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## Compared structure and evolution of the conjugate Demerara and Guinea transform marginal plateaus

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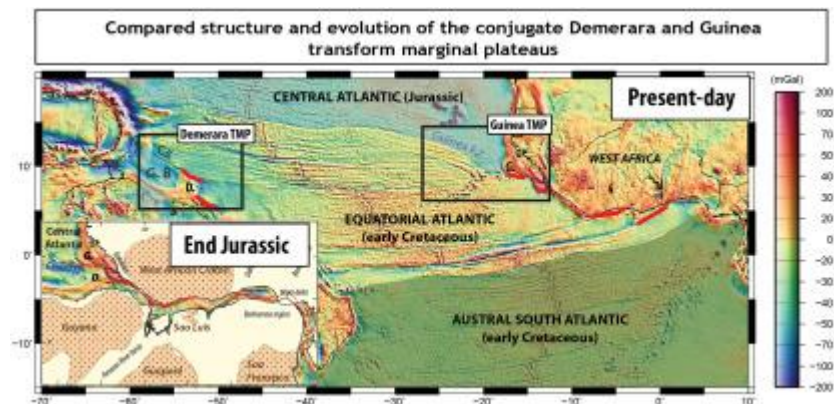
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### Abstract :

The Demerara and Guinea plateaus are conjugate Transform Marginal Plateaus (TMPs) formed at the junction of the Jurassic Central Atlantic Ocean and the Cretaceous Equatorial Atlantic Ocean. We compare their structure and evolution through a combined industrial/academic seismic dataset tied by well data. We show that these TMPs record a complete evolution history from the Jurassic Central Atlantic to the Equatorial Atlantic breakup and seafloor spreading phases. Both plateaus first formed as volcanic margins displaying successive SDR wedges migrating towards the newly forming Central Atlantic domain. In this context, Demerara and Guinea, conjugates of the Bahamas, seem to have formed in relation to plume activity at the southern end of the Central Atlantic domain. Our dataset suggests that the Demerara and Guinea plateaus initially represented two distinct extrusive centres separated by a crustal basement high. Later, during the Cretaceous Equatorial opening phase, both plateaus separated in a transform mode following this discontinuity. Deformation is notably asymmetric during this phase: Aptian to Albian folding, strike-slip, transtensive deformation and complex vertical movements on the Demerara side and only minor deformation on the Guinean side, except on its divergent Sierra Leone termination. The deformation is sealed on both plateaus by a regional upper Albian erosion unconformity. Extensional reactivation occurs on the Guinea side (probably through a general collapse?). To conclude, this study provides new insights into the nature and origin of TMPs and the key tectono-sedimentary archives they may contain to understand the polyphase breakup conditions of Gondwana.

## Graphical abstract



## Highlights

► We describe and compare the tectono-sedimentary evolution of the Demerara and Guinea conjugate TMPs. ► They first formed as Jurassic volcanic margins at the Central Atlantic southern end. ► They then separated in a transform mode during the Cretaceous Equatorial Atlantic opening. ► Therefore, they contain long-term tectono-sedimentary archives of the polyphase Gondwana breakup.

**Keywords :** Transform Marginal plateau, Passive margin, Volcanic margin, Atlantic, Demerara, Guinea

## Introduction

Transform Marginal Plateaus (TMPs) have been defined as planar submarine reliefs extending the continental shelf of transform margins (Mercier de Lépinay et al., 2016; Loncke et al., 2020). They have been identified on a third of the world's transform margins (Mercier de Lépinay et al., 2016; Loncke et al., 2020). Their mean water depth varies between 1200 to 3000 m and their areal extent can reach 300 000 to 570 000 km<sup>2</sup>. TMPs mostly form at the junction of oceanic basins of different ages (Mercier de Lépinay et al., 2016; Loncke et al., 2020), and many of them underwent heavy volcanism and magmatism, probably related to hotspot activity, in at least one of their evolution stages (e.g. Vøring, Walvis, Exmouth, Hatton-Rochat TMPs; Loncke et al., 2020). Mostly, their crust is continental, heavily intruded by magmatic and volcanic bodies. However, some plateaus appear to correspond to thick or thickened oceanic crust domains (15-20 km; see Mercier de Lépinay et al., 2016 and Loncke et al., 2020 for a more complete review).

TMPs clearly form in complex geodynamic nodes recording a long-term, polyphase history. They provide key information on tectonic conditions and paleogeographic evolution before and after the Gondwana breakup. However, sedimentary archives associated with their formation have been largely overlooked compared to those of other parts of continental margins, either because they were not defined in three dimensions and properly understood as they were believed to be oceanic plateaus, or because they are such vast domains that their complete and continuous exploration remained very challenging.

Some of these TMPs can be identified as conjugate margins, i.e. adjacent structural blocks before rifting and breakup. For example, the Demerara/Guinea TMPs formed at the

southern tip of the Jurassic Central Atlantic Ocean and later separated in a transform mode during the highly oblique Cretaceous Equatorial Atlantic gateway opening.

We propose in this paper to use a combination of industrial and academic seismic data to analyse and compare for the first time the evolution of two conjugate TMPs, the Demerara and Guinea TMPs. We focus our analysis on their polyphased tectonic and sedimentary evolution of these submarine reliefs and discuss their origin and formation as well as their importance for the understanding of the opening of the Central and Equatorial Atlantic domains.

## 1. Geological setting

The Demerara and Guinea conjugate TMPs formed through a two-stage breakup history (Figure 1). First, the western Demerara and Guinea margins formed during the Jurassic Central Atlantic opening (Figure 1B). Later, the Demerara and Guinea TMPs separated by a transform motion related to the highly oblique Cretaceous opening of the Equatorial Atlantic (Figure 1C) (Klitgord & Schouten, 1984; Benkhelil et al., 1995; Campan, 1995; Labails et al., 2010; Moulin et al., 2010; Reuber et al., 2016).

Many questions remain unanswered regarding the Jurassic ocean that developed west of Demerara. Only a very small fragment remains (the Guyana Basin), a consequence of the Antilles subduction (Figure 1). In their reconstructions, Pindell and Kennan (2009) propose that a major transform zone (the Guyana Transform) initially shifted the Guyana basin from the proto-Caribbean seaway. Later, kinematic plate reconstructions consider the appearance of a triple junction between the North American, South American and Northwest African plates at the transition from the Central Atlantic to the Equatorial Atlantic tectonic phases (Pindell & Kennan, 2009, Campan, 1995, Labails et al., 2010) (see kinematic reconstructions at 124 and 104 Ma in Figure 1). This triple junction allowed the connection between the Central Atlantic, a proto Caribbean domain already connected to the Central Atlantic at Jurassic times, and the newly opened Equatorial Atlantic gateway (Pindell & Kennan, 2009). It is suggested that this new Cretaceous oceanic basin split the initially continuous Jurassic Central Atlantic domain between the Guinea and Demerara plateaus (Pindell and Kennan, 2009). Pindell and Kennan (2009) propose that the Jurassic conjugate of the western Demerara and Guinea margins corresponds to the Blake-Bahamas margin (see kinematic reconstruction at 170 Ma in Figure 1).

The Equatorial Atlantic rifting and seafloor spreading phases are better documented: rifting occurred during the early Barremian to Aptian (Basile et al., 2005) in a highly oblique mode, connecting the laterally shifted Central Atlantic and South Atlantic oceanic domains (Figure 1). Demerara and Guinea initially drifted apart in a transform mode (dextral lateral motion) and the first oceanic crust is proposed to have formed during the late Aptian around 115 Ma ago (Basile et al., 2005). Later, at 105 Ma, a slight modification in the oceanic opening direction resulted in the oblique separation of Demerara and Guinea, explaining why, from that time onward, oceanic transform zones are slightly oblique to the Demerara and Guinea transform margins (Campan, 1995; Basile et al., 2013; Reuber et al., 2016) (Figure 1).

There is significantly more knowledge available on the geological history of the Demerara Plateau than for the Guinea Plateau, and more data from scientific and industrial cruises available for the Demerara Plateau.

### 1.1. Demerara

The Demerara Trench (TMP) forms a submarine relief off the French Guiana and Suriname continental shelves, and measures 230 km long by 170 km wide. It has been thoroughly investigated by seismic surveys and multibeam bathymetry (Gouyet, 1988; Loncke et al., 2009; Basile et al., 2013; Pattier et al., 2013 and 2015; Loncke et al., 2016; Sapin et al., 2016; Fanget et al., 2020; Figure 2A), wide angle seismics (Greenroyd et al., 2007, 2008 and Musser et al., 2021) and ODP drilling (Erbacher et al., 2004; Mosher et al., 2007). The Demerara TMP has three borders with the ocean (Figure 2, 1) its western border corresponds to a Jurassic divergent margin, (2) its northern border corresponds to a Cretaceous transform margin, and (3) its eastern border corresponds to a Cretaceous divergent margin (Gouyet, 1988; Basile et al., 2013; Sapin et al., 2016).

