external levees (*sensu* Kane and Hodgson, 2011) is related to a decrease in slope gradient from the continental slope (> 2°) to the continental rise (< 1°). The sinuous channel-levees systems develop on a relatively gentle slope (0.9°) from 1,500 to 2,200 m water depth. These channels are mainly erosive in their axial part (Normark et al., 1993) while deposition occurs on low-developed external levees (25 m maximum levees height for channel D; Figure 7). The external levees of the four central channels (B, C, D and E in Figure 2) show high reflectivity that suggests frequent turbidity currents overspill. These channels are deeply incised in the seafloor (average 70 m deep for channel D and 90 m deep for channel A; (Figure 7 and Figure 10) below the associated levees, when present. This feature is similar to the modern Congo Channel (Babonneau et al., 2002) and is opposed to the morphology of aggrading channels (such as the Amazon Channel) where the thalweg is perched above the base of the levees system (Damuth, 1995). This entrenched morphology prevents extensive overflow of turbidity currents and is the probable cause of low development of external levees and inhibits channel bifurcation by avulsion. It has been proposed for the Congo Channel that the entrenched morphology of the channel confines the flow and keeps the energy high enough to allow a transport of sediment to very distant areas (Babonneau et al., 2002).

Several studies have documented that sinuosity of submarine channels increases with time (Peakall et al., 2000; Babonneau et al., 2002; Deptuck et al., 2003, 2007; Kolla, 2007). The sinuous upper parts of the channels (1.3 < sinuosity < 1.75 for channel D; Figure 7C) have consequently undergone a long history whereas the distal straighter parts of the channels are in a more immature stage. Moreover, the height of the external levees and the depth of the channels both decrease in the lower parts of the channels system (Figure 7). These morphological changes are due to a slope gradient decrease (< 0.5° from transect 6 along channel D; Figure 7) that progressively slows down the flow velocity and reduces its erosional power. Simultaneously, deposition of fine particles by spilling of the upper part of the flow on the external levees leads to a progressive decrease of the fine-grained fraction transported by the channelized flows (Normark et al., 1993; Peakall et al., 2000).

At 2,200 m water depth, the appearance of numerous erosional features such as isolated and amalgamated spoon–shaped scours (Figure 8 C1), erosional lineations and subsidiary channels with limited surface expression (10-20 m deep, Figure 8 B2, B3) are characteristic of the channel lobe transition zone (Figure 8) (Kenyon et al., 1995; Wynn et al., 2007; Jegou et al., 2008; Mulder and Etienne, 2010). The appearance of these features correlates with a second abrupt decrease in slope gradient (from 0.9° to 0.3°) and with the transition from bedded-rough to rough echo-facies indicating a change in the sedimentary process. This area corresponds to deposition by spreading flows in an unchanneled area referred as the intermediate depocenter in Figure13 and covering area surface of ca. 4,250 km². However, the low penetration of the 3.5 kHz echosounder and the limited number of seismic lines in this area did not allow a more detailed interpretation of the sedimentary processes in this part of the system.

5.1.3 Mid-system valley and distal lobe complexes

The presence of a steeper slope downslope of the intermediate depocenter (0.6°) led to the incision of the mid-system valley, which acts as an outlet channel for turbidity currents that are energetic enough to travel through the flatter depositional area (Figure13b). The upstream part of the valley is multi-sourced and has migrated upstream by retrogressive erosion, whereas the downstream part appears more stable with a straighter pathway and steeper flanks, these features being similar to the Tanzania Channel described by Bourget et al. (2008). The pathway of the valley seems to be controlled by the seafloor topography as the valley deviates near the rocky seamount located west of Sao-Tomé. This large mid-system valley corresponds to a single feeding "source" for the lower fan and, consequently, the final depositional area is located downstream of the valley.

At the outlet of the mid-system valley, the echofacies shows an area mainly characterized by rough echofacies (III) forming stacked lenses. This area, referred as

the upper lobe area in Figure13, constitutes the main lobe complex (*sensu* Prélat and Hodgson, 2013) of the Ogooue Fan. According to the seismic data, the depositional area of the lobe complex is ~ 100 km long, reaches ~ 40 km in width, spreads over 2,860 km² and reaches up to 40 m in thickness. The transparent lenses are interpreted as lobe elements and seem to be bounded by erosive bases (Mulder and Etienne, 2010). Some incisions (< 15 m deep) are imaged on the top surface of the lobes; two of them are visible in Figure 12. The area where incisions are present is interpreted as the channelized part of the lobe. This lobe area presents a gentle slope (0.3°) oriented north-south, suggesting that topographic compensation would shift future lobe element deposition southward. However, the few numbers of seismic lines do not allow the precise internal geometry and the timing of the construction of the different lobe units.
This depositional area is not the distalmost part of the Ogooue Fan. West of this lobe, evidences of active sedimentation are visible on the reflectivity map (Figure 2, Figure 4). The reflectivity map shows high-backscatter finger-shape structures suggesting pathways of gravity flows (Figure 2b, detail A). These lineations (< 10 m deep) are concentrated in a 20 km wide corridor just west of the lobe area and then form a wider area extending up to 550 km offshore the Ogooue Delta. This part of the system follows the same scheme as the one previously described between the intermediate depocenter and the upper lobe area (Figure13b). The corridor appears on a segment of steeper slope (0.3°) just at the downslope end of the upper lobe area (0.2°). This corridor, which disappears when the slope becomes gentler (0.1°), was certainly formed by the repeated spill-over of the fine-grained top of turbidity currents over the upper lobe area. This architecture suggests that this corridor is dominated by sediment bypass (*sensu* Stevenson et al., 2015). On the most distal segment with a very low slope gradient (0.1-0.2°) sediment deposition dominates.

5.1.4 Isolated systems

On the northern part of the slope, the isolated system composed of the Cape Lopez Canyon, Cape Lopez intraslope lobe, channel A and northern lobe follows the same scheme (Figure13c). Cape Lopez Canyon terminates at 650 m water depth at an abrupt decrease in slope gradient (from more than 1.7° to 0.6°) caused by the present of the Mount Loiret (Figure 10). The Cape Lopez intraslope lobe occupies a small confined basin, 6 km wide and 16 km long and covers an area of 106 km². This lobe appears very similar with the "X fan" described in Jobe et al. (2017) on the Niger Delta slope (8 km x 8 km, 76 km²) and is in the same size range as the intraslope complexes studied in the Karoo Basin by Spychala et al. (2015) (6-10 km wide and 15-25 km). The two successive depositional areas, composed by the Cape Lopez lobe and the northern lobe, are located on areas with a low slope gradient (0.6-0.3°) whereas erosion and sediment bypass dominate on segments of steeper slope gradient (1.6°). The high slope gradient between the two depositional areas favored the construction of a straight deeply entrenched channel (>100 m deep near the knickpoints) without levee (Figure 7b) instead of a large valley similar to the central mid-system valley.

In the southern part of the fan, channel F transports sediments southward (Figure13d). At 2,200 m water depth, a transparent echofacies appears associated with the pathway of this channel. This echofacies suggests that sediment transported by this channel might be partly deposited in this area by turbidity current overflow. This channel might also be associated with a depositional lobe; however, the area covered by the MOCOSED survey does not allow us to image it.

