Seismic stratigraphy of Cretaceous eastern Central Atlantic Ocean: Basin evolution and palaeoceanographic implications

Yannick Murlot, Grme Calvs, Peter D. Clift, Guillaume Baby,
Anne-Claire Chaboureaux, Franois Raison

► To cite this version:

Yannick Murlot, Grme Calvs, Peter D. Clift, Guillaume Baby, Anne-Claire Chaboureaux, et al.. Seismic stratigraphy of Cretaceous eastern Central Atlantic Ocean: Basin evolution and palaeoceanographic implications. Earth and Planetary Science Letters, 2018, 499, pp.107-121. 10.1016/j.epsl.2018.07.023 . insu-01857493

HAL Id: insu-01857493

<https://hal-insu.archives-ouvertes.fr/insu-01857493>

Submitted on 16 Aug 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destine au dpt et la diffusion de documents scientifiques de niveau recherche, publis ou non, manant des tablissements d'enseignement et de recherche franais ou trangers, des laboratoires publics ou privs.

Manuscript Number: EPSL-D-18-00035R1

Title: SEISMIC STRATIGRAPHY OF CRETACEOUS EASTERN CENTRAL ATLANTIC OCEAN:
BASIN EVOLUTION AND PALAEOCEANOGRAPHIC IMPLICATIONS

Article Type: Letters

Keywords: Seismic reflection, contourite, palaeobathymetry,
palaeoceanography, Cretaceous, Central Atlantic Ocean.

Corresponding Author: Dr. GEROME CALVES, Ph.D.

Corresponding Author's Institution: UNIVERSITE TOULOUSE 3

First Author: Yannick Murlot, Ph.D.

Order of Authors: Yannick Murlot, Ph.D.; GEROME CALVES, Ph.D.; Peter D
Clift, Ph.D.; Guillaume Baby, Ph.D.; Anne-Claire Chaboureaud, Ph.D.;
François Raison, MSc

Abstract: The evolution and resulting morphology of a Cretaceous
contourite drift in the eastern Central Atlantic oceanic basin is
investigated in unprecedented detail using seismic imaging and age-
calibrated cross-margin sections. The margin, from the shelf, slope to
deep-water and abyssal plain is constructed by a succession of erosive
and depositional mounded structures that relate to bottom-water currents
and sediment winnowing. The regional mapping of these drifts, sediment
waves and gravitational sedimentary systems allows us to test the Upper
Cretaceous paleocirculation model. Combined with flexural backstripping
of the regional cross section, it reveals the water-depth range at which
the observed sedimentary features occur. A possible late Albian to
Turonian contourite drift system is observed from Guinea to Mauritania.
The development of a shallow to deep oceanic circulation system is a key
element in the rock record, with implications for the palaeoceanography
and layering of the Cretaceous ocean. The Cretaceous geological interval
and oceanic model mirrors the stratification of the modern ocean and the
morphology of its seafloor from offshore Morocco to Guinea.

Highlights :

- Morphology and evolution of a Cretaceous contourite drift in the eastern Central Atlantic oceanic basin
- Backstripping of the regional cross section reveals the water-depth range at which the observed sedimentary features occur
- Cretaceous geological interval and oceanic model mirrors the stratification of the Modern Ocean and the morphology of its seafloor

1 SEISMIC STRATIGRAPHY OF CRETACEOUS EASTERN CENTRAL ATLANTIC

2 OCEAN: BASIN EVOLUTION AND PALAEOCEANOGRAPHIC IMPLICATIONS

3 Yannick Murlot¹, Jérôme Calvès^{1,*}, Peter D. Clift², Guillaume Baby¹, Anne-Claire

4 Chaboureaux³, François Raison⁴

5 ¹ Université Toulouse 3, GET-OMP, 14 Avenue Edouard Belin, 31400, Toulouse, France (*corresponding
6 author: gerome.calves@get.omp.eu)

7 ² Department of Geology and Geophysics and Coastal Studies Institute, E235 Howe-Russell, Louisiana State
8 University, Baton Rouge, Louisiana 70803, USA

9 ³ CVA, 7 chemin de la Marouette, 64100 Bayonne, France

10 ⁴ Total E&P, CSTJF, Avenue Larribau, F-64018, Pau Cedex, France

11 Keywords: Seismic reflection, contourite, palaeobathymetry, palaeoceanography, Cretaceous,
12 Central Atlantic Ocean.

13 ABSTRACT

14 The evolution and resulting morphology of a Cretaceous contourite drift in the eastern Central
15 Atlantic oceanic basin is investigated in unprecedented detail using seismic imaging and age-
16 calibrated cross-margin sections. The margin, from the shelf, slope to deep-water and abyssal
17 plain is constructed by a succession of erosive and depositional mounded structures that relate
18 to bottom-water currents and sediment winnowing. The regional mapping of these drifts,
19 sediment waves and gravitational sedimentary systems allows us to test the Upper Cretaceous
20 paleocirculation model. Combined with flexural backstripping of the regional cross section, it
21 reveals the water-depth range at which the observed sedimentary features occur. A possible
22 late Albian to Turonian contourite drift system is observed from Guinea to Mauritania. The
23 development of a shallow to deep oceanic circulation system is a key element in the rock
24 record, with implications for the palaeoceanography and layering of the Cretaceous ocean.
25 The Cretaceous geological interval and oceanic model mirrors the stratification of the modern
26 ocean and the morphology of its seafloor from offshore Morocco to Guinea.

1. Introduction

The sedimentary architecture of passive margins is generally shaped by both gravitational processes (*e.g.* turbidites, debris flows) and along-slope oceanic bottom currents (contourite drifts) (*e.g.* Rebesco et al., 2017). The modern ocean seafloor records the interaction between surface and deep bottom-water currents through their expression in the erosion and deposition of sediments (Heezen and Hollister, 1964). Features such as mounded contourite drifts mark some of the most extensive expression of interactions between sediment and water masses across the seafloor of modern oceanic sedimentary basins (Faugères et al., 1999; Stow et al., 2002; Mosher et al., 2017). The acquisition of seafloor photography, subsurface seismic reflection profiles and the sampling of marine sediments has allowed the identification of sediment transport by bottom-water currents in various bathymetric domains (*e.g.* abyssal plain and shelf). This is particularly well known in the Atlantic, Pacific and Indian Oceans (Faugères et al., 1999; Hernández–Molina et al., 2008a and b; Rebesco et al., 2014).

During the Cretaceous, palaeoceanographic circulation patterns in the Tethys, Atlantic, Indian and Pacific Oceans have been inferred from the tracking of oceanic water masses using the neodymium (Nd) isotope character of fish teeth. In addition, global and regional modeling combining atmospheric and oceanic circulation has been performed to illustrate possible ocean circulation patterns and specify water mass exchanges between the different oceans (Poulsen et al., 2001; Donnadieu et al., 2016; Uenzelmann–Neben et al., 2016). However, these simulations could not resolve the full water column stratification because they investigated the surface and intermediate oceanic currents without any constraints on the paleo-seafloor and its interaction with deep bottom-water currents.

Studies based on Nd isotope character of Upper Cretaceous fish teeth sampled in the Equatorial Atlantic domain (MacLeod et al., 2008; Martin et al., 2012) propose two intermediate oceanic currents: a first one originating in the Demerara Rise region (Demerara

Bottom Water: DBW, Figure 1) and a second initiating from the South Atlantic Ocean and circulating toward the Central Atlantic Ocean through the Equatorial Gateway (Southern Component Waters: SCW, Figure 1) (Robinson and Vance, 2012). Other studies, also based on Nd isotopes, assume that in the northern Central Atlantic Ocean, a surface current originating in the Tethys Ocean would have run through the Central Atlantic to the lowest latitudes (Northern Component Waters: NCW, Figure 1) (Pucat et al., 2005; MacLeod et al., 2008). However, these Upper Cretaceous large-scale ocean circulation patterns remain debated because recent studies have emphasized the importance of paleobathymetric obstacles. Indeed, critical topographic barriers could have limited connections between the ocean basins, forcing water masses to evolve in more restricted areas (Voigt et al., 2013; Uenzelmann-Neben et al., 2016).

The present day water column in the eastern Central Atlantic Ocean is stratified into the following layers: shallow (0–500 m depth, *e.g.* South Atlantic Central Water – SACW), intermediate (500–1500 m depth, *e.g.* Antarctic Intermediate Water – AIW) and deep (1500 m–seafloor, *e.g.* Antarctic Bottom Water – ABW) water masses (Emery and Meincke, 1986). The present day shallow subsurface oceanic layers have been also well studied by the oceanographic and marine geology communities. Many sedimentary structures related to bottom-water currents and gravity-driven processes have been identified on the modern seafloor along the Northwest African Margin between Morocco and Mauritania (*e.g.* Wynn et al., 2000; Schwab et al., 2007). In contrast to these well documented features related to modern bottom-water currents, only a few examples of Cretaceous sedimentation related to bottom current processes are found. These studies are restricted to the northern Central Atlantic Ocean (Morocco: Dunlap et al., 2013; Northwest Iberia: Soares et al., 2014). Between 24° and 8° N from the Western Sahara to Guinea (Figure 1) the authors found no

studies that document Cretaceous sedimentation in relation to processes that involve interaction between the seafloor and deep bottom currents.