Gouyet, 1988 and Basile et al., 2013 described the Cretaceous deformation of the Demerara plateau, consisting of mainly compressional and wrench-related deformations peneplained by a regional and prominent unconformity, late Albian in age. Loncke et al., 2016 showed that deformation styles differ in relation to the second-order segmentation of the transform border, varying from pure strike-slip deformation to transtensional deformation. Sapin et al., 2016 focused on the eastern Demerara border and showed its deep structure - with a continent to ocean transition zone characterized by a few tilted blocks with thick fan-shaped Aptian to Mid-Albian syn-rift deposits and a narrow necking zone. In their interpretation, the breakup unconformity is proposed to be mid-Albian in age (~104 Ma) and correlates laterally with the major late Albian unconformity described by Gouyet, 1988, Erbacher et al., 2004 and Basile et al., 2013. This unconformity has been

drilled and was partly formed in a sub-aerial environment (Gouyet, 1988; Erbacher et al., 2004). Sapin et al., 2016 defined it as a wave-cut surface in the proximal domain. It is covered either by Upper Albian detrital sediments or Cenomanian black shales (Erbacher et al., 2004). Above the Albian unconformity, Late Cretaceous and Cenozoic sediments deposited conformably in a marine environment. In summary, post-Albian sediments form a thick prograding wedge, with a thickness of 4 km under the continental shelf, progressively thinning towards the northern outer edge of the Demerara Plateau. Different stages of sedimentation occurred in chronological succession: (1) in the Late Cretaceous, fine clastic and black shale deposition dominated sedimentation, (2) from the Paleocene to Miocene, sedimentation was dominated by carbonates with the development of an upslope carbonate platform and the deposition of chalk oozes at depth, and finally (3) the Plio-Pleistocene stage corresponds to the Amazon (and probably Maroni) flow onset and the associated increase in terrigenous input. Simultaneously, vigorous thermohaline currents caused the emplacement for contourites, particularly under the influence of the North Atlantic Deep Water in the outer Demerara domain (Tallobre et al., 2016, Fanget et al., 2020).

A first set of wide-angle experiments has authenticated the Demerara Plateau as continental crust which underwent limited thinning during the opening of the Central Atlantic and was later reworked orthogonally by the transform equatorial opening (Greenroyd et al., 2007 and 2008). Reuber et al., 2016 subsequently published deep-penetrating reflection seismic lines imaging very wide and thick Seaward Dipping Reflector (SDR) packages thickening towards the Jurassic Central Atlantic domain. A second set of higher resolution wide-angle and reflection seismic profiles confirmed this observation and shows a 30-km-thick crust underlying Demerara with velocities fitting those of a LIP (Large Igneous Province)-type crust (Museum et al., 2021). Reuber et al. (2016) and Museum et al. (2021) propose that the Demerara Plateau is part of an inherited Jurassic volcanic margin bordering the southern end of the Central Atlantic Ocean.

## 1.2. Guinea

The Guinea TMP is considerably less investigated (Figure 2B). It forms a triangular submarine relief off the Guinée-Bissau continental shelf, 120 km in width and 220 km in length. It has two borders with the ocean: (1) its western border corresponds to a divergent Jurassic margin related to the Central Atlantic opening, (2) its southern border corresponds to a Cretaceous transform margin related to the Equatorial Atlantic opening.

Based on the analysis of seismic data acquired in the eighties, Marinho et al. (1988) and Benkhelil et al. (1995) propose successive phases for the formation of the Guinea Plateau:

(1) an extensional Cretaceous phase expressed through numerous normal faults along the southern Guinean Plateau, (2) a volcanic phase during Aptian/Albian times along the divergent to transform southwestern corner of the plateau, (3) a short compressional event in the same area, and 4) Cenozoic volcanism responsible for the emplacement of numerous volcanoes immediately south of the plateau and along the transform border. Benkhelil et al. (1995) propose a schematic reconstruction of the relative location and tectonic evolution of the Demerara and Guinea TMPs by comparing their observations with those of Gouyet, 1988. Their reconstruction includes four stages: (1) in their Late Jurassic pre-rift reconstruction, Jurassic normal faults mainly faced the Central Atlantic Ocean domain along both plateaus; (2) later, in the Early Cretaceous (Hauterivian to Berriasian), the Equatorial rift developed following pre-existing pan-African lines of weakness and the Demerara and Guinea Plateaus began to slide relatively to one another in a dextral movement. During this phase, deformation was mainly transensional in Guinea and transpressional in northwest Demerara. The eastern Demerara margin and Sierra-Leone margin separated as rifted margins. Thereafter, (3) a short post-rift compressional event during the Late Albian is explained by block readjustments and the collision of north Demerara and southwest Guinea linked to a rotation pole shift (the ~105 Ma event described by Rabinowitz and Labrecque 1979; Campan, 1995; Basile et al., 2013; Reuber et al., 2016). The authors underline discrepancies in the timing of this compressional event off Demerara and Guinea. (4) From the Late Cretaceous to the Early Cenozoic, extension is again dominant - a general collapse of the margin prevailed in relation to the final continental separation between America and Africa. Along the southern Guinea Margin, widespread magmatism then occurred along or close to the ocean-continent boundary. More recently, based on recent 2D and 3D seismic datasets and drill-holes acquired on the southern Guinea Plateau and the Sierra Leone margin, Olyphant et al. (2017) show that volcanics and basalts are widespread along the transform to divergent corner off Guinea and Liberia. Their age is mainly Albian but Early Aptian basalts have also been drilled. These are emplaced mainly in relation to Aptian to Albian rifted tilted blocks. Olyphant et al. (2017) emphasize the asymmetry of rifting between Demerara and Guinea.

## 2. Data and Methods

This study uses a combination of industrial seismic datasets, made available by TOTAL SA and academic datasets, to describe seismic units and deformation along the Demerara and Guinea Plateaus. We mapped the main unconformities, sequence boundaries and regional reflectors/horizons. This allowed us to build isochron and isopach maps for the main horizons and unconformities - assuming simplified seismic velocities. Where possible, we



tied our observations to drill data. These seismic units were correlated between the Demerara and Guinea Plateaus.

### 2.1. Demerara data

For Demerara, the dataset consists of 2D industrial seismic reflection data from different surveys (Figure 2A) with heterogeneous quality and a line spacing varying from dense (2-5 km) to wider (10-15 km). The most recent surveys (2012) cover the surface of the Demerara Plateau almost entirely, with line spacings from 5 to 10 km, and their penetration reaches 9 s TWTT (Two Way Travel Time) enabling us to image structures beneath the Albian unconformity. In the centre and western side of the plateau, off Suriname, seismic data are of excellent quality but the recording was cut at 8 s TWTT. A few deep-penetrating ION lines were also available, enabling the plateau to be imaged down to 13 s TWTT.

This 2D industrial dataset was completed by two academic datasets: (1) the GUYAPLAC dataset (<https://doi.org/10.17600/3010050>), consisting of a wide grid of 2D lines with line spacing from 13 to 50 km which enabled us to image the French Guiana margin and the transition from the slope to the oceanic domain (orange lines in Figure 2A). The mean penetration of these seismic data is 4 to 5 s TWTT. (2) The IGUANES dataset (<https://doi.org/10.17600/13010030>), consisting of regional and high-resolution seismic lines, allowed us to image the transition from the Demerara Plateau to the oceanic domain offshore Suriname and French Guiana (blue lines in Figure 2A). Their penetration varies from 3 to 5 s TWTT.

All in all, the available seismic dataset for Demerara was dense enough to build reliable isodepth and isochore maps of the main seismic surfaces and units.

On the Demerara Plateau, data from several borehole logs were available (Figure 2A) but most did not reach the pre-Albian series (West-Tapir, Surinam, Maroni, Galibi, Acari, Caracara). DSDP leg 143/144 ends at the Cenomanian/Turonian boundary. Drill L10 is 1.5 km deep and reaches the Precambrian basement. North-Coronie and ODP 207 reached Aptian claystones but they could not be used for lateral calibration due to the poor quality of the seismic lines.