5.2 The Ogooue Fan among other complex slope fans

The Ogooue Fan develops on a stepped-slope (Prather, 2003) which creates a succession of depositional areas on segments with gentle slope (referred as 'steps' in Smith, (2004)) and segments of steeper slope ("ramps" in Smith, 2004) associated with erosion or sediment bypass (Figure13) (Demyttenaere et al., 2000; O'Byrne et al., 2004; Smith, 2004). The depositional behavior in these systems is guided by an equilibrium profile of the system that forms preferential areas of sedimentation or erosion (Komar, 1971; Ferry et al., 2005). As described in the conceptual model of O'Byrne et al. (2004), erosion is favored where local gradient increases, the eroded sediments being delivered downstream resulting in a local increase in sediment load (O'Byrne et al., 2004; Gee and Gawthorpe, 2006; Deptuck et al, 2012). This kind of fan geometry is common along the West African margin where abrupt changes in slope gradient and complex seafloor morphology are inherited from salt tectonic movement (Pirmez et al., 2000; Ferry et al., 2005; Gee and Gawthorpe, 2006; Gee et al., 2007). Deptuck (2012) has described the influence of stepped-slope on sedimentary processes along the western Niger Delta. He showed that differences of slope gradient between ramps (0.8° to 2.1°) and steps (0.3° to 1.1°) induce the transition from vertical incision and sediments removal to preferential sediments accumulation (Deptuck et al., 2007; Deptuck, 2012). Gradient changes along the Gabonese margin are however lower than the ones reported in Deptuck, (2012) and variation in slope gradient of 0.2° appears to be enough to modify sedimentary processes. The impact of subtle changes of slope gradients has already been highlighted by studies of the Karoo basin (Van der Merwe et al., 2014; Spychala et al., 2015; Brooks et al., 2018) and Moroccan margin where sedimentary processes are controlled by very subtle gradient changes (<0.1°) (Wynn et al., 2012).

Moreover, in the case of the modern Ogooue Fan, and conversely to what is observed in the Congo and Niger systems, the presence of several bathymetric highs including the volcanic islands of the CVL and the Mount Loiret constitutes additional stresses for the flows and creates a more complex slope profile. These bathymetric highs induce a lateral shift of the pathways of different channels as well as the pathway of the mid-system valley and form several downslope depositional lobes such as the Cape Lopez lobe that is constrained by the presence of the Mount Loiret. Several complex-slope systems have already been described in the literature with slope complexity due to salt-related deformations (e.g. Gulf of Mexico (Prather et al., 1998; Beaubouef and Friedmann, 2000), offshore Angola (Hay, 2012) or basin thrusting (offshore Brunei; McGilvery and Cook, 2003, Markan margin; Bourget et al., 2010). For these systems, the slope evolves rapidly, and sedimentation and erosion are unlikely to establish an equilibrium profile. In contrast, the Gabonese margin reached a mature evolutionary stage with only weak and slow salt tectonic activity (Chen et al., 2007), and sedimentation and erosion certainly dominate the short-term evolution of the slope. The Ogooue Fan appears to be much more similar to the morphology of the Northwest African margin where the Madeira, the Canary and the Cape Verde islands create a complex slope morphology along the Moroccan and Mauritanian margin (Masson, 1994; Wynn et al., 2000, 2002, 2012).

5.3 Sedimentary facies distribution

The main processes involved in the deposition of the Upper Quaternary sediments of the Ogooue Fan are pelagic and hemipelagic suspension fall-out together with turbidity currents. Fine-grained pelagic/hemipelagic ‘background’ sedimentation is dominant across a large area of the margin, particularly on the lower rise and the adjacent basin plains. These sediments are then overprinted by downslope gravity flows such as turbidity currents. However, the previously described fan organization implies a specific distribution of the sedimentary facies and grain-size distribution within the system (Figure 6).

Cores collected in the upslope area (KC18 and KC17) show mostly hemipelagic sediments with a very low carbonate content. This reflects significant detrital flux associated with proximity to the Ogooue platform and the influence of the Ogooue river plume. Core KC19 collected down the slope just at the transition from canyon to channel-levee complexes show two several meters-thick sandy successions corresponding to top-cut-out Bouma sequences (Ta) interbedded with the upper slope hemipelagites. These sandy turbidites, which are the thickest sand beds recorded in all the cores (Figure 6), indicate the occurrence of high-density turbidity currents flowing down the canyons. The lack of the upper parts of the turbidite is consistent with deposition in the canyons of coarse-grains located at the base of the turbidity currents, whilst the finer upper part of the current is transported downstream and/or spills over the external levees. External levee deposits have been sampled by core KC13, which shows numerous turbidites made up of centimeter-thick, fining upwards parallel or ripple cross-laminated of silt and fine sands (Figure 5). Unfortunately, no core has been collected directly in the intermediate depocenter. However, the rough echofacies III found in this area associated with various erosional features both suggest a high sand/mud ratio.

The mid-system valley acts as a conduit for the sediments coming from the upper part of the system, transporting them further downstream. However, the sediments resulting from the erosion of this valley constitute certainly a part of the sediments deposited in the lobe complex area. According to the available bathymetric data, the volume of sediment removed from the mid-system valley is between 8 and 10 km^3. We assume that these sediments are mainly fine-grained due to the deep location of the valley. Core KC14, collected on an internal terrace of the valley, shows that this valley is also an area of active sedimentation notably due to down-flank sliding. The bottom of the valley comprises slump deposits and coarse-grained sediments deposited by gravity flows coming from the upper part of the system.

Downstream of the mid-system valley, core KC11 show that coarse-grained turbidity currents are deposited in the proximal part of the lobe complex. The abrupt transitions between erosional/bypass and depositional behavior observed notably at the mouth of the mid-system valley is the result of hydraulic jumps affecting flows when they become unconfined between channel sides and spread laterally (Komar, 1971; Garcia and Parker, 1989). Core KC15, located in the lower lobe area, is composed of very thin silty turbidites corresponding to the upper parts of the Bouma sequence interbedded with hemipelagic deposits. The upper lobe acts as a trap for the basal sand-rich parts of gravity flows. Consequently, only the upper part of the flows, which is composed of fine-grained sediments, travels beyond this area. The spatial distribution of facies suggests a filling of successive depocenters with a downslope decrease of the coarse-grained sediment proportion (Figure 6). The same facies distribution can be observed in the northern system. No sandy turbidites are recorded in KC21 located in the Northern lobe, only fine-grained sedimentation, whereas the study of cores taken in the Cape Lopez lobe shows the presence of numerous sandy turbidites (Biscara et al., 2011). The Northern lobe is thus fed by the downslope flow stripped suspended fines transported at the top of turbidity currents flowing through the Cape Lopez Canyon, similarly to intraslope lobes observed in other locations (e.g. Spychala et al., 2015; Jobe et al., 2017). Whatever the current pathways are, the deposited material has a continental origin as suggested by the abundance of quartz, micas and plant debris in the coarse-grained fraction. The important proportion of planktic foraminifers in the coarse-grained fraction of turbidites located in the distal part of the system (core KC10- KC11- KC15) suggests that turbidity currents previously entrained pelagic and hemipelagic deposited upslope where such deposits cover large areas (Viana and Faugères, 1998). The presence of volcanoclastic debris in a sandy layer found at the base of core KC01 suggests that sedimentary input may also come from the volcanic islands of Sao Tomé or Annobon. However, acoustic data indicate that these inputs are limited to the close vicinity of the Sao-Tomé and Annobon islands. In contrast to the model proposed by Wynn et al., (2000) for the Northwest African slope, the volcanic islands and other seamounts present on the Ogooue Fan act mainly as obstacles for the flow pathway but are not important sediment sources for the fan.