This study aims at understanding the occurrence of specific sedimentary features present in the deep-sea Cretaceous Ocean record and their implication for the oceanic circulation. This paper uses 2D seismic reflection profiles, borehole data from Deep Sea Drilling Project (DSDP) Sites 367 and 368 located along the Northwest African margin.

We document a variety of sedimentary features observed over a range of palaeobathymetry from the continental shelf, the slope to the deep abyssal plain during the Cretaceous. We also quantify paleobathymetric domains both in the shelf and the deep basin using flexural decompaction of regional geological sections where we have observed bottom-water current-related sedimentary features. These new results allow to understand deep-water oceanic circulation in the eastern Central Atlantic Ocean during the Cretaceous.

2. Data and Methods

2.1. Seismic stratigraphy

In this study, we use a combination of both 2D seismic sections and drilling data from the shallow to deep-water Central Atlantic margin (30°–10° N; Figure 1; Figure S1, Shipboard Scientific Party, 1978) to reconstruct the sedimentary architecture of this margin with the objective of better understanding the Upper Cretaceous palaeoceanography. The average spacing between lines is ~10 km with exception in the distal offshore domain where only regional lines exist. The margin is described with standard seismic stratigraphic techniques based on reflection terminations and seismic reflection facies, as well as the relationship to the geometry of individual seismic reflections (terminations). This approach allows the seismic profile to be divided into chronostratigraphic packages. Thus, eight seismic surfaces were used to define seven seismic units in the studied interval. An age calibration was obtained

using well data (*e.g.* Hardenbol et al., 1981; Davison, 2005; see Table 1; Figures 1 and 2). These data provide important evidence for the timing of formation and the distribution of several sedimentary features related to channel-levees, deep-sea fans and mass transport complexes (Posamentier and Kolla, 2003). The data are also used to understand sediment remobilization by bottom ocean currents (*e.g.*, contourite drift) in both the basin and the slope (Faugères et al., 1999; Stow et al., 2002). Seismic reflection horizons, interpreted in the travel-time domain, to provide a seismic stratigraphic framework were depth-converted using a combination of velocities based on geophysical methods (sonobuoy records, check-shot) and regional isopach maps or depth cross-section from long–offset seismic records. Time–depth data and the depth conversion equation can be found in the supplementary files (Figure S2).

2.2. Mesozoic stratigraphy of the eastern Central Atlantic Ocean

In the Senegal and Mauritania basins, DSDP Sites 367 and 368 sampled the post–rift Mesozoic stratigraphic sequences of the deep ocean basin (Figures 1 and 2). DSDP Site 367 shows that the basalts of the oceanic crust are overlain by a Jurassic to Lower Cretaceous sedimentary unit consisting of interbedded limestone with marl and cherts (Figure 2, Lancelot et al., 1978a). These lithological units were deposited in a bathyal pelagic environment with the presence of clastic deposits input by turbidity currents during the Lower Cretaceous (Jansa et al., 1978). The Barremian to Aptian sequence comprises alternating limestone with marl and thin black shale. This shalier unit progressively grades into thick black shale deposits from the transition between the Barremian and the Aptian, as observed at DSDP Sites 367 and 368. These black shales are platform material remobilized by turbidity currents and deposited in the abyssal plain (Lancelot et al., 1978a; Jansa et al., 1978). The increase in proportion of shale during the Lower Cretaceous is also evidenced by drilling results at DSDP Site 398 in the northern Central Atlantic Ocean (Northwest Iberia). Soares et al. (2014) observed

contourite drifts and sediment waves on seismic reflection profiles at this location (Figure 2). The Albian to Upper Cretaceous sequence, deposited in a similar environment as during the Aptian, is composed of dominant black shale facies interbedded with more silty, less shaly layers, as illustrated in DSDP Sites 367 and 368 (Figure 2). This lithology is different from that found at DSDP Site 398 where Upper Cretaceous formations correspond to limestone interbedded with claystone and marl units (Figure 2, Ryan et al., 1979). Cenozoic diabase sills intruded the Albian to Turonian black shales at DSDP Site 368. In the area of DSDP Sites 367 and 368, the Cretaceous sequence is of particular interest because it comprises turbidites deposited as a result of remobilization (Jansa et al. 1978).

2.3. Backstripping and paleobathymetric estimates

The aim of our backstripping study is to give constraints on the paleobathymetric range of deposition of contourite drift deposits that are observed in the deeper and distal parts of the margins. In these locations, there are limited or no core samples that allow calibration of absolute value of bathymetry. For this analysis, we use a flexural backstripping approach that has been used in various geological settings to infer paleodepth down to basement in sedimentary basins and to reconstruct vertical movements (*e.g.* Clift et al., 1995; Calvès et al., 2008). Subsidence of the study area has been investigated in two sedimentary basins: (1) to the north of the margin in the Aaiun Basin (Morocco) linked to DSDP Site 397 (von Rad and Einsele, 1980), and, (2) to the south in the Senegal Basin (Latil–Brun and Lucazeau, 1988). The studied stratigraphic interval is characterized by normal post-rift thermal subsidence (von Rad and Einsele, 1980; Latil–Brun and Lucazeau, 1988). The investigated period and study area has been calibrated with a thermal subsidence corresponding to a coefficient of extension of 1.2 (Latil–Brun and Lucazeau, 1988). This factor has been set as an input in the backstripping computation. The 2D backstripping method is a standard basin analysis

approach, with numerous published results attesting that this particular method is robust within the limits of the approach (*e.g.* Kusznir et al., 1995; Roberts et al., 1998).

In detail, the first step is the removal of the present-day water column covering the whole section leading to the computation of the flexural isostatic response specific to this removal. Then, the uppermost sedimentary layer (initially overlain by the water column) is also removed from the section. This involves the decompaction of underlying sediments in response to this removal and unloading, which is computed by the software from the physical parameters of the remaining sedimentary units (*i.e.* lithology, density and porosity, Table 1). The 2D backstripping method provides several restored 2D-sections, which can be also corrected by the flexural strength of the lithosphere commonly expressed by the effective elastic thickness (T_e , in km). This parameter expresses the thickness of a perfectly elastic layer with similar flexural properties to the lithosphere (*e.g.* Watts, 1978). Low values of effective elastic thickness (<5 km) illustrate a weak lithosphere which suffers from deformation because of the flexural isostatic response of the sedimentary load variation. In contrast, a high value of T_e (> 15 km) represents a strong lithosphere which is affected by moderate or low deformation during the flexural isostatic response of the sedimentary load (*e.g.* Roberts et al., 2009). The elastic thickness in the studied area has been estimated with the global T_e grid map (*e.g.* Watts, 2015; Global T_e grid: ftp://ftp.earth.ox.ac.uk/pub/tony/TOG/global_te.grd). The continental and oceanic T_e values from the study area are compiled in the supplementary data. The median T_e value for the oceanic domain is 26.6 km (s.d.: 6.6) and for the continental areas 17.5 km (s.d.: 8.7) (see supplementary files: Figure S2). We used different values of T_e (0, 10, 20 and 30 km) to compute paleobathymetric ranges depending on the flexural rigidity of the plate.

3. Results

3.1. Margin geometry

The present-day structure of the Northwest African margin is well documented (*e.g.* Emery and Uchupi, 1984). It is composed of four sedimentary basins between Morocco and Sierra Leone (Figure 1) which are dominated by a large and flat continental shelf (>100 km) with a maximum water depth of 200 m (*e.g.* Senegal Shelf, Figures 3 and 4, Wynn et al., 2000; Davison, 2005). Offshore Morocco and Mauritania, the shelf becomes narrower and is affected by salt tectonics and volcanism (von Rad et al., 1982). Two E–W sections, one N–S section and one NW–SE section have been selected to illustrate the geometry of the margin and its evolution from the Jurassic to the Upper Cretaceous offshore Mauritania, Senegal and Guinea (Figures 3 and 4). Offshore Mauritania, the E–W profile illustrates the Jurassic sequence that has a maximum extent of 200 km in width and a maximum thickness of 2.5 km in the basin (Figures 3A and B). This sequence is thicker under the shelf (up to 5 km of thickness, Figure 3B). This Tethyan-type carbonate platform extends all around the Central Atlantic domain (Emery and Uchupi, 1984). During the Cretaceous, slopes had a low gradient (Figure 3B) and the sedimentary thickness thinned into the basin towards DSDP Site 368 (from 4.5 km to 1.5 km thick, Figure 3B).

In the Senegal E–W section (Figure 3C), the Jurassic sequence has a maximum thickness of 1 km in the deep basin and 3.5 km under the shelf, which is less than that observed offshore Mauritania (Figure 3D). The paleo-slope was steep which is characteristic of a deep carbonate bank margin, such as that of the modern Bahamas (Mullins and Neumann, 1979). During the Cretaceous, the sedimentary pile accumulated a maximum thickness of 5 km in the deep basin, that thinned further west, and reached <1 km thick at DSDP Site 367 (Figure 3D). The paleo-slope remained steep during this period, consistent with a deep carbonate bank margin geometry. An erosional surface (SU) is observed between 220 and 245 km along the seismic reflection profile shown in Figure 3D. This surface is correlated to Senonian in age

and illustrates the absence of Albian to Upper Cretaceous sedimentary cover under in outer shelf and the related slope.