Conversely, the Sinnamary, FG2 and Demerara A2 drills were used to calibrate seismic data: (1) Sinnamary, located in the southeast of the Demerara Plateau, crosses through the post-Albian Cenomanian to the Upper Paleocene series, which are mainly composed of sands and claystones. This drill ends in gneiss and shales containing garnets, biotite, quartz and feldspaths. These rocks have not been dated but are interpreted as related to the

Guianese Precambrian Basement. (2) The FG-2 drill, located in the eastern Demerara Plateau crosses the post-Albian series composed of shales and intercalated carbonates and sands. This drill crosses the Albian unconformity and sandy series deposited in a continental or shallow marine environment. These sediments do not contain any microfossils or fossils and ages are proposed to vary from Aptian to Barremian. The drill ends in a series of Barremian basalts intercalated with sands (Gouyet, 1988). (3) Demerara A2 is located in the middle of the Demerara Plateau. It crosses post-Albian claystones and carbonate layers as well as the Albian unconformity and reaches claystones and carbonates deposited in a shallow water marine environment which were difficult to date. Two interpretations are favoured in the industry: the first interpretation dates claystones and carbonates down to the Berriasian. The second proposes an Aptian to Berriasian age for the claystones and Jurassic (Oxfordian) for the carbonates. In both cases, the drilled carbonates are related to a carbonate platform developed along the Central Atlantic Demerara margin from Jurassic to Neocomian.

## 2.2. Guinea data

The Guinea dataset is far less dense (Figure 2B). No drills have been performed on the plateau itself but two drills were obtained at the southern border of the plateau. The 2D seismic lines available for this study originate from different sources and are of contrasting quality: digitized old seismic lines in the south (blue box at the south Guinea Plateau) with a mean spacing of 5 km between lines. Along the main part of the plateau, nine seismic lines with 25 km spacing are available for interpretation (green box in Figure 2B). One line allows correlation with the SABU-1 drill hole; however, since it crosses a volcanic edifice reliable correlations between SABU-1 and lateral horizons are difficult to make. On the Guinea Plateau, the main reflectors and seismic units were defined and correlated from one line to another. Contrary to Demerara, the dataset was not dense enough to build isodepth and isochore maps.

Volcanic Albian series have also been drilled (Olyphant et al., 2017) in the SABU-1 well. Well GB-2B reaches the top of the Barremian and crosses Aptian clastics and volcanics where, the Albian series exclusively consist of basalts and are overlain by sandy Upper Cretaceous sediments corresponding to marine deltas.

## 3. Results

Figures 3 and 4 present regional synthetic cross-sections through the Demerara and Guinea plateaus derived from the interpretation of available seismic lines. Seven main seismic

units (A to G) are defined for Demerara. Each of these units is bounded by a major unconformity (labelled Uc). Wells only reached post-Albian unit G and pre-Albian units E and D; Unit F was not reached by drilling. The Uc8 unconformity corresponds to the late Albian unconformity.

For Guinea, similar seismic units can be defined (except unit F) by analogy with the seismic facies, internal arrangements and unconformities observed on the Demerara Plateau.

In the following paragraphs, the units (seismic facies, internal geometries, deformation) emplaced before and during the Jurassic Central Atlantic tectonic phase are described in relation to the regional cross-sections in Figures 3 and 4 and additional, more focused seismic sections and maps as needed. We then describe those emplaced during the Cretaceous Equatorial Atlantic phase.

3.1. Early deformation and sedimentation related to the Central Atlantic opening phase

3.1.1. Unit A

Unit A is the oldest seismic unit identified. It is only imaged in the very eastern part of the Demerara Plateau (Figure 3, regional cross-section B and extension of unit A in Figure 5C). This unit is bounded on its top by a major erosional unconformity, Uc1 (Figure 5B). In some cases, unit A and Uc1 have been strongly eroded by later events; for example, Figure 5A illustrates how unit A directly outcrops underneath the Uc8 erosive Albian unconformity.

Unit A has heterogeneous acoustic facies with chaotic and sometimes high-amplitude reflections (Figures 5A and 5b). The internal reflectors of unit A seem to be intensively deformed with evidence of east-dipping normal faulting rooting on planar basal *decollement* planes (see details in Figures 5A and 5B). Oblique high-amplitude reflections cross the main stratification (Figure 5B, oblique reflections underlined by dotted purple lines) and may be interpreted as volcanic or igneous intrusions.

Mostly, the internal reflectors of unit A tilt westwards. This tilt is interpreted to have occurred after the extensional phase responsible for the formation of the eastward oriented normal faults and *decollement* planes (Figure 5A). The Uc1 unconformity also tilts towards the NW (Figure 5C).

It is likely that the Sinnamary well that ended on the highly deformed Precambrian basement reached unit A, but the low quality of connecting seismic lines did not allow clear correlation.

### 3.1.2. Unit B

Unit B onlaps onto Uc1 and unit A. It is bounded at its top by a major angular unconformity, Uc4, which is locally clearly formed by erosional processes (Figures 3, 4, and 6). This unit shows high-amplitude and continuous reflectors dipping westward. It has a clear fan-shaped geometry with series thickening towards the west (Figures 3, 4 and 6). Based on deep-reflection seismic data and gravity inversion, Reuber et al. (2016) qualified these west-dipping reflectors as Seaward Dipping Reflectors (SDRs), interpreted as thick lava flows intercalated with sedimentary layers. In its thickest domain, unit B reaches up to 8 s TWTT (Two Way Travel Time) on Demerara (Figure 6) and at least 5 s TWTT on Guinea (Figure 4A). Considering the seismic velocities from recent wide-angle seismic experiments, which range between 4 and 5.5 km/s along the Demerara Plateau at those depths, unit B reaches between 6 and 22 km on Demerara (Museum et al., 2021).

In detail, three sub-units (B1 to B3) separated by unconformities (Uc2 to Uc4) were defined within unit B of Demerara (Figure 6). The seismic facies vary from one sub-unit to another: while B1 presents relatively rough acoustic facies, B2 is more bedded with some very high-amplitude reflectors. These high-amplitude reflectors are difficult to correlate laterally between the seismic lines. B3 presents a notably continuously bedded seismic facies. These sub-units also have a different lateral extension: sub-unit B1 is only clearly imaged in the eastern part of the plateau domain above unit A, whereas sub-unit B2 extends further westwards and seems to onlap on acoustic basement high to the west (lateral continuity of unit A? Igneous crustal intrusion? Fault contact?) (Figure 6D). Similarly, sub-unit B3 extends even further westward and also ends on a basement high (Figure 6D). To summarize, B1, B2 and B3 form successive seaward dipping fan-shaped bodies that progressively migrated westward.

On the Guinea Plateau, the base of unit B is not imaged due to poor seismic data penetration. Also, for Demerara, the dataset with 9 s TWTT maximal penetration did not allow mapping of the base of unit B. However, it was possible to calculate an isopach map of the shallowest sub-unit B3, at least for the eastern Demerara Plateau (Figure 6B). This isopach map (in s TWTT) clearly shows that B3 thickens towards the NW, namely in a seaward direction. Conversely, B3 thins towards the east, pinching out on B2 and B1 (Figure 6A and B). Interestingly, B3 also pinches out towards the NE, i.e. towards the future transform margin border (Figure 6B). The top of unit B, Uc4, is also clearly NW-dipping, towards the Central Atlantic Ocean. A few seismic lines enabled us to extend the interpretation towards the Central Atlantic Ocean domain (e.g. line A in Figure 3, Museum et al., 2021). The top of unit B, Uc4, correlates with the top of the oceanic basement

(Figure 3A) and is interpreted to correspond to the Central Atlantic breakup unconformity, probably Jurassic in age (not drilled).

Along the edge of the Guinea Plateau, Uc4 also correlates with the top of the postulated oceanic crust (Figure 4B).

Finally, unit B is sometimes clearly truncated by Uc4 (Figure 4A, 4C, 4D and Figure 6D, toplaps under Uc4 underlined by red arrows) suggesting a phase of aerial/shallow marine erosion after deposition. The domains where Uc4 is clearly erosive on the Demerara side are underlined in Figure 6C, in brown). Off Guinea, Uc4 is erosive on all available lines.

### 3.1.3. Units C and D

Unit C onlaps the postulated Central Atlantic breakup unconformity Uc4. This unit is only visible in the westernmost Demerara and northern Guinea plateau and thickens towards the Central Atlantic domain (Figures 3 and 4). Unit C is sealed by the Uc5 unconformity, which is a high-amplitude reflector (Figure 7) and shows internal bedding but displays rather rough acoustic facies. In contrast, unit D is characterized by high-amplitude and very continuous, clear reflectors (Figure 7A). The Uc6 unconformity forms the top of unit D. This unit has a much greater regional extension than unit C and is present almost along the entire Guinea and Demerara plateaus (Figures 3, 4 and 7C).

Unit C has not been drilled and sampled, so its nature remains unknown. It might correspond to the first post-breakup unit deposited on the Central Atlantic slope dipping towards the west. An isopach map of unit C could be calculated (Fig 7B) for Demerara. This isopach map provides evidence for a NW-SE oriented depression, probably structurally controlled.