5.4 Palaeoceanographic control on the fan activity

The results of Mignard et al. (2017) concerning the study of five cores located along the central part of the Ogooue Fan showed that the fluvial system fed the fan with sediments almost only during times of relative low sea-level. This relative sea-level control on turbidite activity (switch on/off behavior) is classical for mid and low latitude passive margin fans where canyon heads are detached from terrestrial sediment sources (e.g. Mississippi Fan (Bouma et al., 1989), Amazon Fan (Flood and Piper, 1997), Rhone Fan (Lombo Tombo et al., 2015), Indus Fan (Kolla and Coumes, 1987). Conversely, sedimentation during periods of relative high sea-level such as the Holocene, is dominated by hemipelagic to pelagic fall-out with a low part of fine terrigenous particles. Therefore, all cores collected in the central part of the system are capped by 8 to 20 cm of light-brown nannofossil ooze corresponding to Holocene hemipelagites (Figure 5).

However, the northern part of the system appears to have a different behavior. Biscara et al., (2011) showed that the Cape Lopez lobe is currently recording both hemipelagic and turbidity current sedimentation despite the present-day high sea-level. This lobe is fed with sediment from the Cape Lopez Canyon, which incises the shelf to the edge of the Mandji Island (Biscara et al., 2013). The deep incision of the continental shelf up to the coast combined with the longshore sediment transport along the Mandji Island and the narrow shelf in this area (4 km wide) favor the capture of sediment by this canyon during time of high sea-level (Reyre, 1984; Biscara et al., 2013). The northern lobe, which is directly connected to the Cape Lopez lobe by Channel A, appears to be also fed by terrigenous sediments during the Holocene. Core KC21, located at the entrance of the northern lobe, is entirely composed of *facies 3*, even for sediments deposited during MIS1 (Figure 5).

In the Ogooue Fan, the shelf width between the littoral area and the canyon heads is the main control factor on the fan activity. During periods of relative low sea-level, the canyons of the central part of the system receive sediment from the river system that extended across the subaerially exposed continental shelf. During periods of relative high sea-level, river sediments are unable to reach the canyon heads south of the Manji Island and accumulate on the continental shelf close to the Ogooue Delta. However, part of these sediments mixed with sediments coming from the south Gabon margin are drift-transported and contribute to supply the Cape Lopez Canyon and consequently the Cape Lopez and Northern Lobe. Due to their specific location and favorable hydrodynamic conditions on the shelf, sedimentation on the Cape Lopez and the Northern lobes is active during relative sea-level highstands, in contrast to the rest of the Ogooue Fan. Examples of this type of supply have already been described along the California margin where the La Jolla canyon is fed by drift-transported sediments during highstand (Covault et al., 2007, 2011) but also on the southeast Australian coast near the Fraser Island (Boyd et al., 2008), which appears very similar to the Mandji Island.

6 Conclusions

This study provides the first data on the morphology of the recent Ogooue Deep-sea fan and interpretations on sedimentary processes occurring in this environment. The Gabonese margin presents a pelagic/hemipelagic background sedimentation overprinted by downslope gravity flows. The fan is made up of various architectural elements and consists of both constructional and erosional sections. The pattern of sedimentation on the margin is controlled by subtle slope gradient changes (< 0.3°). The long-term interaction between gravity flows and the seafloor topography has induced the construction of successive depocenters and sediment bypass areas. The gravity flows have modified the topography according to a theoretical equilibrium profile, eroding the seafloor where slopes are steeper than the theoretical equilibrium profiles and depositing sediments when slopes are gentler than the theoretical equilibrium profile. Three successive main sediment depocenters have been identified along a longitudinal profile. They are associated with three areas of low slope gradient (0.3°-0.2°). The two updip deposition areas – the intermediate depocenter and the upper lobe area – have recorded coarse-grained sedimentation and are connected by a well-developed large mid-system valley measuring 100 km long and located on a steeper slope segment (0.6°). The distalmost depocenter – the lower lobe area - receive only the fine-grained portion of the sediment load that has bypassed the more proximal deposit areas. Sedimentation on this margin is made more complex by the presence of several volcanic islands and seamounts that constrain the gravity flows. The presence on the slope of the Mount Loiret has caused the formation of an isolated system composed of the Cape Lopez Canyon and lobe, which continues downstream by the Northern Lobe area. The Ogooue Fan is currently in a low activity period since the recent Holocene rise of sea-level. Nowadays, the sedimentation is mostly located on the shelf, in the Ogooue Delta and on the upper slope. The fan was more active during the last glacial lowstand. Nonetheless, the northern part of the system appears to have an asynchronous activity with the rest of the fan as this part is fed by the drift-transported sediments during time of relative high sea-level when the activity in the rest of the system is shut-down.

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8 References

Amy, L.A., Kneller, B.C., McCaffrey, W.D.: Facies architecture of the Grès de Peïra Cava, SE France: landward stacking patterns in ponded turbiditic basins. J. Geol. Soc. 164, 143–162. https://doi.org/10.1144/0016-76492005-019, 2007.

Anka, Z., Séranne, M., Lopez, M., Scheck-Wenderoth, M., Savoye, B.: 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 (ZaiAngo project). Tectonophysics 470, 42–56. https://doi.org/10.1016/j.tecto.2008.04.009, 2009.

Babonneau, N., Savoye, B., Cremer, M., Klein, B.: Morphology and architecture of the present canyon and channel system of the Zaire deep-sea fan. Mar. Pet. Geol. 19, 445–467. https://doi.org/10.1016/S0264-8172(02)00009-0, 2002.

Barfod, D.N., Fitton, J.G.: Pleistocene volcanism on São Tomé, Gulf of Guinea, West Africa. Quat. Geochronol. 21, 77–89. https://doi.org/10.1016/j.quageo.2012.11.006, 2014.

Beaubouef, R.T., Friedmann, S.J.: High resolution seismic/sequence stratigraphic framework for the evolution of Pleistocene intra slope basins, western Gulf of Mexico: depositional models and reservoir analogs., in: Deepwater Reservoirs of the World. Presented at the SEPM, 20th Annual Research Conference, pp. 40–60, 2000.

Bertoni, C., Cartwright, J.: 3D seismic analysis of slope-confined canyons from the Plio-Pleistocene of the Ebro Continental Margin (Western Mediterranean). Basin Res. 17, 43–62. https://doi.org/10.1111/j.1365-2117.2005.00254.x, 2005.

Biscara, L., Mulder, T., Hanquiez, V., Marieu, V., Crespin, J.-P., Braccini, E., Garlan, T.: Morphological evolution of Cap Lopez Canyon (Gabon): Illustration of lateral migration processes of a submarine canyon. Mar. Geol. 340, 49–56. https://doi.org/10.1016/j.margeo.2013.04.014, 2013.