The N-S section offshore Mauritania illustrates the structure of the Mauritanian Basin between the shelf in the region of Ras Nouadhibou to the north and the shelf in the region of Dakar to the south (Figure 4A). The profile shown in Figure 4A does not reach the base of the Jurassic sequence. Nevertheless, the steep paleo-slope seen in the top Jurassic reflection illustrates a typical carbonate-bank margin geometry in the region of Ras Nouadhibou between 420 and 500 km along the seismic profile shown in Figure 4B. The Lower Cretaceous sequence is thicker, up to 5 km, while the whole thickness of younger Cretaceous units does not exceed a maximum of 2 km in this region (Figure 4B).

The NW-SE section offshore Guinea illustrates the geometry of the Guinean Plateau (Figures 4C and 4D). The Guinean Plateau forms a prominent corner between the Senegal and the Sierra Leone basins (Figure 1). It corresponds to a submarine bathymetric high in ~700 m of water-depth (Figure 4D). The base of the Jurassic could not be identified between 30 km and 160 km along this profile as the seismic data do not image to this depth (Figure 4C). However, the Mesozoic unit (<6 km thick under the shelf and 3 km in the basin, Figure 4D) is dominated by a Jurassic to the Cenomanian carbonate sequence from the. It turns into a mixed carbonate/clastic regressive sequence in the Upper Cretaceous which remains thin (<0.5 km) both under the plateau and in the basin (Figure 4D). Until the top of the Cenomanian, the paleo-slope remains steep while it becomes gentler within the Upper Cretaceous and the Cenozoic (Figure 4D).

3.2. Seismic facies and associated deposits

3.2.1. Mounded seismic feature nearby DSDP Site 367 during Jurassic to Lower Cretaceous

The DSDP Site 367 (Figure 1, 3C and 5A) has been drilled on a thin sedimentary section located on top of a basement high. This high is standing at a shallow level below the seafloor, 1.121 sTWT mbsf, compared to the surrounding deeper part at ~1.61 sTWT mbsf to the east and 1.475 sTWT mbsf to the west in the deep basin (legacy seismic images are included in supplementary Figure S1; Shipboard Scientific Party and David Bukry, 1978). To the west of DSDP Site 367, the Lower Cretaceous sequence is thick (>620 m) compared to the east (400 m), and includes several moderate to high amplitude reflections that show onlap terminations on a positive topographic structure inherited from the underlying oceanic crust (Figure 5A). Within the lower Cretaceous sequence the main seismic facies is composed of well-stratified sub-parallel reflection with moderate to high amplitude and good lateral continuity (Figure 5A). A slight change of thickness is observed from the east to the west of DSDP Site 367. The Aptian sequence presents low to moderate amplitude reflections with terminations that onlap on the Lower Cretaceous thickened structure observed to the West of DSDP Site 367 (Figure 5B). The sequence thins above the Lower Cretaceous mounded structure and is associated to top lap terminations in its upper section. The slight decrease in thickness laterally, internal seismic facies, the low-mounded geometry, and the location above a structural high suggest that these features could be sheeted drifts. These sheeted drifts forms a sedimentary drape above the irregularities of the oceanic basement observed in many deep-water distal margins (Hernández-Molina, et al., 2008a). The moat surrounding these basement-tectonic controlled drift cannot be yet mapped here due to the low spatial seismic coverage.

3.2.2. Base of slope seismic facies during Cenomanian to Late Cretaceous

Two main seismic facies are observed at the base of slope of the NW African Margin. The first seismic facies consists of lenticular features with locally high amplitude reflections (HAR) packages within lower amplitude extensive continuous reflections packages (Figure 6A). These facies corresponds to deep-sea fans architectural elements that are the channel-

247 levees complexes, with the channel (HAR) and the overbank deposits and levees (e.g. Flood
248 et al., 1991)(Figure 6A). The deep-sea fan apex ends updip with onlap terminations on the
249 base of the continental slope (Figure 6A). Cretaceous deep-sea fan complexes observed in the
250 study area show a maximum thickness of 1 km over an average length of 60 km. Overall, they
251 are thicker at the foot of the continental slope and become gradually thinner towards the deep
252 basin.

253 The second seismic facies observed within or at the base of slope consists of composite facies
254 such as chaotic to discontinuous seismic facies packages, bright steeply-dipping reflections,
255 rotated discontinuous stratal re-flections and low amplitude structureless facies (Figure 6).

256 Each of these facies can be interpreted as mass transport deposits/complexes (MTD/MTC)
257 with its headscarp and toe (e.g. Bull et al., 2009). The mass-transport complexes (MTC) are
258 the result from the destabilization of sedimentary material by gravitational processes. Most of
259 the observed MTCs in this study area show on seismic sections an elongated geometry with
260 chaotic and discontinuous reflections of variable amplitude (Figure 6). The base and top of the
261 MTCs are often associated with a high amplitude continuous seismic reflection that is better
262 imaged in the downslope parts of the basin and gradually onlaps the slope (Figure 6A). The
263 MTCs within the study area have thicknesses ranging between 50 and 1000 m over an average
264 length of 70 km.

265 3.2.3. *Sediment remobilization by bottom-water currents from the Albian to the Late*

266 *Cretaceous*

267 Sedimentary features related to bottom-water currents have been observed both within the
268 Albian-Cenomanian interval and in the Upper Cretaceous (Figures 6B and 7). The oldest
269 structures are particularly observed at the base of the slope of the Guinean Plateau (Figures
270 4C and 6B). Albian sediment waves are characterized by draping continuous reflections of
271 variable amplitudes leading to characteristic wavy structures (Figure 6B). Their average

length is about 2 km and their average thickness is 200 m. These sediment waves migrate upslope towards the east, as expressed by displacement of their crests (Figure 6B) and are not associated to any turbiditic fan in this interval. On top of this deposit, elongated-mounded contourite drifts accumulated during the Cenomanian, shown as continuous low amplitude reflections with mounded geometry. These reflection packages are bounded by non-depositional zones, the moats, which are revealed by particular reflection terminations (*e.g.* toplaps and onlaps, Figure 6B). These contourite drifts have an average thickness of 200 m and their length varies between 5 and 15 km.

Other examples of sedimentary features related to ocean bottom-water currents have been observed within the Upper Cretaceous in the Senegal and Mauritania basins (Figures 3C, 4A and 7). Numerous sediment waves with an average wavelength of 3 km and a thickness of 100 to 200 m were deposited in the proximal part of the Senegal deep-water basin seismic profile and the DSDP Site 367 (Figure 7A). Some of them are coeval with the deposition of the MTC and show crest migration upslope towards the east (Figure 7A). In southern Mauritania, several elongated mounded structures have been identified that indicate the action of bottom-water currents (Figure 7B). These are associated with low angle incisions on their flank, which represent the moat where bottom-currents flow faster and mobilize sediment on the flank to build a contourite drift. No canyon or indication of downslope transport has been identified in trend with this moat. The moats are characterized by low to moderate continuous reflections which present terminations in downlap and toplap (Figure 7B). The mound crests migrate southward (upslope). These contourite drifts are similar to those observed in Guinea within the Cenomanian section, where they have an average length of 5 to 15 km and a thickness ranging between 200 and 300 m (Figure 6B).

3.3. Cretaceous palaeobathymetry of slope and deep-water basin domains

Flexural 2D backstripping of four seismic profiles illustrates the geometry of the margin in Senegal, Mauritania and Guinea (Figures 3 and 4) and allows us to quantify the paleo water-depth in which the sedimentary features, generated by gravity process or ocean bottom current activity, were deposited. The result along the E–W Mauritania profile (Figures 4A and 8A) shows that the unloaded sediments at 93 Ma (top Cenomanian) were deposited at a maximum paleo–depth ranging between 3800 m ($T_e = 0$ Km) and 3750 m ($T_e = 30$ km) while at 100 Ma (top Albian), the maximum palaeobathymetry in the basin ranged from 4150 m ($T_e = 0$ km) to 4000 m ($T_e = 30$ km). Along the N–S Mauritania section (Figure 4A), contourite drifts (Figure 7B) are identified and interpreted as 100 Ma old from 2600 m ($T_e = 0$ km) to 2200 m depth ($T_e = 30$ km) and at 93 Ma between 2550 m ($T_e = 0$ km) and 2300 m ($T_e = 30$ km, Figure 8B). In the Senegal Basin where sedimentary bodies related to bottom–water current were deposited during the Lower Cretaceous (Figure 5), the maximum of the estimated palaeobathymetry ranges from 5550 m ($T_e = 0$ km) to 5700 m ($T_e = 30$ km) at 145 Ma (base of the sheeted contourite drift, Figure 8C). At 125 Ma (top of the sheeted contourite drift), the water depths are estimated to reach 5300 m ($T_e = 0$ km) or 5400 m ($T_e = 30$ km, Figure 8C). The sediment waves observed on this profile (Figure 7A) were deposited after 93 Ma at a depth ranging from 5150 m ($T_e = 0$ km) to 5050 m ($T_e = 30$ km, Figure 8C). The sediment waves observed offshore Guinea during the Albian (Figure 6B) were formed in a water depth ranging between 4200 m ($T_e = 0$ km) and 4100 m ($T_e = 30$ km, Figure 8D). During the Cenomanian, the estimated paleo–depth of the contourite drift (Figure 6B) ranges from 4150 m ($T_e = 0$ km) to 4050 m ($T_e = 30$ km, Figure 8D).