Unit D is characterized by high-amplitude and continuous reflectors and two internal highs with small diffraction hyperbolae (Figure 7A). The top of this unit was sampled by the Demerara A2 drill (Figure 3). It consists of carbonates considered to be Jurassic/Neocomian in age. We therefore interpreted the very high-amplitude reflectors of unit D as constitutive of a carbonate platform and propose that the internal diffraction hyperbolae correspond to carbonate reefs (Figure 7A).

The isopach map of unit D of Demerara shows that this unit generally thickens from the SE Demerara Plateau towards the NW. This unit thins progressively and then vanishes towards the deepest areas of the Central Atlantic continental slope (illustrated in Figures 3B and 7A)

## 3.2. Second phase of deformation and sedimentation (Equatorial Atlantic opening phase)

### 3.2.1. Unit E

Unit E overlies U6 and unit D. Its seismic facies contrast with unit D, with lower-amplitude and less continuous reflectors. Unit E was drilled off Demerara (A2 drill and FG2, Figure 3). It consists of Barremian/Aptian claystones and sand alternations. The top of unit E is in most cases eroded as shown by the U8 Top Albian unconformity, sometimes by a younger U7 undated angular unconformity. Because of its strong erosion, the initial thickness of unit E cannot be properly estimated over its complete extent. However, unit E is very well preserved on the western slope of the Demerara Plateau (Figure 3A and Figure 8A, B, C) and the western slope of the Guinea Plateau (Figure 4B), where it forms a thick depocenter involved in gravity tectonics.

On the rest of the Demerara Plateau, the thickness of preserved unit E is highly dependent on the later deformation and erosion phases recorded by U7 and U8 unconformities. Most lines evidence a north-eastward thickening of unit E in the central plateau domain (Fig 3C and Fig 8C). This is particularly clear in Figure 8E, where unit E displays a fan-shaped structure with a clear thickening towards the future transform boundary. This suggests strong subsidence of the NE Demerara border at the time of unit E deposition. Off Guinea, these patterns of thickening towards the future transform boundary are less clear but unit E is relatively thick and well preserved towards the southern Guinea transform border (Figures 4C and D).

### Syn-E deformations

#### Demerara

On Demerara, unit E is characterized by a highly variable thickness and records crustal-scale and gravity-driven deformations (Figures 8, 9, 10):

- In west Demerara, gravity-driven deformation of this unit is particularly spectacular, with (1) an upslope extensional domain with numerous growth faults that root on U6 or on a seismic transparent/chaotic mobile layer (Figures 8A and 8C) above (2) a downslope compressional domain with numerous imbricated thrusts (Fig 8B). The shape and spatial distribution of these extensional and compressional gravity-driven provinces could be accurately mapped (Fig 8C).
- In the central and north Demerara Plateau, unit E and older units are involved in two types of deep-seated tectonic structures: (1) folds and thrusts (Figure 8C

and Figures 10 A, B, C, D), and (2) strike-slip faults inferred from abrupt seismic unit lateral facies or thickness changes (Figure 10 A, B, C). These strike-slip faults are either transpressional (positive flower structures in Figures 10A, B, C) and/or reactivated/related to normal faults (Figure 10D). Units B, C and D deformed after their deposition (no thickness variations of these units in relation to tectonic features, see Figure 10). Contrastingly, unit E shows thickness variations in relation to these tectonic features, evidencing its syn-tectonic deposition: for example, unit E thins towards the summit of folds as shown in Figures 8E, 10A and 10C. These folds and strike-slip faults heavily deform unit D, and the depth map of Uc6 (Top of unit D, Figure 11A) displays two main fold directions: WNW-ESE and NNW-SSE.

- In the eastern plateau, unit E (and possibly F) is involved in deep-seated extensional tectonics: unit E forms clear fan-shaped deposits in relation to tilted blocks (Figure 9). The corresponding normal faults have also been mapped (Figure 11D). These fan-shaped geometries are sealed by the Uc8 unconformity that laterally passes to the top of the oceanic crust and clearly corresponds to the Cretaceous Equatorial Atlantic breakup unconformity.

#### Guinea

On the Guinea Plateau, unit E has different characteristics: it is intensively faulted by a dense network of multidirectional low-offset normal faults interpreted as compactional polygonal faults (Figure 4C). It does not show any syn-sedimentary compressional deformation. In the southwestern part of the Guinea Plateau it is involved in gravity-driven deformation, with a basal *decollement* localized on top of unit D (Figure 4B).

In the southwesternmost corner of the plateau, following the transform boundary of the plateau, unit E is (1) involved in a few large folds (Figure 4C), (2) shifted laterally by two major normal or transtensional faults (Figure 4C). The deformation seems to post-date the deposition of unit E and has been mapped in a schematic tectonic map in Figure 11E.

#### 3.2.2. Unit F

In some areas of the Demerara Plateau, unit E is strongly eroded by the Uc7 unconformity and unit F then deposited above it. Unit F is eroded as shown by the late Albian Uc8 unconformity. Therefore, unit F, is not accurately dated by drilling but as it is comprised between E and Uc8, it may be Aptian to Lower/mid Albian in age. The spatial extension of unit F is shown in Figure 11C (in yellow) and 12C (isopach map). Unit F is characterized by parallel bedded low-amplitude reflectors conformably deposited on Uc7 (Figure 12). In the central part of the plateau, it forms a lens-shaped basin preserved between Uc7 and Uc8

unconformities, with a maximum thickness of 0.9 s TWTT (Figure 12A). In the northern Demerara Plateau, Uc7 is tilted towards the transform border and unit F is thicker, reaching more than 1.2 s TWTT in thickness (Figure 12B and 13). It is affected by northward-dipping normal faults (Figure 12B) and was emplaced in a transtensional margin segment defined by Loncke et al., 2016 (Segment B in Figure 13). Lateral correlations of E and F towards the eastern Demerara divergent segment were complex due to data spacing and heterogeneity and there is some ambiguity between E and F in this domain. We suspect that unit F is present in this domain, conformably lying above E (Figure 9). On the Guinea Plateau, unit F was not identified but it could be present further south, along the Sierra-Leone divergent segment. Olyphant et al. (2017) describe thick fan-shaped syn-rift deposits of Aptian to late Albian in age that could be partly the same age as F (see discussion).

### 3.2.3. Uc8 late Albian unconformity

All deformed units are eroded and sealed on the Demerara and Guinea plateaus by a major planar erosion unconformity, Uc8, which is late Albian in age. This erosion surface is planar shaped and has therefore been considered as a suberial wave-cut surface (Basile et al., 2013; Sapin et al., 2016). Due to the seismic grid density, this unconformity could only be mapped entirely on the Demerara Plateau (Figure 11B). Its actual depth varies over most of the plateau between 3.5 and 2.5 s TWTT (Figure 11B). It reaches a maximum depth towards the northern Demerara transform border (5 s TWTT) probably due to late post-rift subsidence at the continent-ocean transition.

Under this unconformity, recent Barremian to Late Albian units E and F crop out along most of the plateau (Figure 11C). Approaching the northern Demerara plateau, older Jurassic to B3 units also crop out, mostly at the top of major eroded folds. On the eastern Demerara border, units A and B2 directly crop out under the unconformity (Figure 11C).

### 3.2.4. Acoustic Ridges at the transform continent-ocean transition

The seismic profiles imaging the Demerara transform border and the Continent-Ocean Transition (COT) are of academic origin (IGUANES cruise, Loncke et al., 2016). These profiles have lower penetration than industrial profiles. We nevertheless tried to compile all available information on a set of industrial/academic profiles (Figure 13). The transform border transition domain of this compilation is divided into different segments following observations by Loncke et al., 2016: (1) along the NW Demerara Border, Segment "A" shows a narrow transition from the plateau to the ocean. This segment was



interpreted as a purely transform segment by Loncke et al., 2016. (2) Further east, the transform continent-ocean transition zone becomes broader with a series of tilted normal fault blocks. Segment “B” was interpreted as a transtensional oblique segment by Loncke et al., 2016. Due to poor seismic penetration and the presence of major strike-slip faults, the possible lateral continuity of units B, D and E could not be proven. In contrast, F is clearly mapped in this domain. The tilted blocks are filled with fan-shaped and deformed sediments that also could not be dated relatively (unit E or F?). (3) Finally, along the SE segment of the Demerara transform border, Segment “C” trends more parallel to transform directions. It is characterized by acoustic ridges (Figure 13, in light red). These ridges have been mapped by Basile et al., 2013 and show an en echelon pattern in map view (Figure 11). Again, the timing of formation of these ridges relative to units A, B, C, D and E could not be clarified due to poor acoustic penetration and chaotic seismic facies. The flank of one of these ridges was dredged allowing the recovery of 173.4 Myr old magmatic rocks (Figure 13, composite line 5, black stars) (Dredges C1 and C2 in Basile et al., 2020).