Biscara, L., Mulder, T., Martinez, P., Baudin, F., Etcheber, H., Jouanneau, J.-M., Garlan, T.: Transport of terrestrial organic matter in the Ogooué deep sea turbidite system (Gabon). Mar. Pet. Geol. 28, 1061–1072. https://doi.org/10.1016/j.marpetgeo.2010.12.002, 2011.

Bouma, A.H., Coleman, J.M., Stelting, C.E., Kohl, B.: Influence of relative sea level changes on the construction of the Mississippi Fan. Geo-Mar. Lett. 9, 161–170. https://doi.org/10.1007/BF02431043, 1989.

Bouma, A.H., Treadwell, T.K.: Deep-sea dune-like features. Mar. Geol. 19, M53–M59. https://doi.org/10.1016/0025-3227(75)90078-X, 1975.

Bourget, J., Zaragosi, S., Ellouz-Zimmermann, S., Ducassou, E., Prins, M.A., Garlan, T., Lanfumey, V., Schneider, J.-L., Rouillard, P., Giraudeau, J.: Highstand vs. lowstand turbidite system growth in the Makran active margin: Imprints of high-frequency external controls on sediment delivery mechanisms to deep water systems. Mar. Geol. 274, 187–208. https://doi.org/10.1016/j.margeo.2010.04.005, 2010.

Bourget, J., Zaragosi, S., Garlan, T., Gabelotaud, I., Guyomard, P., Dennielou, B., Ellouz-Zimmermann, N., Schneider, J.: Discovery of a giant deep-sea valley in the Indian Ocean, off eastern Africa: The Tanzania channel. Mar. Geol. 255, 179–185. https://doi.org/10.1016/j.margeo.2008.09.002, 2008.

Bourgoin, J., Reyre, D., Magloire, P., Krichewsky, M.: Les canyons sous-marins du cap Lopez (Gabon). Cah Ocean. 6, 372–387, 1963.

Boyd, R., Ruming, K., Goodwin, I., Sandstrom, M., Schröder-Adams, C.: Highstand transport of coastal sand to the deep ocean: A case study from Fraser Island, southeast Australia. Geology 36, 15. https://doi.org/10.1130/G24211A.1, 2008.

Brooks, H.L., Hodgson, D.M., Brunt, R.L., Peakall, J., Poyatos-Moré, M., Flint, S.S.: Disconnected submarine lobes as a record of stepped slope evolution over multiple sea-level cycles. Geosphere 14, 1753–1779. https://doi.org/10.1130/GES01618.1, 2018.

Cameron, N.R., White, K.: Exploration Opportunities in Offshore Deepwater Africa. IBC 'Oil Gas Dev. West Afr. Lond. UK, 1999.

Chen, J.-C., Lo, C.Y., Lee, Y.T., Huang, S.W., Chou, P.C., Yu, H.S., Yang, T.F., Wang, Y.S., Chung, S.H.: Mineralogy and chemistry of cored sediments from active margin off southwestern Taiwan. Geochem. J. 41, 303–321, 2007.

Cita, M.B., Beghi, C., Camerlenghi, A., Kastens, K.A., McCoy, F.W., Nosetto, A., Parisi, E., Scolari, F., Tomadin, L.: Turbidites and megaturbidites from the Herodotus abyssal plain (eastern Mediterranean) unrelated to seismic events. Mar. Geol. 55, 79–101. https://doi.org/10.1016/0025-3227(84)90134-8, 1984.

Clift, P., Gaedicke, C.: Accelerated mass flux to the Arabian Sea during the middle to late Miocene. Geology 30, 207. https://doi.org/10.1130/0091-7613(2002)030<0207:AMFTTA>2.0.CO;2, 2002.

Covault, J.A., Normark, W.R., Romans, B.W., Graham, S.A.: Highstand fans in the California borderland: The overlooked deep-water depositional systems. Geology 35, 783. https://doi.org/10.1130/G23800A.1, 2007

Covault, J.A., Romans, B.W., Fildani, A., McGann, M., Graham, S.A.: Rapid Climatic Signal Propagation from Source to Sink in a Southern California Sediment-Routing System. J. Geol. 118, 247–259. https://doi.org/10.1086/651539, 2010.

Covault, J.A., Romans, B.W., Graham, S.A., Fildani, A., Hilley, G.E.: Terrestrial source to deep-sea sink sediment budgets at high and low sea levels: Insights from tectonically active Southern California. Geology 39, 619–622. https://doi.org/10.1130/G31801.1, 2011.

Damuth, J.: The Amazon-HARP Fan Model: Facies Distributions in Mud-Rich Deep-Sea Fans Based on Systematic Coring of Architectural Elements of Amazon Fan, 1995.

Damuth, J.E.: Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin. Mar. Pet. Geol. 11, 320–346. https://doi.org/10.1016/0264-8172(94)90053-1, 1994.

Damuth, J.E.: Use of high-frequency (3.5–12 kHz) echograms in the study of near-bottom sedimentation processes in the deep-sea: a review. Mar. Geol. 38, 51–75, 1980a.

Damuth, J.E.: Quaternary sedimentation processes in the South China Basin as revealed by echo-character mapping and piston-core studies, in: Hayes, D.E. (Ed.), Geophysical Monograph Series. American Geophysical Union, Washington, D. C., pp. 105–125. https://doi.org/10.1029/GM023p0105, 1980b.

Damuth, J.E.: Echo character of the western equatorial Atlantic floor and its relationship to the dispersal and distribution of terrigenous sediments. Mar. Geol. 18, 17–45. https://doi.org/10.1016/0025-3227(75)90047-X, 1975.

Damuth, J.E., Embley, R.W.: Upslope flow of turbidity currents on the northwest flank of the Ceara Rise: western Equatorial Atlantic*. Sedimentology 26, 825–834. https://doi.org/10.1111/j.1365-3091.1979.tb00975.x, 1979.

Damuth, J.E., Hayes, D.E.: Echo character of the East Brazilian continental margin and its relationship to sedimentary processes. Mar. Geol. 24, 73–95. https://doi.org/10.1016/0025-3227(77)90002-0, 1977.

Demyttenaere, R., Tromp, J.P., Ibrahim, A., Allman-Ward, P.: Brunei Deep Water Exploration: From Sea Floor Images and Shallow Seismic Analogues to Depositional Models in a Slope Turbidite Setting, in: Weimer, P. (Ed.), Deep-Water Reservoirs of the World: 20th Annual. Society of economic palaeontologists and mineralogists, pp. 304–317. https://doi.org/10.5724/gcs.00.20, 2000.

Deptuck, M.E.: Pleistocene Seascape Evolution Above A “Simple” Stepped Slope—Western Niger Delta, in: Prather, B.E., Deptuck, M.E., Mohrig, D., Van Hoorn, B., Wynn, R.B. (Eds.), Application of the Principles of Seismic Geomorphology to Continental-Slope and Base-of-Slope Systems: Case Studies from Seafloor and Near-Seafloor Analogues. SEPM (Society for Sedimentary Geology). https://doi.org/10.2110/pec.12.99, 2012.