4. Discussion

4.1. Evolution of the Cretaceous deep-water sedimentation

The margin geometry between Mauritania, Senegal and Guinea shows some differences during the Cretaceous (Figures 3 and 4), which may influence sedimentation in the deep-

water basin. Indeed, two types of sedimentary features have been observed: (1) those related to gravitational processes, including channel-levee complexes and mass transport complexes and (2) those related to the remobilization of sediments, either in suspension or from the seafloor, by oceanic bottom currents, including contourite drifts and sediment waves. Based on the results of our study, a three-stage evolution of Cretaceous deep-water sedimentation is defined (Figure 9). Three paleogeographic maps illustrating the evolution of sedimentation in the eastern Central Atlantic depict geological time intervals of the Lower Cretaceous (Neocomian to Albian, Figure 9A), the Albian-Cenomanian (Figure 9B) and the Upper Cretaceous (from the Turonian to the Maastrichtian, Figure 9C).

4.1.1. Initiation of distal bottom currents during the Lower Cretaceous

During the Lower Cretaceous, few deep-sea fans formed along the slope and remained mostly located off Senegal (Figure 9A). This finding suggests that basin sedimentation (from the base of the slope) was mainly influenced by turbidity currents. In addition, at DSDP Site 367 seismic interpretation and cored sediments show argillaceous and carbonate facies deposited in deep pelagic environments during the Lower Cretaceous (Aptian excluded), occasionally influenced by turbidity currents (Jansa et al., 1978). The Lower Cretaceous unit thickens towards the west, which is inconsistent with turbidity current-driven sedimentation and presents morphological characteristics similar to abyssal sheeted drifts (Faugères et al., 1999; Rebesco et al., 2014). Such bodies are also observed in the Namibian basin and off the NW Iberian Margin during the Cretaceous (Hopkins, 2006, Soares et al., 2014). We suggest that these deposits mark the presence of a bottom current driving remobilization and deposition of sediments near the location of DSDP Site 367. This bottom current would have developed at a water-depth of almost 4000 m, as indicated by the backstripped section (Figure 8C). In the lower part of the Lower Cretaceous limestone sampled at DSDP Site 367, the ‘filament microfacies’ has been interpreted as an indicator of sediment reworking by bottom currents

(Jansa et al., 1978) consistent with the sheeted contourite drift observed in the vicinity of DSDP Site 367 (Figure 5B). In addition, the upper section drilled at this site shows remobilized turbidites (Jansa et al., 1978).

4.1.2. Evidence of Albian to Cenomanian bottom currents within a gravity-driven deep sedimentation setting

From the Albian to the end of the Cenomanian, sedimentation in the basin of the eastern Central Atlantic Ocean was mostly influenced by gravity-driven processes, particularly by turbidity currents. This influence is illustrated by regular and continuous deposition of deep-sea fans exclusively located along the base of the continental slope (Figure 9B). In comparison with the Lower Cretaceous, increasing number of deep-sea fan deposits illustrates an increase in the sedimentary material exported to the basin from the continent. This change in sedimentation is also evidenced by the sequence at DSDP Site 367 with Jurassic sedimentation predominantly pelagic and carbonate-rich but becoming detrital-dominated in the Lower Cretaceous (Lancelot et al., 1978a). This change is related to higher sedimentary inputs by several deltas along the Northwest African coast since the Albian (Flicoteaux et al., 1988; Davison et al. 2005; Figure 9B).

Increasing detrital contribution preserved at DSDP 367 is associated with turbidity currents supply to the basin with sediments that originated from the river mouth (Jansa et al., 1978). However, erosion surfaces and sharp contacts observed in the Albian-Cenomanian black shale sequence could also be related to remobilization processes. Indeed, it has been shown that sedimentation on most modern margins is influenced by the combined action of gravity-driven processes and bottom current related processes (Faugères et al., 1999; Calvès et al., 2013; Rebesco et al., 2017). In addition, our results clearly show the presence of contourite drifts and sediment wave fields related to bottom currents in the southern part of the NW African margin (Figures 6B and 9B). This observation indicates that bottom-water currents

remobilized deep sea sediments in the Albian-Cenomanian offshore southern Senegal and downslope on the Guinean Plateau (Figure 9B). These contour-current sedimentary features are observed to have formed further offshore than the depositional zone dominated by turbidity currents. Such bodies are coeval with deep-sea fan deposition, this indicates that the NW African Margin was influenced by mixed sedimentation in the basin since the Albian. This observation is consistent with prior work by Wynn et al. (2000), who demonstrated that the modern NW African margin is influenced by both gravity-driven and bottom current related processes (Figure 1) in similar bathymetry to that reconstructed for the Albian-Cenomanian period, at 1500 and over 4000 m of water-depth (Figure 8).

4.1.3. Abrupt changes in the Upper Cretaceous deep-sea sedimentation influenced by bottom currents

Following the transgression of the early Turonian (~94 Ma), the formation of deep-sea fans in the deep basin ceased and several MTCs formed along the NW African margin (Figure 9C). MTCs are initiated by a loss of stability and then a destabilization of the sediments (Dott, 1963). This destabilization may be due, among others, to a vertical movement of the margin that caused sediments to fail, or to excessive sediment accumulation along the continental slope that caused instability and gravitational collapse of the underlying sedimentary cover. In the case of the NW African margin, several geodynamic events such as convergence between Africa and Europe were responsible for deformation and vertical movement in the northern margin (Guiraud and Bosworth, 1997). These forces could be appropriate triggers for MTCs. Indeed, during the Upper Cretaceous, many sediment waves that are laterally associated with MTCs were formed off Senegal in >4000 m water-depth, from the northern Guinean Plateau to the south of Mauritania (Figure 9C). In comparison with the sediment waves deposited during the Albian, these are of greater wavelength and have an extent to the west into the deep basin (Figure 9C). In addition, a contourite drift is located down the continental slope below

1700 m water depth in southern Mauritania is associated with a sediment wave field (Figure 9C). These various elements illustrate the presence of bottom–water currents that appear to have had a stronger influence in Upper Cretaceous deep–water sedimentation compared to earlier since they are observed in greater number (Figure 9).

4.2. Implications for Cretaceous oceanic paleocirculation pattern

Many studies agree on the nature of oceanic circulation patterns in the Central Atlantic Ocean during the Cretaceous. Indeed, it seems that the transition between the Cenomanian and the Turonian (~94 Ma) was a key period illustrating ocean circulation change between the Lower and Upper Cretaceous (Bralower and Thierstein, 1984; Poulsen et al., 2001; Pucat et al., 2005; Trabuco Alexandre et al., 2010; Donnadiu et al., 2016). During the Lower Cretaceous, the Atlantic Ocean would have had a slow to sluggish oceanic circulation with very little renewal of water deeper than 1500 m (Barron, 1983; Bralower and Thierstein, 1984). This sluggish circulation would have favoured the development of anoxic and oxygen-depleted waters (Schlanger and Jenkyns, 1976; Bralower and Thierstein, 1984). As a result, an important stratification of the ocean water column is inferred with little or no renewal of deep-water masses (Schlanger and Jenkyns, 1976; Bralower and Thierstein, 1984). The water mass circulation in the Central Atlantic Ocean during the Lower Cretaceous would have exclusively affected water-depths shallower than 500 m, with ocean currents originating from the Tethys Ocean and circulating into the eastern Central Atlantic Ocean (Poulsen et al., 2001; Pucat et al., 2005). In contrast, palaeogeographic changes during the Turonian, 90–94 Ma (*e.g.*, opening of the Equatorial Atlantic Ocean) would have progressively led to increasing oceanic circulation and better ventilation of the seafloor by bottom currents during the Upper Cretaceous in the whole Central Atlantic (Poulsen et al., 2001; Donnadiu et al., 2016). This change would have resulted in the formation of deep-water currents that originated from the eastern Pacific and the South Atlantic oceans, and flowed northward to the Central Atlantic