#### 4. Interpretation and discussion

##### 4.1. Tectono-Sedimentary synthesis

Our analysis enables us, for the first time, to propose a complete tectono-sedimentary evolution of the Demerara and Guinea TMPs from the Jurassic Central Atlantic opening phase to the Cretaceous Equatorial Atlantic opening phase. The density of data is far greater for Demerara than for Guinea. Therefore, we will first summarize the main results obtained for Demerara and then extend the discussion to the Guinea Plateau.

We were able to build two Wheeler diagrams for Demerara: one along an E-W section across Demerara, illustrating the chronology of events along the Western Central Atlantic Demerara margin and the Eastern Demerara Equatorial Atlantic divergent margin (Figure 14); the other across a S-N section summarizing the chronology of events along the North Demerara Equatorial Atlantic transform margin (Figure 15).

**Unit A** is interpreted as a continental basement unit, probably a direct extension of the Guianese craton. It formed before the opening of the Central Atlantic and is only preserved in the easternmost part of the Demerara TMP (Figures 5 and 14). It underwent an extensional phase that could not be correlated clearly to any regional tectonic phase (old Paleozoic or Proterozoic basin? Or more recent, related to the first stages of the Central Atlantic breakup phase?) (Figure 5A). Unit A also displays high-amplitude reflectors that may correspond to Jurassic magmatic dykes and intrusions (Figure 5B and 5C). Unit A,

based on its seismic velocity (an upper layer with  $V_p=6.4$  to  $6.7$  km/s, underlain by a high-velocity lower crust with velocities varying from  $7.2$  to  $7.4$  km/s) and internal structure, is proposed by Museur et al. (2021) to correspond to the Guiana shield crust injected by volcanic intrusions that are probably Jurassic in age.

Unit A is eroded by a major, probably subaerial, unconformity (Uc1), suggesting an emerged continental crust before unit B emplacement (Figures 5 and 14).

**Unit B** is extremely thick, reaching a maximum of  $22$  km thickness using published wide-angle seismic velocities (Museur et al., 2021) (Figures 6, 13, 14). In detail, unit B can be divided into sub-units whose respective limits migrate westwards through time. It onlaps a basement high that is an acoustically poorly penetrated ridge in the northern Demerara plateau (Figure 15). Based on a deep-penetrating line, Reuber et al. (2016) interpret this basement high as a sliver of continental crust (unit A?). Along the western plateau, unit B seems to downlap on an acoustic basement body that could not be characterized by our dataset but which has been qualified as “igneous crust” by Reuber et al. (2016) and a “middle crustal unit” by Museur et al. (2021). This contact can be interpreted in different ways: 1) sedimentary downlap? 2) detachment fault contact? 3) contact between intruded crust and SDRs? (Figure 14). As already underlined by Reuber et al. (2016) and Museur et al. (2021), unit B shows all the characteristics of volcanically formed Seaward Dipping Reflectors (SDRs) with at least three successive SDR wedges and might be related to the Central Atlantic opening (Figure 14). We favour this hypothesis - which is also sustained by the fact that the top of unit B, Uc4, correlates with the top of the Central Atlantic Oceanic crust (Figure 3A). Therefore, we follow the hypotheses of Reuber et al. (2016), Museur et al. (2021) and Basile et al. (2020) and interpret the western Demerara Plateau as a Jurassic volcanic margin (Figure 14) related, depending on the authors, to the “Bahamas hotspot” (Reuber et al., 2016) or the “Sierra Leone hotspot” (Basile et al., 2020).

Unit B is overlain by **unit C**, only present in the western part of the Demerara Plateau, which seems to have subsided mainly after the emplacement of unit B (Figures 7 and 14). Unit C onlaps unit B in a domain that probably corresponds to a first sediment deposition on the newly formed Central Atlantic continental slope. This unit has never been drilled but is interpreted as of marine origin (Figure 14).

The top of unit D has been drilled and is interpreted to relate to Oxfordian Jurassic carbonates forming a platform marked by at least two reefs. We interpret this unit as formed on the Central Atlantic paleo-shelf and slope domains.

**Unit E** was then deposited along the complete Demerara Plateau in a marine environment. It consists of Barremian/Aptian claystones and sand alternations deposited in shallow environments close to the Guiana craton (Figure 15) and deeper marine environments along the Western Demerara Central Atlantic margin (Figure 14). This unit recorded both gravity-driven and crustal deformations: on the western Demerara slope, unit E is involved in a large-scale gravity-driven slide (Figure 8). On the eastern Demerara Plateau, unit E (and probably later on unit F) shows fan-shaped geometries in relation to rifted blocks associated with the Cretaceous opening of the Equatorial Atlantic domain (Figures 9 and 14). On the northern Demerara Plateau, unit E is involved in compressional and strike-slip tectonics (Figures 10 and 15). The thickness variations of unit E in synclines indicate its syn-tectonic deposition (Figure 10). However, the relative chronology of compressional and strike-slip deformation could not be clarified with the available dataset.

The top of unit E is eroded as shown by two unconformities, respectively Uc7 and Uc8 (Figures 10, 12, 14 and 15). Uc8 was interpreted to record the complete emersion and peneplanation of the plateau at sea level (Sapin et al., 2016). The age of Uc8 is relatively well constrained to be Late Albian (Gouyet, 1988; Erbacher et al., 2004). Uc7 had not been defined before this study and formed sometime during the Aptian to Late Albian.

Uc7 corresponds to a conformable surface (no emersion) imaged along most of the western and central plateau (Figures 14 and 15), but it is a clear and prominent erosion surface (emersion) along the northern Demerara Plateau (Figure 15) and in some places of the central plateau (Figures 12A and 14). On the northern Demerara Plateau, **unit F**, trapped between Uc7 and Uc8, can be very thick towards the Equatorial Atlantic domain (Figure 12C) and affected by numerous northward-dipping gravitational normal faults (Figure 12B).

The E, Uc7, F and Uc8 succession reveals complex vertical movements of the Demerara Plateau between Barremian and Late Albian times. The deposition of the sediments of unit E implies a subsidence of the plateau, coeval with compressional and strike-slip tectonics as shown by lateral thickness changes of unit E close to the tectonic structures (Figure 10).

The presence of Uc7, when it corresponds to an erosion surface, implies that at least some parts of the plateau emerged after deposition of unit E. The part of the plateau that has undergone the largest erosion by Uc7 is the northern transform border (Figure 15), implying an important uplift of this part of the plateau after unit E deposition. This part of the plateau is also the one where unit F is the thickest (Figure 12C), implying fast subsidence of the transform margin after the Uc7 erosional phase. This fast subsidence is also recorded by normal gravity faulting towards the Equatorial Atlantic within unit F.

Subsequently, unit F was eroded by Uc8, meaning a second phase of uplift and then emersion.

Finally, the entire plateau is eroded by Uc8 (Figures 11C, 14, 15), which is probably related to a major emersion phase. After Uc8, sediments deposited conformably and no further deformation other than gravity-driven slides are observed. A first simple hypothesis is to relate this Uc8 unconformity to the equatorial breakup unconformity that seals deformation related to the transform-dominated opening of this oceanic domain. However, this does not explain the lateral extent of this unconformity, not only affecting the equatorial margins but of the entire plateau, including its Central Atlantic side. The clear understanding of the mechanism of this regional uplift of the Demerara Plateau, which might be tectonic as well as thermal, will need additional investigation. Basile et al. (2020) propose that it may result from a thermal pulse related to the Sierra Leone hotspot.

, Analysis of the **Guinea Plateau** is less accurate than for the Demerara Plateau, but most units could be defined by analogy, except for units E and F. In turn, unit B is present and shows a clear fan-shaped geometry with Seaward Dipping Reflector sequences dipping westward (Figure 4A). It is eroded by the Uc4 unconformity that correlates with the top of the oceanic crust (Figure 4B). Even if the seismic images are highly similar, we have no proof of the exact synchronicity between the Guinea and Demerara B unit.

Therefore, we consider the western Guinea margin as a Jurassic volcanic margin in the lateral continuity of Demerara. Above unit B, units C and D have also been defined with seismic facies similar to those in Demerara. As for Demerara, unit C is thicker towards the Western Central Atlantic margin than towards the equatorial domain and was probably deposited on the Jurassic margin's paleo-slope. Unit D displays very continuous and high-amplitude packages interpreted to be a carbonate platform. Unit E's geometry is quite different to that of Demerara, appearing heavily deformed by polygonal compactional faults off Guinea (Figure 4B, 4C); its syn-compressional deposition is not documented, unlike that of Demerara. Unit F also could not be recognized on Guinea and unit E is directly eroded by the major regional Uc8 unconformity, interpreted as related to subaerial erosion. Normal faults and a large syncline seem to have developed after the formation of Uc8 (Figure 4C) along the SW transform corner of Guinea.