Deptuck, M.E., Steffens, G.S., Barton, M., Pirmez, C.: Architecture and evolution of upper fan channel-belts on the Niger Delta slope and in the Arabian Sea. Mar. Pet. Geol. 20, 649–676. https://doi.org/10.1016/j.marpetgeo.2003.01.004, 2003.

Deptuck, M.E., Sylvester, Z., Pirmez, C., O’Byrne, C.: Migration–aggradation history and 3-D seismic geomorphology of submarine channels in the Pleistocene Benin-major Canyon, western Niger Delta slope. Mar. Pet. Geol. 24, 406–433. https://doi.org/10.1016/j.marpetgeo.2007.01.005, 2007.

Déruelle, B., Ngounouno, I., Demaiffe, D.: The ‘Cameroon Hot Line’ (CHL): A unique example of active alkaline intraplate structure in both oceanic and continental lithospheres. Comptes Rendus Geosci. 339, 589–600. https://doi.org/10.1016/j.crte.2007.07.007, 2007.

Dill, R.F., Dietz, R.S., Stewart, H.: deep-sea channels and delta of the Monterey submarine canyon. Geol. Soc. Am. Bull. 65, 191. https://doi.org/10.1130/0016-7606(1954)65[191:DCADOT]2.0.CO;2, 1954.

Droz, L., Marsset, T., Ondras, H., Lopez, M., Savoye, B., Spy-Anderson, F.-L.: Architecture of an active mud-rich turbidite system: The Zaire Fan (Congo–Angola margin southeast Atlantic): Results from ZaAngo 1 and 2 cruises. AAPG Bull. 87, 1145–1168, 2003.

Droz, L., Rigaut, F., Cochonat, P., Tofani, R.: Morphology and recent evolution of the Zaire turbidite system (Gulf of Guinea). Geol. Soc. Am. Bull. 108, 253–269. https://doi.org/10.1130/0016-7606(1996)108<0253:MAREOT>2.3.CO;2, 1996.

Embley, R.W.: New evidence for occurrence of debris flow deposits in the deep sea. Geology 4, 371. https://doi.org/10.1130/0091-7613(1976)4<371:NEFOOD>2.0.CO;2, 1976.

Ferry, J.-N., Mulder, T., Parize, O., Raillard, S.: Concept of equilibrium profile in deep-water turbidite system: effects of local physiographic changes on the nature of sedimentary process and the geometries of deposits. Geol. Soc. Lond. Spec. Publ. 244, 181–193. https://doi.org/10.1144/GSL.SP.2005.244.01.11, 2005.

Field, M.E., Gardner, J.V.: Pliocene-Pleistocene growth of the Rio Ebro margin, northeast Spain: A prograding-slope model. Geol. Soc. Am. Bull. 102, 721–733. https://doi.org/10.1130/0016-7606(1990)102<0721:PPGOTR>2.3.CO;2, 1990.

Fildani, A., Normark, W.R.: Late Quaternary evolution of channel and lobe complexes of Monterey Fan. Mar. Geol. 206, 199–223. https://doi.org/10.1016/j.margeo.2004.03.001, 2004.

Flood, R.D., Piper, D.J.W.: Amazon Fan sedimentation: the relationship to equatorial climate change, continental denudation, and sea-level fluctuations., in: Flood, R.D., Piper, D.J.W., Klaus, A., Peterson, L.C. (Eds.), Proceeding of the Ocean Drilling Program, Scientific Results. pp. 653–675, 1997.

Garcia, M., Parker, G.: Experiments on hydraulic jumps in turbidity currents near a canyon-fan transition. Science 245, 393–396. https://doi.org/10.1126/science.245.4916.393, 1989.

Garlan, T., Biscara, L., Guyomard, P., Le Faou, Y., Gabelotaud, I.: Rapport de la campagne MOCOSED 2010, Modèle de couches sédimentaires du Golfe de Guinée (Rapport de mission). SHOM, 2010.

Gaullier, V., Bellaiche, G.: Near-bottom sedimentation processes revealed by echo-character mapping studies, north-western Mediterranean Basin. AAPG Bull. 82, 1140–1155, 1998.

Gay, A., Lopez, M., Cochonat, P., Sultan, N., Cauquil, E., Brigaud, F.: Sinuous pockmark belt as indicator of a shallow buried turbiditic channel on the lower slope of the Congo basin, West African margin. Geol. Soc. Lond. Spec. Publ. 216, 173–189. https://doi.org/10.1144/GSL.SP.2003.216.01.12, 2003.

Gee, M.J.R., Gawthorpe, R.L.: Submarine channels controlled by salt tectonics: Examples from 3D seismic data offshore Angola. Mar. Pet. Geol. 23, 443–458. https://doi.org/10.1016/j.marpetgeo.2006.01.002, 2006.

Gee, M.J.R., Gawthorpe, R.L., Bakke, K., Friedmann, S.J.: Seismic Geomorphology and Evolution of Submarine Channels from the Angolan Continental Margin. J. Sediment. Res. 77, 433–446. https://doi.org/10.2110/jsr.2007.042, 2007.

Giresse, P.: Carte sédimentologique des fonds sous-marins du delta de l'Ogooué, 1969.

Giresse, P., Odin, G.S.: Nature minéralogique et origine des glauconies du plateau continental du Gabon et du Congo. Sedimentology 20, 457–488, 1973.

Guillou, R.: MOCOSED 2010 cruise, Pourquoi pas ? https://doi.org/10.17600/10030110, 2010.

Hanquiez, V., Mulder, T., Lecroart, P., Gonthier, E., Marchès, E., Voisset, M.: High resolution seafloor images in the Gulf of Cadiz, Iberian margin. Mar. Geol. 246, 42–59. https://doi.org/10.1016/j.margeo.2007.08.002, 2007.

Hay, D.: Stratigraphic evolution of a tortuous corridor from the stepped slope of Angola, in: Prather, B.E., Deptuck, M.E., Mohrig, D., Van Hoorn, B., Wynn, R.B. (Eds.), Application of the Principles of Seismic Geomorphology to Continental-Slope and Base-of-Slope Systems: Case Studies from Seafloor and Near-Seafloor Analogues. SEPM (Society for Sedimentary Geology). https://doi.org/10.2110/pec.12.99, 2012.

Heezen, B.C., Tharp, M., Ewing, M.: The Floors of the Oceans, in: Geological Society of America Special Papers. Geological Society of America, pp. 1–126. https://doi.org/10.1130/SPE65-p1, 1959.

Jacobi, R.D.: Sediment slides on the northwestern continental margin of Africa. Mar. Geol. 22, 157–173. https://doi.org/10.1016/0025-3227(76)90045-1, 1976.

Jansen, J.H.F., Van Weering, T.C.E., Gieles, R., Van Iperen, J.: Middle and late Quaternary oceanography and climatology of the Zaire-Congo fan and the adjacent eastern Angola Basin. Neth. J. Sea Res. 17, 201–249, 1984.

Jegou, I., Savoye, B., Pirmez, C., Droz, L.: Channel-mouth lobe complex of the recent Amazon Fan: The missing piece. Mar. Geol. 252, 62–77. https://doi.org/10.1016/j.margeo.2008.03.004, 2008.