Ocean (Poulsen et al., 2001; Trabucho Alexandre et al., 2010; Robinson and Vance, 2012; Voigt et al., 2013; Donnadieu et al., 2016). Our results show an evolution of deep-sea sedimentation with a similar timing to that currently proposed for the evolution of the palaeocirculation of the Central Atlantic Ocean during the Cretaceous. Indeed, we observe more sedimentary features related to bottom currents in the Upper Cretaceous sequence than during the preceding Mesozoic periods (Figures 9 and 10). In addition, this study confirms the presence of bottom currents during the Upper Cretaceous as proposed by Robinson and Vance (2012) and constrains the palaeobathymetry at which these bottom currents affected the sedimentation (Figures 8). These constraints help to reduce the great uncertainty about Cretaceous palaeobathymetry in the eastern Central Atlantic Ocean. Actually, the paleowater-depths of the Cretaceous bottom currents had been estimated by modeling and by neodymium isotope analysis in fish teeth, but it remained qualitative (Poulsen et al., 2001; MacLeod et al., 2008; Trabucho Alexandre et al., 2010; Donnadieu et al., 2016). It is now clear that the Central Atlantic Ocean palaeobathymetry was already close to present-day depth since the Lower Cretaceous (>4000 m in the deep basin, Figure 8C). Moreover, the organization of the modern water column on the NW African margin involves surface (0~600 m), intermediate (~600-1500 m) and the deep-waters that extend down to 4000 m depth with specific temperatures and salinities (Figure 10A). These water masses originate from other basins, including the South Atlantic and the Antarctic Oceans (Emery and Meincke, 1986). Bathymetry and water column stratification of the eastern Central Atlantic Ocean could be similar between the Upper Cretaceous and present-day, which is consistent with the establishment of a global circulation since the Upper Cretaceous (Poulsen et al., 2001). However, our results do not support the hypothesis that proposes a sluggish to slow deep-water circulation for the Central Atlantic Ocean before the Upper Cretaceous (Barron, 1983; Bralower and Theirstein, 1984, Poulsen et al., 2001). Indeed, this work documents the

presence of active bottom currents flowing since the Lower Cretaceous (Figures 5, 6, 9 and 10) which suggests active deep oceanic circulation since the Early Cretaceous. This findings supported by other studies which have illustrated the movements of deep-water masses flowing in the Central Atlantic Ocean during the Cretaceous. For example, Soares et al. (2014) in a study of the northwest of the Iberia margin and in a study of Dunlap et al. (2013) offshore Morocco illustrated the presence of contourite drifts and sediment waves on the seafloor since the Lower Cretaceous. Dunlap et al. (2013) proposed that sediment waves evolved in water-depths of <3000 m, which is similar to water depths for sediment waves and contourite drift development observed in this study offshore of Mauritania and Guinea (Figures 8B and 10B).

5. Conclusions

This study provides evidence of sedimentary features related to bottom current activity and layered oceanic circulation since the Lower Cretaceous in the Central Atlantic offshore of Mauritania and Guinea. Lower Cretaceous contourite drifts formed in paleowater-depths of >4000 m in the distal domain of the NW African margin near the location of DSDP Site 317. During the Albian-Cenomanian, contourite drifts and sediment waves formed along the base of the continental slope and combined with gravity-driven sedimentation in the Guinean and Senegal basins. From the Turonian to the Maastrichtian, an increase in the number of sediment wave fields is noted in the abyssal plain of the Senegal Basin. These particular features seem disconnected from gravity-driven sedimentation that affected the slope and the proximal parts of the abyssal plain. In addition, contourite drifts were identified in the Mauritanian basin during this period. These results support an Upper Cretaceous oceanic model of a better ventilated Central Atlantic Ocean, and bottom current flow starting in the Lower Cretaceous which is inconsistent with hypotheses that call for a sluggish to stagnant ocean at that time. Heterogeneity of sediments associated with organic rich sediments in the

eastern Central Atlantic domain has been unraveled by tracing methods (Mourlot et al., 2018).
More works of the Cretaceous deep-sea sediments and oceans circulation still need to be
done.

AUTHORS CONTRIBUTIONS

Y.M. and G.C. designed the study and implemented the analysis. Y.M. G.C. P.D.C. G.B. A.-
C.C. and F.R. contributed to data analysis. F.R. and A.-C.C. supported Y.M. for data handling
and in-house management. The manuscript was written by G.C. and Y.M.

ACKNOWLEDGMENTS

Y.M. and G.B. thank Total E&P for funding their research project at the Université Toulouse
3 – Paul Sabatier. Thanks to François Leparmentier, Jean-Marc Pince (Total E&P) and
Samuel Toucanne (IFREMER, LGS, Plouzané) for valuable discussions. We also thank Alan
Roberts and Nick Kusznir for allowing us to use Flex–Decomp™. We are grateful to TGS for
the permission to publish the seismic lines. Seismic data sourced from the Virtual Seismic
Atlas (VSA; [link](#)) have been used to produce the Figure 3A (survey: VER-01 MWT and
VERMAU-01, seismic data property of CGG Veritas). PC thanks the Charles T. McCord Jr
Chair in Petroleum Geology at LSU. We would also like to thank the editor Jean-Philippe
Avouac, Joe Cartwright and an anonymous reviewer for their helpful comments.

REFERENCES

- Barron, E. J., 1983. A warm, equable Cretaceous: The nature of the problem, *Earth Sci. Rev.*,
19, 305–338
- Berrocso, A.J., MacLeod, K.G., Martin, E., Bourbon, E., Londoño, C.I., and Basak, C.,
2010. Nutrient trap for Late Cretaceous organic-rich black shales in the tropical North
Atlantic: *Geology*, v. 38, p. 1111–1114. doi:10.1130/G31195.1.

- 494 Boyer, T.P., J. I. Antonov, O. K. Baranova, C. Coleman, H. E. Garcia, A. Grodsky, D. R.
 495 Johnson, R. A. Locarnini, A. V. Mishonov, T.D. O'Brien, C.R. Paver, J.R. Reagan, D. Seidov,
 496 I. V. Smolyar, and M. M. Zweng, 2013. World Ocean Database 2013, NOAA Atlas NESDIS
 497 72, S. Levitus, Ed., A. Mishonov, Technical Ed.; Silver Spring, MD, 209 pp.,
 498 doi:10.7289/V5NZ85MT
- 499 Bralower, T. J., and Thierstein, H. R., 1984. Low productivity and slow deep–water
 500 circulation in mid–Cretaceous oceans. *Geology*, 12(10), 614–618.
- 501 Bull, S., Cartwright, J., and Huuse, M., 2009. A review of kinematic indicators from mass-
 502 transport complexes using 3D seismic data. *Marine and Petroleum Geology*, 26(7), 1132–
 503 1151. <https://doi.org/https://doi.org/10.1016/j.marpetgeo.2008.09.011>
- 504 Calvès, G., Clift, P. D., and Inam, A., 2008. Anomalous subsidence on the rifted volcanic
 505 margin of Pakistan: No influence from Deccan plume. *Earth and Planetary Science Letters*,
 506 272(1–2). doi:10.1016/j.epsl.2008.04.042
- 507 Calvès, G. , Toucanne, S. , Jouet, G. , Charrier, S. , Thereau, E. , Etoubleau, J. , Marsset, T. ,
 508 Droz, L. , Bez, M. , Abreu, V. , Jorry, S. , Mulder, T. and Lericolais, G., 2013, Inferring
 509 denudation variations from the sediment record; an example of the last glacial cycle record of
 510 the Golo Basin and watershed, East Corsica, western Mediterranean sea. *Basin Res*, 25: 197-
 511 218. doi:10.1111/j.1365-2117.2012.00556.x
- 512 Clift, P. D., Turner, J., and Party, T. O. D. P. L. 152 S., 1995. Dynamic support by the Iceland
 513 Plume and its effect on the subsidence of the northern Atlantic margins. *Journal of the*
 514 *Geological Society*, 152(6), 935–941. doi:10.1144/GSL.JGS.1995.152.01.09

- 515 Davison, I., 2005. Central Atlantic margin of North West Africa: Geology and hydrocarbon
516 potential (Morocco to Guinea), *J. Afr. Earth Sci.*, 43, 254–274,
517 doi:10.1016/j.jafrearsci.2005.07.018.
- 518 Donnadieu, Y., Pucéat, E., Moiroud, M., Guillocheau, F., Deconinck, J.–F., 2016. A better–
519 ventilated ocean triggered by Late Cretaceous changes in continental configuration. *Nature*
520 *Communications* 7, 10316. doi:10.1038/ncomms10316
- 521 Dott, R.H., 1963. Dynamics of subaqueous gravity depositional processes. *AAPG Bull.*,
522 47,104–128.
- 523 Dunlap, D., Wood, L., Moscardelli, L., 2013. Seismic geomorphology of early North Atlantic
524 sediment waves, offshore northwest Africa. *Interpretation* 1, SA75–SA91. doi:10.1190/INT–
525 2013–0040.1
- 526 Emery, K. O., and Uchupi, E., 1984. *The geology of the Atlantic Ocean*. Springer Science &
527 Business Media. doi: 10.4319/lo.1986.31.3.0669
- 528 Emery, W.J., and Meincke J., 1986. Global water masses: Summary and review, *Oceanologia*
529 *Acta*, 9(4), 383–391.
- 530 Faugères, J.–C., Stow, D.A.V., Imbert, P., Viana, A., 1999. Seismic features diagnostic of
531 contourite drifts. *Marine Geology* 162, 1–38. doi:10.1016/S0025–3227(99)00068–7
- 532 Flicoteaux, R., Latil–Brun, M.–V., Michaud, L., 1988. Histoire de la subsidence post–rift du
533 bassin côtier mauritano–sénégal–guinéen. Relation avec l’amincissement crustal pendant la
534 période jurassique à Crétacé inférieur. Comparaison avec l’évolution des marges péri–
535 atlantiques au niveau de l’Atlantique Central et Equatorial (côte est des U.S.A., Sud–Sahara,
536 Côte d’Ivoire et Plateau du Demerara). *Journal of African Earth Sciences (and the Middle*