#### 4.2. Demerara/Guinea paleogeography before the Equatorial Atlantic opening

Our analysis provides new insights into the paleogeographical evolution of the Demerara and Guinea plateaus before their separation. Figure 16 presents schematic

paleogeographic reconstitutions during the deposition/emplacement of units B, C, D and E with the relative positions of Demerara and Guinea from Moulin et al. (2010).

**Unit B** forms thick SDR packages dipping towards the Central Atlantic domain. This unit is present on both plateaus (Figure 16-1, apparent dip directions indicated by black symbols). Unit B is sealed by the Uc4 unconformity, which is clearly erosive along the entire Guinea Plateau and in the southeast and central parts of the Demerara Plateau (Figure 16-1, domains where Uc4 expresses as an erosion surface underlined in pink hatching). We interpreted these eroded domains as indicators of subaerial emersion. Numerous internal erosion surfaces within B (for example, limiting sub-units B1, B2 and B3) argue for regular emersion/erosion phases alternating with deposition or lava flow effusion phases (shallow marine environments or continental flood basalts?). Sub-units B1, B2 and B3 onlap unit A in the eastern Demerara Plateau. We therefore interpret this “unit A eastern core” as a remnant of a paleo-proterozoic continental basement on which the first syn-rift volcanic flows emplaced. Sub-units B1, B2 and B3 probably represent successive SDR wedges thickening westwards progressively opening the Central Atlantic domain. Towards the NE and NW Demerara, unit A could not be identified and only sub-unit B3 could be mapped with confidence (Figure 6B), overlaying deeper units that could not be clearly identified (B2? B1? Acoustic ridges? Figure 13). Nevertheless, sub-unit B3 clearly pinches out along the north Demerara border (Figure 6B), suggesting that a basement high limited north Demerara and Guinea at that time. A very deep-penetrating seismic line crossing the north Demerara Plateau, published by Reuber et al., 2016 (Figure 4b in Reuber et al., 2016) soundly supports this interpretation: on this line, three successive SDR wedges (sub-unit B1, B2 and B3?) pinch out towards north Demerara on a high standing seismic unit interpreted as a continental crust basement. We therefore propose for the paleogeographic reconstruction in Figure 16-1 that unit B initially pinched out between Demerara and Guinea. In other words, we suggest an initial disconnection between the Demerara and Guinea effusives separated by a basement high (inherited continental fabric?). We used the B3 pinch-out to trace this limit in map view. This limit parallels the Jurassic Fault Zones and the future Cretaceous Jurassic Limit (CJL) and Guinea FZ (Figure 16-1).

**Unit C** records the first post-rift subsidence phase (blue arrows, figure 16-2). Two localized depocenters record localized subsidence domains on Demerara and Guinea (pink arrows, Figure 16-2). The NW-SE orientation of the deepest part of the unit C depocenter at Demerara may relate to a local second-order transform segmentation of the volcanic margin. A fracture zone is indeed visible on the ocean crust in the extension of this

depocenter (Mercier de Lépinay, 2016). From that stage, sediments are interpreted to have been deposited in a marine environment.

**Unit D** then deposited uniformly on most of the Demerara and Guinea margins during the upper Jurassic and possibly Berriasian and Barremian. This unit has been drilled and corresponds to a carbonate neritic platform on the Demerara/Guinea continental shelves and probably to marls on the Jurassic margin paleo-slope (Figure 16-3). This unit onlaps the proximal South American/African cratons.

The last reconstitution in Figure 16-4 concerns **unit E**. Unit E has been drilled and mainly consists of Barremian to Aptian sandstones and claystones in the plateau domain. Its thickness could not be mapped completely as it was highly eroded under the Late Albian Uc8 unconformity (Figures 8C, 10 and 11D). On several seismic lines, despite the fact it is highly eroded, unit E shows fan-shaped geometries with a general thickening towards northern Demerara (Figures 8C, 10C, 10D and 12B). This has been translated on the paleogeographic reconstruction in Figure 16-4 by a N-W-E oriented depocenter between Demerara and Guinea. This depocenter was emplaced in the extension of the CJL and Guinea FZ, probably recording the first phases of opening and subsidence of the Equatorial Atlantic domain. In turn, unit E is well-preserved in the gravity-driven mobile belts along the Jurassic margin slopes (Figures 8A, 16-4). It is also well-preserved along the future eastern Demerara and Sierra Leone divergent margins together with rotated and tilted blocks recording the first rifting phases between America and Africa, south of Demerara and Guinea (Figure 9, Figure 16-4). Barremian volcanism is mentioned off Demerara, just before the Aptian (Gouyet, 1983), probably signing the first phases of rifting between Demerara and Guinea (in purple in Figure 16-4). Aptian volcanism is also mentioned in several drills related to Guinea and Sierra Leone (Olyphant et al., 2017). This phase of rifting would result in the first marine connection between the Equatorial domain and the Central Atlantic (Soares et al., 2011).

#### 4.3. Equatorial Atlantic opening phase

At Demerara, the Equatorial Atlantic opening phase *sensu largo* probably began during the Barremian, coeval with the deposition of unit E and the first basaltic activity. The deformation related to this opening phase spans the deposition of Unit E (Barremian to Aptian in age), highly syn-tectonically deformed, and the late Albian unconformity sealing all deformations, thus during a period that lasted less than 30 Myrs. During this time-lapse, at least two different units formed: Units E and F sealed by two major unconformities Uc7 and Uc8. Unit F and Uc7 could not be dated directly but are interpreted as latest Aptian to late Albian in age. Between the deposition of Unit E and the formation of Uc8, several

compressional, strike-slip and extensional structures were formed at Demerara (Figure 11D) and could not be clearly dated relatively. Demerara also underwent successive uplift and subsidence phases, recorded respectively by erosion unconformities (Uc7 and Uc8) and the deposition of sedimentary Units E and F.

For the Guinea Plateau, the main deformational phases seem to postdate Uc8: they consist mainly of normal faulting and large wavelength folds (Figures 4C and 11E). The relative dating of these events could not be achieved with our dataset. They may correspond to late gravitational readjustments along the steep transform margin. Further south, along the Sierra Leone divergent segment, the conjugate of the eastern Demerara plateau, extensional syn-rift deformation clearly spans from the Aptian (the rift onset unconformity is Aptian) to the Late Albian (fan-shaped syn-rift deposits) and are associated with small but numerous Aptian and Albian volcanic bodies (Olyphant et al., 2017).

The complexity and asymmetry of the deformation and vertical movements of Demerara and Guinea prevent us from proposing a simple tectonic model for Demerara/Guinea during the Equatorial Atlantic opening phase. In addition, the detailed kinematic evolution between the Aptian and Late Albian is poorly constrained (no magnetic inversions exist during this period of the Cretaceous), thus making kinematic models relatively inaccurate for this key period (Campan, 1995; Klitgord and Schouten, 1984; Moulin et al., 2010).

However, we propose a tentative schematic tectonic evolution model for the Equatorial Atlantic domain based on our observations and the kinematic model of Campan, 1995 (Figure 17). In this model, we propose:

- (1) An early Aptian active transform deformational phase coeval with the deposition of Unit E (Figure 17-1). During this phase, folding and strike-slip deformation occur near the future Demerara transform margin with deformation intensifying when approaching the transform axis. At the same time, no folds or clear strike-slip faults have been observed on the Guinea Plateau. Most folds are parallel to the future transform margin on Demerara. (Figure 17-1). The origin and exact timing of these folds remains highly questionable: do they record a collision phase between the two plateaus related to complex kinematic rearrangements during the first phases of opening? We did not identify any oblique disposition of the folds, unlike the acoustic ridges, which are arranged en echelon in the very eastern part of the transform continent-ocean transition zone (Figure 13, Segment C and Figure 17-1). The contact of these ridges with units A to E is not well-imaged and their nature is debatable: they could represent transpressive en echelon ridges of

reworked basement or en echelon volcanic ridges (Basile et al., 2013, in red in Figure 17-1). Two dredges sampled one of the ridges, indicating that it consists, at least in part, of 173.4-Ma-old magmatic rocks (Figure 13, black stars). Based on geochemistry results and kinematic reconstructions, Basile et al. (2020) propose that these rocks relate to Jurassic hotspot activity. It is therefore possible that these ridges represent fragments of an old cratonic basement (unit A?) deeply intruded by Jurassic volcanics and later reworked during the transform motion between Demerara and Guinea.