Jobe, Z.R., Lowe, D.R., Uchytil, S.J.: Two fundamentally different types of submarine canyons along the continental margin of Equatorial Guinea. Mar. Pet. Geol. 28, 843–860. https://doi.org/10.1016/j.marpetgeo.2010.07.012, 2011.

Jobe, Z.R., Sylvester, Z., Howes, N., Pirmez, C., Parker, A., Cantelli, A., Smith, R., Wolinsky, M.A., O'Byrne, C., Slowey, N., Prather, B.: High-resolution, millennial-scale patterns of bed compensation on a sand-rich intraslope submarine fan, western Niger Delta slope. Geol. Soc. Am. Bull. 129, 23–37. https://doi.org/10.1130/B31440.1, 2017.

Kane, I.A., Catterall, V., McCaffrey, W.D., Martinsen, O.J.: Submarine channel response to intrabasinal tectonics: The influence of lateral tilt. AAPG Bull. 94, 189–219. https://doi.org/10.1306/08180909059, 2010.

Kane, I.A., Hodgson, D.M.: Sedimentological criteria to differentiate submarine channel levee subenvironments: Exhumed examples from the Rosario Fm. (Upper Cretaceous) of Baja California, Mexico, and the Fort Brown Fm. (Permian), Karoo Basin, S. Africa. Mar. Pet. Geol. 28, 807–823. https://doi.org/10.1016/j.marpetgeo.2010.05.009, 2011.

Kenyon, N.H., Millington, J., Droz, L., Ivanov, M.K.: Scour holes in a channel-lobe transition zone on the Rhône Cone, in: Atlas of Deep Water Environments. Springer, Dordrecht, pp. 212–215. https://doi.org/10.1007/978-94-011-1234-5_31, 1995.

Kneller, B.: Beyond the turbidite paradigm: physical models for deposition of turbidites and their implications for reservoir prediction. Geol. Soc. Lond. Spec. Publ. 94, 31–49. https://doi.org/10.1144/GSL.SP.1995.094.01.04, 1995.

Kolla, V.: A review of sinuous channel avulsion patterns in some major deep-sea fans and factors controlling them. Mar. Pet. Geol. 24, 450–469. https://doi.org/10.1016/j.marpetgeo.2007.01.004, 2007.

Kolla, V., Coumes, F.: Morphology, Internal Structure, Seismic Stratigraphy, and Sedimentation of Indus Fan. AAPG Bull. 71, 650–677, 1987.

Komar, P.D.: Hydraulic jumps in turbidity currents. Bull. Geol. Soc. Am. 82, 1477–1488. https://doi.org/10.1130/0016-7606(1971)82[1477:HJITC]2.0.CO;2, 1971.

Lebigre, J.M.: Les mangroves des rias du littoral gabonais, essai de cartographie typologique. Rev. Bois For. Trop., 1983.

Lee, D.-C., Halliday, A.N., Fitton, J.G., Poli, G.: Isotopic variations with distance and time in the volcanic islands of the Cameroon line: evidence for a mantle plume origin. Earth Planet. Sci. Lett. 123, 119–138. https://doi.org/10.1016/0012-821X(94)90262-3, 1994.

Lerique, J., Barret, J., Walter, R.: Hydrographie, hydrologie, in: Géographie et cartographie du Gabon : atlas illustré. EDICEF, Paris, pp. 14–17, 1983.

Lombo Tombo, S., Dennielou, B., Berné, S., Bassetti, M.-A., Toucanne, S., Jorry, S.J., Jouet, G., Fontanier, C.: Sea-level control on turbidite activity in the Rhone canyon and the upper fan during the Last Glacial Maximum and Early deglacial. Sediment. Geol. 323, 148–166. https://doi.org/10.1016/j.sedgeo.2015.04.009, 2015.

Loncke, L., Droz, L., Gaullier, V., Basile, C., Patriat, M., Roest, W.: Slope instabilities from echo-character mapping along the French Guiana transform margin and Demerara abyssal plain. Mar. Pet. Geol. 26, 711–723. https://doi.org/10.1016/j.marpetgeo.2008.02.010, 2009.

Lonergan, L., Jamin, N.H., Jackson, C.A.-L., Johnson, H.D.: U-shaped slope gully systems and sediment waves on the passive margin of Gabon (West Africa). Mar. Geol. 337, 80–97. https://doi.org/10.1016/j.margeo.2013.02.001, 2013.

Mahé, G., Lerique, J., Olivry, J.-C.: Le fleuve Ogooué au Gabon : reconstitution des débits manquants et mise en évidence de variations climatiques à l'équateur. Hydrol Cont. 5, 105–124, 1990.

Masson, D.G.: Late Quaternary turbidity current pathways to the Madeira Abyssal Plain and some constraints on turbidity current mechanisms. Basin Res. 6, 17–33. https://doi.org/10.1111/j.1365-2117.1994.tb00072.x, 1994.

Masson, D.G., Kenyon, N.H., Gardner, J.V., Field, M.E.: Monterey Fan: channel and overbank morphology, in: Pickering, K.T., Hiscott, R.N., Kenyon, N.H., Ricci Lucchi, F., Smith, R.D.A. (Eds.), Atlas of Deep Water Environments. Springer Netherlands, Dordrecht, pp. 74–79. https://doi.org/10.1007/978-94-011-1234-5_13, 1995.

McGilvery, T.A., Cook, D.L.: The Influence of Local Gradients on Accommodation Space and Linked Depositional Elements Across a Stepped Slope Profile, Offshore Brunei, in: Roberts, H.R., Rosen, N.C., Fillon, R.F., Anderson, J.B. (Eds.), Shelf Margin Deltas and Linked Down Slope Petroleum Systems: 23rd Annual. SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS. https://doi.org/10.5724/gcs.03.23, 2003.

Menard, H.W.: Deep-Sea Channels, Topography, and Sedimentation. AAPG Bull. 39, 255, 1955.

Migeon, S., Weber, O., Faugeres, J.-C., Saint-Paul, J.: SCOPIX: A new X-ray imaging system for core analysis. Geo-Mar. Lett. 18, 251–255. https://doi.org/10.1007/s003670050076, 1998.

Mignard, S.L.-A., Mulder, T., Martinez, P., Charlier, K., Rossignol, L., Garlan, T.: Deep-sea terrigenous organic carbon transfer and accumulation: Impact of sea-level variations and sedimentation processes off the Ogooue River (Gabon). Mar. Pet. Geol. 85, 35–53. https://doi.org/10.1016/j.marpetgeo.2017.04.009, 2017.

Mougamba, R.: Chronologie et architechture des systems turbiditiquess Cénozoïques du Prisme sédimentaire de l'Ogooué (Marge Nord-Gabon). Université de Lille, Lille, 1999.

Mouscardes, P.: OPTIC CONGO 2 cruise, RV Beautemps-Beaupré [www Document]. URL http://campagnes.flotteoceanographique.fr/campagnes/5090050/fr/ (accessed 7.5.18), 2005.

Mulder, T., Alexander, J.: Abrupt change in slope causes variation in the deposit thickness of concentrated particle-driven density currents. Mar. Geol. 175, 221–235. https://doi.org/10.1016/S0025-3227(01)00114-1, 2001.