537 East), The West African connection: Evolution of the central atlantic ocean and its
538 Continental Margins 7, 345–359. doi:10.1016/0899–5362(88)90079–6

539 Flood, R. D., Manley, P. L., Kowsmann, R. O., Appi, C. J., Pirmez, C., 1991. Seismic Facies
540 and Late Quaternary Growth of Amazon Submarine Fan BT - Seismic Facies and
541 Sedimentary Processes of Submarine Fans and Turbidite Systems. In P. Weimer & M. H.
542 Link (Eds.) (pp. 415–433). New York, NY: Springer New York. doi:10.1007/978-1-4684-
543 8276-8_23

544 Guiraud, R., Bosworth, W., 1997. Senonian basin inversion and rejuvenation of rifting in
545 Africa and Arabia: synthesis and implications to plate–scale tectonics. Tectonophysics,
546 Structural Controls on Sedimentary Basin Formation 282, 39–82. doi:10.1016/S0040–
547 1951(97)00212–6

548 Hardenbol, J., Vail, P. R., Ferrer, J., Montadert, L., and Blanchet, R., 1981. Interpreting
549 paleoenvironments, subsidence history and sea–level changes of passive margins from
550 seismic and biostratigraphy. Oceanologica Acta, Special issue, 2, 33–44.

551 Heezen, B.C., Hollister, C., 1964. Deep–sea current evidence from abyssal sediments. Marine
552 Geology 1, 141–174. doi:10.1016/0025–3227(64)90012–X

553 Hernández-Molina, F. J., Maldonado, A., & Stow, D. A. V. 2008a. Chapter 18 Abyssal Plain
554 Contourites. Developments in Sedimentology, 60, 345–378. doi:10.1016/S0070-
555 4571(08)10018-8

556 Hernández–Molina F.J., Llave E., Stow D.A.V., 2008b. Chapter 19 Continental Slope
557 Contourites, Developments in Sedimentology, 60, 379–408. doi:10.1016/S0070–
558 4571(08)10019–X

- 559 Hopkins, A.E., 2006. Seismic stratigraphic interpretation of contourite systems, Namibian
560 continental margin. PhD Thesis, University of Cardiff, Cardiff.
- 561 Jansa, L., Gardner, J.V., Dean, W.E., 1978. Mesozoic sequences of the Central North
562 Atlantic. Initial Reports of the Deep Sea Drilling Project. doi:10.2973/dsdp.proc.41.138.1978
- 563 Kuszniir, N. J., Roberts, A. M., and Morley, C. K., 1995. Forward and reverse modelling of
564 rift basin formation. Geological Society, London, Special Publications, 80(1), 33–56. doi:
565 10.1144/GSL.SP.1995.080.01.02
- 566 Lancelot, Y., Seibold, E., Cepek, P., Dean, W.E., Eremeev, V., Gardner, J.V., Jansa, L.,
567 Johnson, D., Kasheninnikov, V., Pflaumann, U., Graham, J., Bukry, D., 1978a. Site 367: Cape
568 Verde Basin. Initial Reports of the Deep Sea Drilling Project 41, 163–232.
569 doi:10.2973/dsdp.proc.41.103.1978
- 570 Lancelot, Y., Seibold, E., Cepek, P., Dean, W.E., Eremeev, V., Gardner, J.V., Jansa, L.,
571 Johnson, D., Kasheninnikov, V., Pflaumann, U., Graham, J., Bukry, D., 1978b. Site 368:
572 Cape Verde Rise. Initial Reports of the Deep Sea Drilling Project 41, 233–326.
573 doi:10.2973/dsdp.proc.41.104.1978
- 574 Latil–Brun, M.V. and Lucazeau, F., 1988. Subsidence, extension and thermal history of the
575 West African margin in Senegal. Earth and Planetary Science Letters, 90(2): 204–220. doi:
576 10.1016/0012–821X(88)90101–X
- 577 Labails, C., 2007. La marge sud–marocaine et les premières phases d'ouverture de l'océan
578 Atlantique Central. PhD Thesis. Université de Bretagne Occidentale).
- 579 MacLeod, K.G., Martin, E.E., Blair, S.W., 2008. Nd isotopic excursion across Cretaceous
580 ocean anoxic event 2 (Cenomanian–Turonian) in the tropical North Atlantic. Geology 36,
581 811–814. doi:10.1130/G24999A.1

- 582 Martin, E.E., MacLeod, K.G., Jiménez Berrocoso, A., Bourbon, E., 2012. Water mass
583 circulation on Demerara Rise during the Late Cretaceous based on Nd isotopes. *Earth and*
584 *Planetary Science Letters* 327–328, 111–120. doi:10.1016/j.epsl.2012.01.037
- 585 Mosher, D. C., Campbell, D. C., Gardner, J. V, Piper, D. J. W., Chaytor, J. D., and Rebesco,
586 M., 2017. The role of deep-water sedimentary processes in shaping a continental margin: The
587 Northwest Atlantic. *Marine Geology*, 393, 245–259. doi:10.1016/j.margeo.2017.08.018
- 588 Murlot, Y., Roddaz, M., Dera, G. Calvès, G., Kim, J.H., Chaboureaud, A-C., Mounic, S., and
589 Raison, F., 2018, Geochemical evidence for large-scale drainage reorganization in Northwest
590 Africa during the Cretaceous, *G-Cubed*, doi:10.1029/2018GC007448
- 591 Mullins H.T., and Neumann, A.C., 1979. Deep carbonate bank–margin structure and
592 sedimentation in the northern Bahamas. *SEPM Publ.*, 27, 165–192.
- 593 Patriat, M., and Labails, C., 2006. Linking the Canary and Cape–Verde hot–spots, northwest
594 Africa. *Marine Geophysical Research*, 27(3), 201–215. doi: 10.1007/s11001–006–9000–7
- 595 Posamentier, H. W., and V. Kolla, 2003. Seismic geomorphology and stratigraphy of
596 depositional elements in deep-water settings, *J. Sediment. Res.*, 73(3), 367– 388.
- 597 Poulsen, C. J., Barron E. J., Arthur M. A., and Peterson W. H., 2001. Response of the Mid–
598 Cretaceous global oceanic circulation to tectonic and CO₂ forcings, *Palaeoceanography*,
599 16(6), 576–592, doi:10.1029/2000PA000579.
- 600 Pucéat, E., Lécuyer, C., Reisberg, L., 2005. Neodymium isotope evolution of NW Tethyan
601 upper ocean waters throughout the Cretaceous. *Earth and Planetary Science Letters* 236, 705–
602 720. doi:10.1016/j.epsl.2005.03.015
- 603 Purdy, E.G. 1989. Africa Geology and Hydrocarbons Map. Exploration of Africa Project.

- 604 Rebesco, M., Hernández–Molina, F.J., Van Rooij, D., Wåhlin, A., 2014. Contourites and
605 associated sediments controlled by deep–water circulation processes: State–of–the–art and
606 future considerations. *Marine Geology*, 50th Anniversary Special Issue 352, 111–154.
607 doi:10.1016/j.margeo.2014.03.011
- 608 Rebesco, M., Mosher, D., & Piper, D. J. W. 2017. Advancements in Understanding Deep-Sea
609 Clastic Sedimentation Processes: a preface. *Marine Geology*, 393, 1–3.
610 doi:10.1016/j.margeo.2017.10.007
- 611 Roberts, A. M., Kuszniir, N. J., Yielding, G., & Styles, P., 1998. 2D flexural backstripping of
612 extensional basins: the need for a sideways glance. *Petroleum Geoscience*, 4(4), 327–338.
- 613 Roberts, A. M., R. I. Corfield, N. J. Kuszniir, S. J. Matthews, E.–Kåre Hansen, and R. J.
614 Hooper 2009. Mapping palaeostructure and palaeobathymetry along the Norwegian Atlantic
615 continental margin: Møre and Vøring basins, *Petroleum Geoscience*, 15(1), 27–43,
616 doi:10.1144/1354–079309–804
- 617 Robinson, S.A., Vance, D., 2012. Widespread and synchronous change in deep–ocean
618 circulation in the North and South Atlantic during the Late Cretaceous. *Palaeoceanography*
619 27, PA1102. doi:10.1029/2011PA002240
- 620 Ryan, W.B.F., Sibuet, J–C., Arthur, M.A., Lopatin, B.G., Moore, D.G., Maldonado, A.,
621 Rehault, J–P., Iaccarino, S., Sigal, J., Morgan, G.E., Blechschmidt, G., Williams, A.C.,
622 Johnson, D., Barnes, R.O., and Habib, D., 1979. 2. Site 398. Initial Reports of the Deep Sea
623 Drilling Project 47B, 25–233. doi:10.2973/dsdp.proc.47–2.102.1979
- 624 Schlanger, S. O., and Jenkyns, H. C., 1976. Cretaceous oceanic anoxic events: causes and
625 consequences. *Geologie en mijnbouw*, 55(3–4), 179–184.