Simultaneously, the future equatorial divergent margins probably begin to undergo the first extensional deformation and volcanism. Volcanic rocks have been drilled in three places in Demerara and off Sierra Leone (Barremian age off Demerara, Aptian to Albian ages off Guinea with Aptian basalts, and later Albian volcanic clastics were drilled and trachytes were dated to 106 Ma, Olyphant et al., 2017) (Figure 17-1). On north Demerara and Guinea, major gravitational deformation also occurred on the continental slope that faces the Central Atlantic domain (“western mobile belt” in Figure 17-1).

- (2) A second phase marked by the development of the Uc7 unconformity records a major erosional phase along the northern Demerara transform border. We interpret this as being related to an uplift of the transform border during the active transform separation of Demerara and Guinea (Figure 17-2). This uplift could be explained by two different processes: i) uplift due to compressional and transpressional tectonics approaching the transform border, and ii) flexural uplift of the plateau after definitive separation and lithospheric decoupling between Demerara and Guinea as observed in other transform margins (Basile and Alleman, 2002). In this case, Uc7 may be coeval with the first transform valley emplacement between Demerara and Guinea (Figure 17-2). This unconformity has not been observed on the Guinea plateau; however, asymmetry is possible or it may have been eroded by Uc8.
- (3) A third evolutionary phase during the active transform margin stage is marked by the deposition of unit F (Figure 17-3). It was deposited in the central part of the Demerara Plateau and along the northern Demerara transform border. There, it is very thick and involved in gravity tectonics towards the NE (Figure 12B), likely induced by the subsidence of the central part of northern Demerara, probably related to a more transtensional local regime (Segment “B” in Figure 13) and to the definitive onset of an oceanic bathymetric corridor between the two plateaus (Figure 16-3). We suspect that unit F also forms part of the fan-shaped syn-rift deposits in the eastern Demerara divergent segment



- (Figure 9). Indeed, along its Sierra Leone conjugate, these fan-shaped syn-rift bodies could be dated and are mostly Albian in age (Olyphant et al., 2017).
- (4) A fourth phase relates to the erosion of the greater part of the Demerara and Guinea plateaus by Uc8 (Figure 17-3). On Demerara, this unconformity seals all deformations. The exact meaning of this unconformity is difficult to interpret: it consists of a regional planar surface that affects almost the entire Demerara and Guinea plateaus. It could be interpreted as a breakup unconformity associated with the end of active transform deformation and the definitive separation of Demerara and Guinea (Gouyet, 1988; Mosher et al., 2004). Its planar shape and regional extension are nevertheless difficult to explain by this sole process. An alternative is to propose a thermal uplift of Demerara and Guinea at the end of active transform deformation. There are, however, no direct indications for a volcanic/heating pulse at this stage. Basile et al. (2020), using the kinematic reconstructions of Müller et al. (2016) and the hypothesis of a hotspot under Demerara at 173.4 Ma, propose that the same hotspot (Sierra Leone hotspot) formed the Demerara/Guinea plateaus in Jurassic times and the Ceara and Sierra Leone rises during the late Cretaceous/Early Paleogene. Between these major magmatic pulses, the volcanic track associated with this hotspot is less clear. In the kinematic reconstructions of the Sierra Leone hotspot proposed by Basile et al. (2020), Demerara and then Guinea are close to this postulated hotspot between 120 and 100 Myrs.
- (5) Finally, at 106 Ma a kinematic rearrangement (Campan, 1995) leads to the oblique opening and creation of the Equatorial Atlantic seafloor (Figure 17-5). Demerara and Guinea completely separate. Off Guinea, the main deformational phase seems to post-date Uc8 and could have occurred after this kinematic rearrangement. It consists mainly of normal faulting possibly related to the collapse of the transform equatorial margin during oblique opening (Figure 11E and 17-5). The long wavelength folds observed in relation to these normal faults (Figure 4C) may also relate to later kinematic reorientations along the Guinea FZ mechanism already suggested by Tricart et al., 1991.

All in all, the tectonic evolution of the Demerara/Guinea transform borders is extremely complex during the Equatorial opening phase. This could be due to complex kinematic rearrangements that could not be constrained (magnetic quiet zones in the Early Cretaceous between the Aptian and Santonian), to an asymmetric distribution of

deformation during the last separation phase of both plateaus or to later volcanic events that hide former deformation, especially on the Guinean side.

## Conclusions

This study enables us for the first time to describe and compare the tectono-sedimentary evolution of two conjugate TMPs in the Atlantic. The Demerara and Guinea TMPs originated from a twofold history expressed in regional cross sections of Demerara and Guinea through two breakup unconformities:

- (1) In a first Jurassic phase, the Demerara and Guinea plateaus formed as volcanic margins at the southern tip of the Central Atlantic Ocean. Both plateaus are characterized by thick SDR wedges dipping and migrating westward. These SDR wedges pinch out against crustal basement highs visible in southeast and north Demerara. To the north particularly, a NW-SE basement high seems to separate the Demerara and Guinea volcanic systems. The Demerara and Guinea volcanic margins have been associated by Reuber et al. (2016) and Basile et al. (2020) with hotspot activity.
- (2) In a second phase, at least 60 Myrs later, related to the highly oblique Cretaceous Equatorial Atlantic opening, the Demerara and Guinea plateaus separated in a transform mode and thereby became TMPs. The right-lateral separation between both plateaus seems to have followed the NW-SE crustal/lithospheric discontinuity that already influenced magmatic segmentation between Demerara and Guinea during the initial Jurassic volcanic stage. In detail, deformation related to the Cretaceous opening is complex and highly asymmetric between Demerara and Guinea. It is poorly constrained by kinematic reconstructions due to the magnetic quiet period between the Aptian and Santonian. On the northern edge of Demerara, compressive and strike-slip deformation was distributed over a deformational belt more than 100 km wide. The intensity of strike-slip and compressional deformation increases toward the transform border. Normal faults and collapse structures also formed along this border, probably during a later stage when the transform valley deepened and the first oceanic crust was accreted. Successive phases of subsidence and uplift of this transform border are recorded by erosion unconformities and the deposition of sediments towards the newly created equatorial fracture zone valley and ocean floor basin. Off Guinea, only normal faults and long wavelength folds or flexures affect series towards the transform border; they

could have initiated before the late Albian but were clearly reactivated later. A moderate amount of volcanism may have accompanied this second phase, as attested by basalts drilled on Demerara and Guinea. Most deformations are sealed by a major subaerial late Albian unconformity of regional extension. As suggested by its regional extension, well beyond the limits of the transform deformational belts mapped between Demerara and Guinea, this unconformity probably does not only represent a breakup unconformity but may also relate to a thermal or kinematic event contemporaneous with the final separation of both plateaus.

To conclude, this work enables us for the first time to compare two conjugate TMPs formed during the polyphase Gondwana breakup. Our findings show that the Demerara and Guinea TMPs correspond to the remnants of a Jurassic volcanic margin later reworked in a transform mode. We propose, on the basis of our regional seismic interpretation, that the Demerara and Guinea extrusive systems were initially separated by an inherited crustal high, maybe corresponding to a crustal to lithospheric inherited boundary, later localizing the Cretaceous transform.

Finally, we underline that the Demerara and Guinea TMPs formed at the southern terminus of the Central Atlantic domain, close to the Guyana transform connecting to the proto-Caribbean, in a rift barrier configuration. It is possible, as modelled and proposed for other natural cases (including the Sao Paulo/Walvis TMPs), that enhanced mantle melts were induced by this specific rift end configuration (Koopman et al., 2014) and that later, during the Cretaceous, they forced the localization of the transform boundary. To better understand the relations between mantle plumes (active or passive?), volcanic margins, lithospheric transfer zones, breakup propagation and rift barriers in the area, establishing the relative age of Demerara/Guinea/Blake/Bahamas SDR wedges and associated first oceanic crusts should be an important step.

In short, this work may provide first insights into the common mechanisms of the formation of TMPs: (1) enhanced magmatism producing intermediate heavily intruded crust, not typically continental, but also not typically oceanic and rather close to LIP crust. These types of crust seem to form at the terminus of opening systems, locked by major transform systems, (2) final individualization by transform propagation using inherited lithospheric and/or magmatic boundaries. This final breakup phase produces sharp transform boundaries between plateaus and oceanic domains.

**Figure 1:** **A.** Location of Demerara (D) and Guinea (G) Transform Marginal plateaus on the present-day gravity anomaly (free-air anomaly from Sandwell and Smith 2009). Central, Equatorial and South Atlantic realms are shaded in different colours. CJL: Cretaceous/Jurassic limit, GB: Guiana Basin (part of the Jurassic Central Atlantic). a: 15° 20' FZ, b: Marathon FZ, c: Doldrums FZ, d: 4° North FZ, e: Saint Paul FZ, f: Romanche FZ, g: Chain FZ. **B.** Kinematic reconstructions at 104, 124, 154 and 170 Ma, calculated using the GPlates software (Matthews et al., 2016) using rotation poles from earlier studies (Campan, 1996, Moulin et al., 2016). The Sierra Leone hotspot location is from Basile et al. (2020). BB: Blake Bahamas.