Mulder, T., Etienne, S.: Lobes in deep-sea turbidite systems: State of the art. Sediment. Geol. 229, 75–80. https://doi.org/10.1016/j.sedgeo.2010.06.011, 2010.

Normark, W.R., Barnes, N.E., Coumes, F.: Rhone Deep-Sea Fan: A review. Geo-Mar. Lett. 3, 155–160. https://doi.org/10.1007/BF02462461, 1983.

Normark, W.R., Damuth, J.E.: Sedimentary facies and associated depositional elements of the Amazon Fan, Proceedings of the Ocean Drilling Program. Ocean Drilling Program. https://doi.org/10.2973/odp.proc.sr.155.1997, 1997.

Normark, W.R., Piper, D.J.W.: Initiation processes and flow evolution of turbidity currents: implications for the depositional record, in: From Shoreline to Abyss, SEPM Special Publication. pp. 207–230, 1991.
Normark, W.R., Posamentier, H., Mutti, E.: Turbidite systems: State of the art and future directions. Rev. Geophys. 31, 91–116. https://doi.org/10.1029/93RG02832, 1993.
O'Byrne, C., Prather, B., Pirmez, C., Steffens, G.S.: Reservoir architectural styles across stepped slope profiles: Implications for exploration, appraisal and development. Presented at the AAPG International conference, 2004.
Olausson, E.: Oxygen and carbon isotope analyses of a late quaternary core in the Zaire (Congo) fan. Neth. J. Sea Res. 17, 276–279. https://doi.org/10.1016/0077-7579(84)90050-4, 1984.
Peakall, J., McCaffrey, B., Kneller, B.: A Process Model for the Evolution, Morphology, and Architecture of Sinuous Submarine Channels. J. Sediment. Res. 70, 434–448. https://doi.org/10.1306/2DC4091C-0E47-11D7-8643000102C1865D, 2000.
Pettingill, H.S., Weimer, P.: Worlwide deepwater exploration and production: Past, present, and future. Lead. Edge 21, 371–376. https://doi.org/10.1190/1.1471600, 2002.
Pickering, K., Stow, D., Watson, M., Hiscott, R.: Deep-water facies, processes and models: a review and classification scheme for modern and ancient sediments. Earth Sci. Rev. 23, 75–174. https://doi.org/10.1016/0012-8252(86)90001-2, 1986.
Pilcher, R., Argent, J.: Mega-pockmarks and linear pockmark trains on the West African continental margin. Mar. Geol. 244, 15–32. https://doi.org/10.1016/j.margeo.2007.05.002, 2007.
Piper, D.J.W., Normark, W.R.: Processes That Initiate Turbidity Currents and Their Influence on Turbidites: A Marine Geology Perspective. J. Sediment. Res. 79, 347–362. https://doi.org/10.2110/jsr.2009.046, 2009.
Piper, D.J.W., Normark, W.R.: Sandy fans--from Amazon to Hueneme and beyond. AAPG Bull. 85, 1407–1438, 2001.
Pirmez, C., Beaubouef, R.T., Friedmann, S.J., Mohrig, D.C.: Equilibrium Profile and Baselevel in Submarine Channels: Examples from Late Pleistocene Systems and Implications for the Architecture of Deepwater Reservoirs, in: Weimer, P. (Ed.), Deep-Water Reservoirs of the World. https://doi.org/10.5724/gcs.00.20, 2000.
Prather, B.E.: Controls on reservoir distribution, architecture and stratigraphic trapping in slope settings. Mar. Pet. Geol. 20, 529–545. https://doi.org/10.1016/j.marpetgeo.2003.03.009, 2003.
Prather, B.E., Booth, J.R., Steffens, G.S., Craig, P.A.: Classification, Lithologic Calibration, and Stratigraphic Succession of Seismic Facies of Intraslope Basins, Deep-Water Gulf of Mexico. AAPG Bull. 82, 701–728, 1998.
Prather, B.E., O'Byrne, C., Pirmez, C., Sylvester, Z.: Sediment partitioning, continental slopes and base-of-slope systems. Basin Res. 29, 394–416. https://doi.org/10.1111/bre.12190, 2017.

Pratson, L.F., Coakley, B.J.: A model for the headward erosion of submarine canyons induced by downslope-eroding sediment flows. Geol. Soc. Am. Bull. 108, 225–234. https://doi.org/10.1130/0016-7606(1996)108<0225:AMFTHE>2.3.CO;2, 1996.

Pratson, L.F., Laine, E.P.: The relative importance of gravity-induced versus current-controlled sedimentation during the Quaternary along the Mideast U.S. outer continental margin revealed by 3.5 kHz echo character. Mar. Geol. 89, 87–126. https://doi.org/10.1016/0025-3227(89)90029-7, 1989.

Pratson, L.F., Ryan, W.B.F., Mountain, G.S., Twichell, D.C.: Submarine canyon initiation by downslope-eroding sediment flows: Evidence in late Cenozoic strata on the New Jersey continental slope. Geol. Soc. Am. Bull. 106, 395–412. https://doi.org/10.1130/0016-7606(1994)106<0395:SCIBDE>2.3.CO;2, 1994.

Prélat, A., Hodgson, D.M.: The full range of turbidite bed thickness patterns in submarine lobes: controls and implications. J. Geol. Soc. 170, 209–214. https://doi.org/10.1144/jgs2012-056, 2013.

Rasmussen, E.S.: Structural evolution and sequence formation offshore South Gabon during the Tertiary. Tectonophysics, Dynamics of Extensional Basins and Inversion Tectonics 266, 509–523. https://doi.org/10.1016/S0040-1951(96)00236-3, 1996.

Reading, H.G., Richards, M.: Turbidite systems in deep-water basin margins classified by grain size and feeder system. AAPG Bull. 78, 792–822, 1994.

Reimer, P.: IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55, 1869–1887. https://doi.org/10.2458/azu_js_rc.55.16947, 2013.

Reyre, D.: Evolution géologique et caractères pétroliers d'une marge passive: cas du bassin du Bas Congo–Gabon. Bull. Cent. Rech. Explor. Prod. Elf Aquitaine 8, 303–332, 1984.

Salles, L., Ford, M., Joseph, P.: Characteristics of axially-sourced turbidite sedimentation on an active wedge-top basin (Annot Sandstone, SE France). Mar. Pet. Geol. 56, 305–323. https://doi.org/10.1016/j.marpetgeo.2014.01.020, 2014.

Séranne, M., Anka, Z.: South Atlantic continental margins of Africa: A comparison of the tectonic vs climate interplay on the evolution of equatorial West Africa and SW Africa margins. J. Afr. Earth Sci. 43, 283–300. https://doi.org/10.1016/j.jafrearsci.2005.07.010, 2005.

Séranne, M., Bruguier, O., Moussavou, M.: U-Pb single zircon grain dating of Present fluvial and Cenozoic aeolian sediments from Gabon: consequences on sediment provenance, reworking, and erosion processes on the equatorial West African margin. Bull. Société Géologique Fr. 179, 29–40, 2008.

Séranne, M., Nzé Abeigne, C.-R.: Oligocene to Holocene sediment drifts and bottom currents on the slope of Gabon continental margin (West Africa). Sediment. Geol. 128, 179–199. https://doi.org/10.1016/S0037-0738(99)00069-X, 1999.