- 626 Schwab, A.M., Tremblay, S., Hurst, A., 2007. Seismic expression of turbidity–current and
627 bottom–current processes on the Northern Mauritanian continental slope. Geological Society,
628 London, Special Publications 277, 237–252. doi:10.1144/GSL.SP.2007.277.01.14
- 629 Shipboard Scientific Party and David Bukry, 1978. Site 367: Cape Verde Basin, Part II: Site
630 Reports, in: DSDP Volume 41 (ed. Lancelot et al.), 163–232,
631 doi:10.2973/dsdp.proc.41.103.1978
- 632 Soares, D.M., Alves, T.M., Terrinha, P., 2014. Contourite drifts on early passive margins as
633 an indicator of established lithospheric breakup. Earth and Planetary Science Letters 401,
634 116–131. doi:10.1016/j.epsl.2014.06.001
- 635 Stow, D. a. V., Pudsey, C.J., Howe, J.A., Faugères, J.–C., Viana, A.R., 2002. Deep–water
636 contourite systems: Modern drifts and ancient series, seismic and sedimentary characteristics.
637 Geological Society Memoir.
- 638 Trabucho Alexandre, J., Tuenter, E., Henstra, G. A., van der Zwan, K. J., van de Wal, R. S.,
639 Dijkstra, H. A., and de Boer, P. L., 2010. The mid-Cretaceous North Atlantic nutrient trap:
640 Black shales and OAEs. Palaeoceanography, 25(4). doi: 10.1029/2010PA001925
- 641 Uenzelmann–Neben, G., Weber, T., Grützner, J., Thomas, M., 2016. Transition from the
642 Cretaceous ocean to Cenozoic circulation in the western South Atlantic — A twofold
643 reconstruction. Tectonophysics. doi:10.1016/j.tecto.2016.05.036
- 644 Voigt, S., Jung, C., Friedrich, O., Frank, M., Teschner, C., Hoffmann, J., 2013. Tectonically
645 restricted deep–ocean circulation at the end of the Cretaceous greenhouse. Earth and Planetary
646 Science Letters 369–370, 169–177. doi:10.1016/j.epsl.2013.03.019
- 647 von Rad, U., and Einsele, G., 1980. The evolution of passive continental margins in the light
648 of recent deep drilling results – Mesozoic–Cainozoic subsidence history and

649 palaeobathymetry of the northwest African continental margin (Aaiun Basin to D. S. D. P.
 650 Site 397). Philosophical Transactions of the Royal Society of London. Series A, Mathematical
 651 and Physical Sciences, 294(1409), 37 LP–50.

652 von Rad, U., Hinz, K., Samthein, M. and Seibold, E. 1982. (Eds.), Geology of the Northwest
 653 African Continental Margin, 107–131, 12 figs., Berlin, Heidelberg, New York (Springer).

654 Watts, A. B., 1978. An analysis of isostasy in the world's oceans 1. Hawaiian–Emperor
 655 Seamount Chain, J. Geophys. Res., 83(B12), 5989–6004, doi:10.1029/JB083iB12p05989.

656 Watts, A. B., 2015. 6.01 – Crustal and Lithosphere Dynamics: An Introduction and Overview
 657 A2 – Schubert, Gerald BT – Treatise on Geophysics (Second Edition) (pp. 1–44). Oxford:
 658 Elsevier, doi:10.1016/B978-0-444-53802-4.00110-X

659 Wynn, R.B., Weaver, P.P.E., Ercilla, G., Stow, D.A.V., Masson, D.G., 2000. Sedimentary
 660 processes in the Selvage sediment–wave field, NE Atlantic: new insights into the formation of
 661 sediment waves by turbidity currents. Sedimentology 47, 1181–1197. doi:10.1046/j.1365–
 662 3091.2000.00348.x

663

664 **TABLE**

Section	Figure	Stratigraphic interval	Age (Ma)	Gamma (G)	Density (g/cm ³)	Lithology			
						Sand (%)	Gr. Shale (%)	Silt. Shale (%)	Other (%)
Niger Delta Basin	26	Base Cenozoic at present-day sea level	66 to 0	22.5	2.32	48	31	20	1
		The Cenozoic to base Garscaille	50 to 25	21.7	2.23	35	17	35	13
		The Garscaille to top Garscaille	100 to 114	22.9	2.36	60	1	39	0
		The lower Garscaille to top Aftian	112 to 160	21.7	2.23	35	22	3	40
		The Aftian to top lower Garscaille	160 to 176	22.9	2.32	40	24	3	33
Senegalese Basin	27	The present-day sea level to top Aftian	176 to 185	21.7	2.2	5	0	95	0
		The Aftian to top lower Garscaille	185 to 190	22.9	2.32	35	1	64	0
		The Garscaille to base Garscaille	50 to 25	21.7	2.23	45	0	55	0
		The Garscaille to top Garscaille	100 to 114	22.9	2.36	54	0	46	0
		The Aftian to top Aftian	112 to 160	21.7	2.23	35	0	65	0
Mauritania Basin	28	The Aftian to top lower Garscaille	160 to 176	22.9	2.32	35	0	65	0
		The Garscaille to base Garscaille	50 to 25	21.7	2.23	35	0	65	0
		The Garscaille to top Garscaille	100 to 114	22.9	2.36	54	0	46	0
		The Aftian to top Aftian	112 to 160	21.7	2.23	35	0	65	0
		The Aftian to top lower Garscaille	160 to 176	22.9	2.32	35	0	65	0
Senegalese Basin	29	The Aftian to top lower Garscaille	160 to 176	22.9	2.32	35	0	65	0
		The Garscaille to base Garscaille	50 to 25	21.7	2.23	35	0	65	0
		The Garscaille to top Garscaille	100 to 114	22.9	2.36	54	0	46	0
		The Aftian to top Aftian	112 to 160	21.7	2.23	35	0	65	0
		The Aftian to top lower Garscaille	160 to 176	22.9	2.32	35	0	65	0

665
666 Table 1: Lithology, porosity and density parameters for each sedimentary unit used for the
667 backstripping of stratigraphic cross section illustrated in Figures 3 and 4.

668 **SUPPLEMENTAL FILES**

669 Figure S1: Figure S1: (A) Original map of the Site 367 in the Cape Verde Basin, with location
670 of seismic reflection profiles (Shipboard Scientific Party, 1978). (B) Portion of VEMA 29
671 seismic profile crossing Site 367, Horizons A, B and C corresponds to targets prior of drilling,
672 (C and D) Portions of seismic profile Valdivia 10, with seismic calibrated framework
673 corresponding to (E.) Figure 5A. SF: Sea Floor; P: Base Paleocene; TC: Top Cenomanian;
674 TA: Top Albian; TAp: Top Aptian; TLC: Top Lower Cretaceous; AB: Top Acoustic
675 Basement.

676 Figure S2: (A) Time–depth plot of velocity measurements from radiosonobuoys located off
677 Mauritania and Senegal compiled by Diebold (1996) and checkshot data sourced from DSDP
678 Sites 368, 657 and 397 initial reports (Lancelot et al., 1978b; von Rad et al., 1979; Shipboard
679 Scientific Party, 1988). (B) Porosity curves used for decompaction in FlexDecomp (Sclater
680 and Christie, 1980).

681 Figure S3: (A) Grid map illustrating the repartition of Te data of the continental and oceanic
682 lithospheres sourced by Watts (2015). Delimitation of the continental and the ocean realms is
683 characterized by the Ocean-Continent Boundary (OCB) sourced by Müller et al. (2016). (B)
684 Distribution and frequency of Te values in the continental and ocean realms.

685

FIGURE CAPTIONS

Figure 1: Shaded bathymetric map of the eastern Central Atlantic Ocean showing the geomorphological and oceanographic framework of the studied margin between the Canary Island Seamount Province (CISP) and the Guinean Plateau (GP). Interaction between oceanic currents and terrestrial sedimentary export is illustrated by four regional seismic sections indicated by red lines through Deep Sea Drilling Project (DSDP) Sites 367 and 368. Grey area represents the basement bulge off the margin identified by Patriat and Labails (2006) and the location of the Jurassic shelf edge mapped by Purdy (1989). Magnetic anomalies are reconstructed by Labails (2007). Cretaceous sediment waves observed by Dunlap et al. (2013) are indicated by the blue star. Present-day sediment wave fields are sourced from Wynn et al. (2000). Present-day oceanic circulation with GS–NAC: Gulf Stream–North Atlantic Current. CC: Canary Current. NEC: North Equatorial Current. ECC: Equatorial Counter–Current. ABW: Antarctic Bottom Water. Cretaceous oceanic currents correspond to the Tethys Circumglobal Current (TCC) proposed by Pucat et al. (2005), the Demerara Bottom Water (DBW) proposed by Berrocoso et al. (2010), the North Component Waters (NCW) and the Southern Component Waters (SCW) proposed by Robinson and Vance (2012). MSB: Morocco Salt Basin. AB: Aaiun Basin. MSGB: Mauritania Senegal Guinea Basin. SLB: Sierra Leone Basin. SLR: Sierra Leone Rise. Base map sourced from the Geomapapp (<http://www.geomapapp.org/>)

Figure 2: Lithostratigraphic chart of DSDP Sites 367, 368 (Mauritania Senegal Guinea Basin; Lancelot et al., 1978a; 1978b), DSDP Site 398 (NW Iberian Margin; Ryan et al., 1979) and sedimentary structures identified in this study area. Sediment waves and mass transport complex occurrence offshore Morocco is based on Dunlap et al. (2013) and contourite drift occurrences offshore the NW Iberian Margin is from Soares et al. (2014). Age uncertainties are illustrated by dashed-black arrows. TD: Total Depth; DbF: Debris Flow.