Shepard, F.P.: Submarine Canyons: Multiple Causes and Long-Time Persistence. AAPG Bull. 65. https://doi.org/10.1306/03B59459-16D1-11D7-8645000102C1865D, 1981.
Shepard, F.P.: submarine erosion, a discussion of recent papers. Geol. Soc. Am. Bull. 62, 1413. https://doi.org/10.1130/0016-7606(1951)62[1413:SEADOR]2.0.CO;2, 1951.
Shepard, F.P., Emery, K.O.: Submarine Topography off the California Coast: Canyons and Tectonic Interpretation, Geological Society of America Special Papers. Geological Society of America. https://doi.org/10.1130/SPE31, 1941.
Smith, R.: Silled sub-basins to connected tortuous corridors: sediment distribution systems on topographically complex sub-aqueous slopes. Geol. Soc. Lond. Spec. Publ. 222, 23–43. https://doi.org/10.1144/GSL.SP.2004.222.01.03, 2004.
Spychala, Y.T., Hodgson, D.M., Flint, S.S., Mountney, N.P.: Constraining the sedimentology and stratigraphy of submarine intraslope lobe deposits using exhumed examples from the Karoo Basin, South Africa. Sediment. Geol. 322, 67–81. https://doi.org/10.1016/j.sedgeo.2015.03.013, 2015.
Stanley, D.J., Moore, G.T.: The Shelfbreak: Critical Interface on Continental Margins. SEPM (Society for Sedimentary Geology). https://doi.org/10.2110/pec.83.33, 1983.
Stevenson, C.J., Jackson, C.A.-L., Hodgson, D.M., Hubbard, S.M., Eggenhuisen, J.T.: Deep-Water Sediment Bypass. J. Sediment. Res. 85, 1058–1081. https://doi.org/10.2110/jsr.2015.63, 2015.
Stevenson, C.J., Talling, P.J., Wynn, R.B., Masson, D.G., Hunt, J.E., Frenz, M., Akhmetzhanhov, A., Cronin, B.T.: The flows that left no trace: Very large-volume turbidity currents that bypassed sediment through submarine channels without eroding the sea floor. Mar. Pet. Geol. 41, 186–205. https://doi.org/10.1016/j.marpetgeo.2012.02.008, 2013.
Stow, D.A.V., Piper, D.J.W.: Deep-water fine-grained sediments: facies models. Geol. Soc. Lond. Spec. Publ. 15, 611–646. https://doi.org/10.1144/GSL.SP.1984.015.01.38, 1984.
Sylvester, Z., Cantelli, A., Pirmez, C.: Stratigraphic evolution of intraslope minibasins: Insights from surface-based model. AAPG Bull. 99, 1099–1129. https://doi.org/10.1306/01081514082, 2015.
Syvitski, J.P.M., Vörösmarty, C.J., Kettner, A.J., Green, P.: Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean. Science 308, 376–380. https://doi.org/10.1126/science.1109454, 2005.
Thornton, S.E.: Hemipelagites and Associated Facies of Slopes and Slope Basins. Geol. Soc. Lond. Spec. Publ. 15, 377–394, 1984.
Tripsanas, E.K., Phaneuf, B.A., Bryant, W.R.: Slope Instability Processes in a Complex Deepwater Environment, Bryant Canyon Area, Northwest Gulf of Mexico, in: Offshore Technology Conference. Presented at the Offshore Technology Conference, Offshore Technology Conference, Houston, Texas. https://doi.org/10.4043/14273-MS, 2002.

Twichell, D.C., Roberts, D.G.: Morphology, distribution, and development of submarine canyons on the United States Atlantic continental slope between Hudson arid Baltimore Canyons. Geology 10, 408. https://doi.org/10.1130/0091-7613(1982)10<408:MDADOS>2.0.CO;2, 1982.

Unterseh, S.: Cartographie et caractérisation du fond marin par sondeur multifaisceaux. Vandoeuvre-les-Nancy, INPL, 1999.

Van der Merwe, W.C., Hodgson, D.M., Brunt, R.L., Flint, S.S.: Depositional architecture of sand-attached and sand-detached channel-lobe transition zones on an exhumed stepped slope mapped over a 2500 km2 area. Geosphere 10, 1076–1093. https://doi.org/10.1130/GES01035.1, 2014.

Viana, A.R., Faugères, J.-C.: Upper slope sand deposits: the example of Campos Basin, a latest Pleistocene-Holocene record of the interaction between alongslope and downslope currents. Geol. Soc. Spec. Publ. 129, 287–316. https://doi.org/10.1144/GSL.SP.1998.129.01.18, 1998.

Volat, J.-L., Pastouret, L., Vergnaud-Grazzini, C.: Dissolution and carbonate fluctuations in Pleistocene deep-sea cores: A review. Mar. Geol. 34, 1–28. https://doi.org/10.1016/0025-3227(80)90138-3, 1980.

Weaver, P.P.E., Wynn, R.B., Kenyon, N.H., Evans, J.: Continental margin sedimentation, with special reference to the north-east Atlantic margin: Continental slope sedimentation. Sedimentology 47, 239–256. https://doi.org/10.1046/j.1365-3091.2000.0470s1239.x, 2000.

Wonham, J., Jayr, S., Mougamba, R., Chuilon, P.: 3D sedimentary evolution of a canyon fill (Lower Miocene-age) from the Mandorove Formation, offshore Gabon. Mar. Pet. Geol. 17, 175–197. https://doi.org/10.1016/S0264-8172(99)00033-1, 2000.

Wynn, R. B., Talling, P.J., Masson, D.G., Le Bas, T.P., Cronin, B.T., Stevenson, C.J.: The Influence of Subtle Gradient Changes on Deep-Water Gravity Flows: A Case Study From the Moroccan Turbidite System, in: Prather, B.E., Deptuck, M.E., Mohrig, D., Van Hoorn, B., Wynn, Russell B. (Eds.), Application of the Principles of Seismic Geomorphology to Continental-Slope and Base-of-Slope Systems: Case Studies from Seafloor and Near-Seafloor Analogues. SEPM (Society for Sedimentary Geology). https://doi.org/10.2110/pec.12.99, 2012.

Wynn, R.B., Cronin, B.T., Peakall, J.: Sinuous deep-water channels: Genesis, geometry and architecture. Mar. Pet. Geol. 24, 341–387. https://doi.org/10.1016/j.marpetgeo.2007.06.001, 2007.

Wynn, R.B., Masson, D.G., Stow, D.A., Weaver, P.P.: Turbidity current sediment waves on the submarine slopes of the western Canary Islands. Mar. Geol. 163, 185–198, 2000.

Wynn, R.B., Weaver, P.P.E., Masson, D.G., Stow, D.A.V.: Turbidite depositional architecture across three interconnected deep-water basins on the north-west African margin. Sedimentology 49, 669–695. https://doi.org/10.1046/j.1365-3091.2002.00471.x, 2002.

Zachariasse, W.J., Schmidt, R.R., Van Leeuwen, R.J.W.: Distribution of foraminifera and calcareaous nannoplankton in quaternary sediments of the eastern Angola basin in response to climatic and oceanic fluctuations. Neth. J. Sea Res. 17, 250–275, 1984.