Figure 3: (A) East-West two-way time seismic section through DSDP Site 368 (offshore Mauritania), data sourced from the Virtual Seismic Atlas (VSA; [link](#)). (B) Interpreted geological depth converted section of Figure 3A. SF: Sea Floor; P: Base Paleocene; TC: Top Cenomanian; TA: Top Albian; TAp: Top Aptian; TLC: Top Lower Cretaceous; AB: Top Acoustic Basement. (C) East-West depth converted seismic section through DSDP Site 367 (offshore Senegal), courtesy of TGS. (D) Interpreted geological section of the Figure 3C. Legend is the same as Figure 3B. See Figure 1 for location.

Figure 4: (A) North-South two-way time seismic section along the Mauritanian shelf (east of DSDP Site 368, offshore Mauritania), courtesy of TGS. (B) Depth-converted interpreted geological section derived from Figure 4A. (C) WNW-ESE two-way time seismic section through Guinean Plateau to deep-water, courtesy of TGS. (D) Depth converted interpreted geological section derived from Figure 4C. Legend is the same as Figure 3B. See Figure 1 for location.

Figure 5: (A) Inset of the W–E regional section across the Senegal Basin (Figure 3C) showing the thickening of the lower Cretaceous sediments on Jurassic deposits observed west of DSDP Site 367 (Courtesy of TGS). (B) Interpreted W–E oriented seismic line flattened along a continuous regional event (Top Aptian: TAp) allowing restoration of the basin geometry at the time of the drowning of the mounded structure associated to sheeted contourite drift. Legend is the same as Figure 3B. See Figure 1 for location.

Figure 6: (A) Inset of Cenomanian channel-levee complex deposited at the base of the slope observed on Figure 3C (Courtesy of TGS). High-amplitude reflections: HARs. (B) Inset of Figure 4C illustrating sediment wave and contourite drift deposits between the Albian and Cenomanian intervals. Note the change of scale between the sediment waves and the contourite drift deposits. Mass transport complexes are observed above in the Upper

Cretaceous interval. The crest migration of the sediment waves towards the ESE indicates that the deposition of the sediment is controlled by a bottom current coming from the WNW. Legend is the same as Figure 3B. See Figure 1 for location.

Figure 7: (A) Inset of Upper Cretaceous sediment waves and mass transport complex observed east of DSDP Site 367 (Senegal) on Figure 3B (Courtesy of TGS). Note the extensive erosional surface at the base of the sediment wave sequence. (B) inset from Figure 4A of the offshore Mauritania Basin, the Cenomanian interval is characterized by channel-levee systems whereas the Upper Cretaceous is related to contourite drifts deposits. The crest migration of the contourite drift deposits indicates a sedimentation controlled by a potential oceanic current coming from the North. Legend is the same as Figure 3B. See Figure 1 for location.

Figure 8: 2D sediment-unloaded sections along Figures 3 and 4 showing the paleobathymetric evolution of the seafloor during the Cretaceous. Present day seafloor is marked by the continuous black line whereas age (Ma)/ T_e (km) pairs are associated to different discontinuous lines of different grey scales. Displays are restricted to the areas where bottom current sedimentary features have been observed. (A) E–W Mauritanian section through DSDP Site 368. (B) N–S Mauritanian section. (C) E–W Senegal section through DSDP Site 367. (D) WNW–ESE Guinean Basin section.

Figure 9: Paleogeographic maps of the study area focused on the deep-water sedimentation. (A) Early Cretaceous period (Berriasian-Aptian), the sedimentation in the deep-water area is associated to channel-levees sourced from onshore via deltas and some sediment waves offshore Morocco and mounded drifts near DSDP Site 367. (B) the Albian-Cenomanian period records extensive slope deposits that covers most of the margins from Morocco to Guinea where contourite drift and upper slope erosion occurs. (C). the Upper Cretaceous

period (Turonian to Maastrichtian) is a period of mass slope disturbance with mass transport complexes and important bottom-current sediment wave related fields and contourite drift from Guinea to south Morocco. In the north of the study area a regional hiatus potentially related to uplift/erosion of the margin sourced from the collision of North Africa with European plates.

Figure 10: Synthetic present day and Cretaceous oceanographic-seafloor model. (A) Present-day oceanographic properties along the Northwestern African Margin. (B) Cretaceous synthesis of observed sedimentary features occurrences related to bottom-water currents. (C) Evolution of Cretaceous bottom water sedimentary features record. Oceanographic data (temperature, salinity) are sourced from National Oceanic and Atmospheric Administration (NOAA) world ocean database (WOD13, Station 1550019(C): 21°W 14°N) (Boyer et al., 2013). Present-day water masses names and water depths are sourced from Emery and Meincke (1986). SACW: South Atlantic Central Water. ENACW: Eastern North Atlantic Central Water. AIW: Antarctic Intermediate Water. MW: Mediterranean Water. EASIW: Eastern Atlantic Subarctic Intermediate Water. ABW: Antarctic Bottom Waters. Paleobathymetries related to Cretaceous ocean currents are from: DBW – Demerara Bottom Water (Berrocso et al., 2010); NCW – North Component Waters (MacLeod et al., 2008; Voigt et al., 2013); SCW – South Component Waters (Robinson and Vance, 2012) and TCC – Tethys Circumglobal Current (Pucat et al., 2005).

[Click here to download high resolution image](#)

Figure 02
Click here to download high resolution image

Figure 03
[Click here to download high resolution image](#)

Figure 04
[Click here to download high resolution image](#)

Figure 05
[Click here to download high resolution image](#)

Figure 06
[Click here to download high resolution image](#)

[Click here to download high resolution image](#)

Figure 08

[Click here to download high resolution image](#)

Figure 09

[Click here to download high resolution image](#)

Figure 10

[Click here to download high resolution image](#)

Table 01
Click here to download Table: Table 1_Mourlot-et-al-EPSL-2017.xlsx

Section	Figure	Stratigraphic interval	Age (Ma)	Porosity (%)	Density (g/cc)	Lithology			
						% Sand	% Shaly sand	% Shale	% Limestone
Mauritania Basin	3A	Base Cenozoic to present-day seafloor	65 to 0	58.5	2.69	43	10	15	32
		Top Cenomanian to base Cenozoic	93 to 65	59.5	2.68	32	16	22	30
		Top Albian to top Cenomanian	100 to 93	58.1	2.68	50	0	20	30
		Top Lower Cretaceous to top Albian	125 to 100	59.5	2.68	30	30	0	40
		Top Jurassic to top Lower Cretaceous	145 to 125	55.3	2.67	40	45	0	15
		Top acoustic basement to top Jurassic	170 to 145	69.3	2.71	0	0	10	90
Senegal Basin	3C	Base Cenozoic to present-day seafloor	65 to 0	66.8	2.71	10	0	15	75
		Top Cenomanian to base Cenozoic	93 to 65	57.7	2.69	45	0	40	15
		Top Albian to top Cenomanian	100 to 93	65.6	2.70	13	0	23	64
		Top Aptian to top Albian	112 to 100	64.4	2.70	15	0	35	50
		Top Lower Cretaceous to top Aptian	125 to 112	66.5	2.71	10	0	20	70
		Top Jurassic to Lower Cretaceous	145 to 125	63.0	2.70	7	25	28	40
Mauritania Basin	4A	Top acoustic basement to top Jurassic	170 to 145	69.3	2.71	0	0	10	90
		Base Cenozoic to present-day seafloor	65 to 0	58.5	2.68	43	10	15	32
		Top Cenomanian to base Cenozoic	93 to 65	59.5	2.69	32	16	22	30
		Top Albian to top Cenomanian	100 to 93	58.1	2.68	50	0	20	30
		Top Aptian to top Albian	112 to 100	59.5	2.68	45	50	0	5
		Top Lower Cretaceous to top Aptian	125 to 112	55.3	2.67	30	30	0	40
Guinean Plateau	4C	Top Jurassic to top Lower Cretaceous	145 to 125	69.3	2.71	0	0	10	90
		Base Cenozoic to present-day seafloor	65 to 0	64.0	2.71	10	0	50	40
		Top Cenomanian to base Cenozoic	93 to 65	62.0	2.72	5	0	90	5
		Top Albian to top Cenomanian	100 to 93	64.0	2.72	0	0	80	20
		Top Aptian to top Albian	112 to 100	55.0	2.68	55	5	35	5
		Top Lower Cretaceous to top Aptian	125 to 112	64.0	2.72	20	0	20	60
		Top Jurassic to Lower Cretaceous	145 to 125	63.0	2.70	7	25	28	40
		Top acoustic basement to top Jurassic	170 to 145	69.0	2.17	0	0	10	90