**Figure 2:** Dataset interpreted in this study along the Demerara and Guinea plateaus. Jurassic divergent segments are underlined in light blue. Cretaceous transform segments in light purple, Cretaceous divergent segments in light green. **A.** Dataset along the Demerara Plateau. The coloured boxes indicate the boundaries of the industrial seismic blocks interpreted in this study. Academic public seismic lines interpreted in this study are represented respectively by blue lines (IGUANE survey), and orange lines (GUYAPLAC survey). Stars and circles represent available wells, mostly industrial except ODP 207 and DSDP 143/144 wells. **B.** Dataset along the Guinea Plateau. Coloured boxes indicate the boundaries of the industrial seismic blocks interpreted in this study. No academic data could be integrated in this dataset. No industrial wells were available laterally.

**Figure 3:** Regional synthetic cross-sections of the Demerara TMP with main identified seismic units and unconformities. **A.** Regional line crossing the western Demerara Border (Central Atlantic margin), **B.** Regional line crossing the Demerara Plateau from west to east, from the Central Atlantic domain towards the eastern Demerara margin, **C.** Regional line crossing the shelf, Demerara Plateau and northern Demerara border (transform margin).

**Figure 4:** Regional cross sections of the Guinea TMP with the main identified seismic units and unconformities (by analogy with Demerara). **A** and **B:** Lines across the western Guinea TMP - Central Atlantic margin. **C** and **D:** Lines across the southern Guinea TMP - Transform Equatorial margin.

**Figure 5:** **A/** Seismic cross section illustrating chaotic acoustic facies and internal extensional deformations of unit A (Courtesy of TGS). **B/** Seismic cross section illustrating unit A with chaotic reflections, normal faults and fan-shaped bodies (Courtesy of TGS); oblique reflectors interpreted as possible intrusions are underlined by a bold purple dotted

line. **C/** Isochron map (TWTT) of unconformity Uc1 (Top of unit A). The domain where Uc1 is eroded by Uc8 (upper Albian unconformity) is represented in violet.

**Figure 6: A.** Seismic section illustrating unit B seismic facies with fan-shaped geometries (Courtesy of TGS). Sub-unit B1 displays few internal reflections, sub-unit B2 shows strong high-amplitude reflectors and sub-unit B3 more continuous reflectors. B1 onlaps unit A, B2 onlaps B1 and B3 onlaps B1. Onlaps are underlined by red arrows. Unconformity Uc4 limits unit B. **B.** Time isopach map of unit B3 (TWTT). The solid red line indicates B3 lateral pinch out, **C.** Isochron map of Uc4 (TWTT), **D.** Seismic line showing acoustic facies of sub-units B2 and B3 - ending with a poorly reflective acoustic basement (unit A? lateral equivalent of unit A?), (Courtesy of ION). The main toplaps showing the erosion of unit B by Uc4 are underlined by red arrows.

**Figure 7: A.** Line drawing of seismic cross section illustrating units C and D seismic facies. Unit C onlaps Uc4 and is bounded on its top by the Uc5 unconformity. It shows low-amplitude reflectors. Unit D shows high-amplitude continuous reflectors with some internal diffraction hyperbolae localized on local highs. Unit D is topped by the Uc6 unconformity. Unit D is interpreted as a Jurassic carbonate platform **B.** Time isopach map of unit C (TWTT), **C.** Time isopach map of unit D (TWTT).

**Figure 8: A.** Seismic section showing unit E involved in gravity-driven deformations on the western Demerara slope (Courtesy of ION). The basal mobile layer is indicated in pink. **B.** Map showing the lateral extension of upslope extensional and downslope contraction domains. **C.** Line drawing of illustrating Unit E in the central part of the Demerara Plateau. Note the clear implication in folding and thickening of unit E towards the NE, i.e. the transform Demerara border. Units E and D are eroded by the upper Albian Uc8 unconformity.

**Figure 9:** Seismic cross section showing unit E along the eastern Demerara Plateau (located in map D of Figure 8) (Courtesy of TGS). Here, syn-deformation deposition of unit E (and possibly F) results in fan-shaped geometries in association with rotated tilted blocks that deform unit A.

**Figure 10:** Line-drawings from seismic sections showing compressive and strike-slip deformation when approaching the northern Demerara Plateau (location in Figure 11). Strike-slip faults are underlined in green. Unit D shows rather constant thicknesses, clearly deposited before deformation. Unit E shows thickness variations especially along folds, clearly deposited during the folding phase.

**Figure 11:** **A.** Isochron map of the Uc6 unconformity (top of unit D). Purple and pink lines underline the main folding directions of this surface, respectively oriented NW-SE and NNW-SSE. **B.** Isochron map of the Uc8 unconformity. This surface looks like a peneplain on seismic profiles and probably only deformed after formation by differential subsidence and post-Albian sediment loading. **C.** “Geological map” under unconformity Uc8 (Upper Albian) under which units A to F outcrop, depending on the location. **D.** Schematic map of main post-D and pre-Uc8 deformation on Demerara. **E.** Schematic map of main post D and pre-Uc8 deformations off Guinea.

**Figure 12:** **A.** Line-drawing from cross section showing unit F in the central Demerara Plateau. Here, unit E is eroded by the Uc7 erosion unconformity and unit F is preserved under the Upper Albian Uc8 unconformity. **B.** Line-drawing from cross section showing unit F towards the northern Demerara Plateau. Here, units D and E are eroded by a striking Uc7 erosion unconformity. Unit F is preserved under the Upper Albian unconformity, but highly deformed by extensional faults dipping towards the Equatorial Atlantic domain. **C.** Isopach map of unit F.

**Figure 13:** Composite industrial/academic lines imaging the continent-ocean transition domain along the northern Demerara transform border. The lines are drawn on a free-air gravity map corrected for topography (Lorke et al., 2016).

**Figure 14:** Wheeler diagram along an E-W section across Demerara crossing the Western Central Atlantic and the Eastern Equatorial Atlantic divergent margins.

**Figure 15:** Wheeler diagram along a S-N section crossing the North Demerara Equatorial Atlantic transform margin.

**Figure 16:** Paleogeographic reconstitutions of Demerara/Guinea TMPs during deposition of **1.** Unit B (Sinemurian? ~175 Ma), **2.** Unit C (Mid Jurassic?), **3.** Unit D (Upper Jurassic) and **4.** unit E (Aptian). The relative positions of Demerara and Guinea are from Moulin et al. (2010). CJL = Cretaceous Jurassic Limit. Off Guinea, the extension of Jurassic carbonates and Aptian volcanics are inspired by Olyphant et al. (2017).

**Figure 17:** Tentative tectonic reconstitutions of the Demerara/Guinea TMP during the Equatorial opening phase. These reconstructions are inspired by the kinematic reconstructions of Campan (1995).

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Author respective contributions

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**Marion Mercier de Lépinay<sup>1</sup>**: Investigation, Visualization

**Christophe Basile<sup>2</sup>**: Investigation, Writing - Review & Editing

**Agnès Maillard<sup>3</sup>**: Investigation, Writing - Review & Editing

**Walter R. Roest<sup>4</sup>**: Investigation, Writing - Review & Editing, Funding acquisition

**Philippe De Clarens<sup>5</sup>**: Investigation, Resources

**Martin Patriat<sup>4</sup>**: Writing - Review & Editing

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#### Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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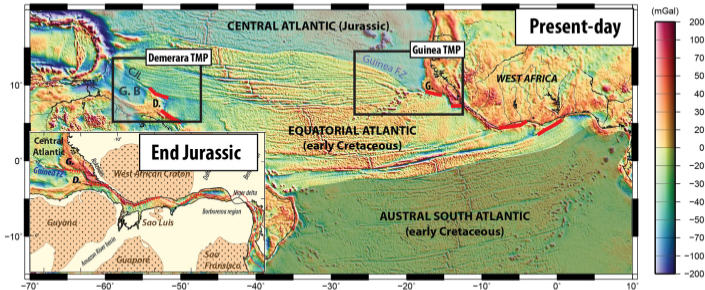
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Graphical abstract

## Highlights

- We describe and compare the tectono-sedimentary evolution of the Demerara and Guinea conjugate TMPs.
- They first formed as Jurassic volcanic margin at the Central Atlantic southern end.
- They then separated in a transform mode during the Cretaceous Equatorial Atlantic opening.
- Therefore, they contain long-term tectono-sedimentary archives of the polyphase Gondwana breakup

# Compared structure and evolution of the conjugate Demerara and Guinea transform marginal plateaus



Graphics Abstract

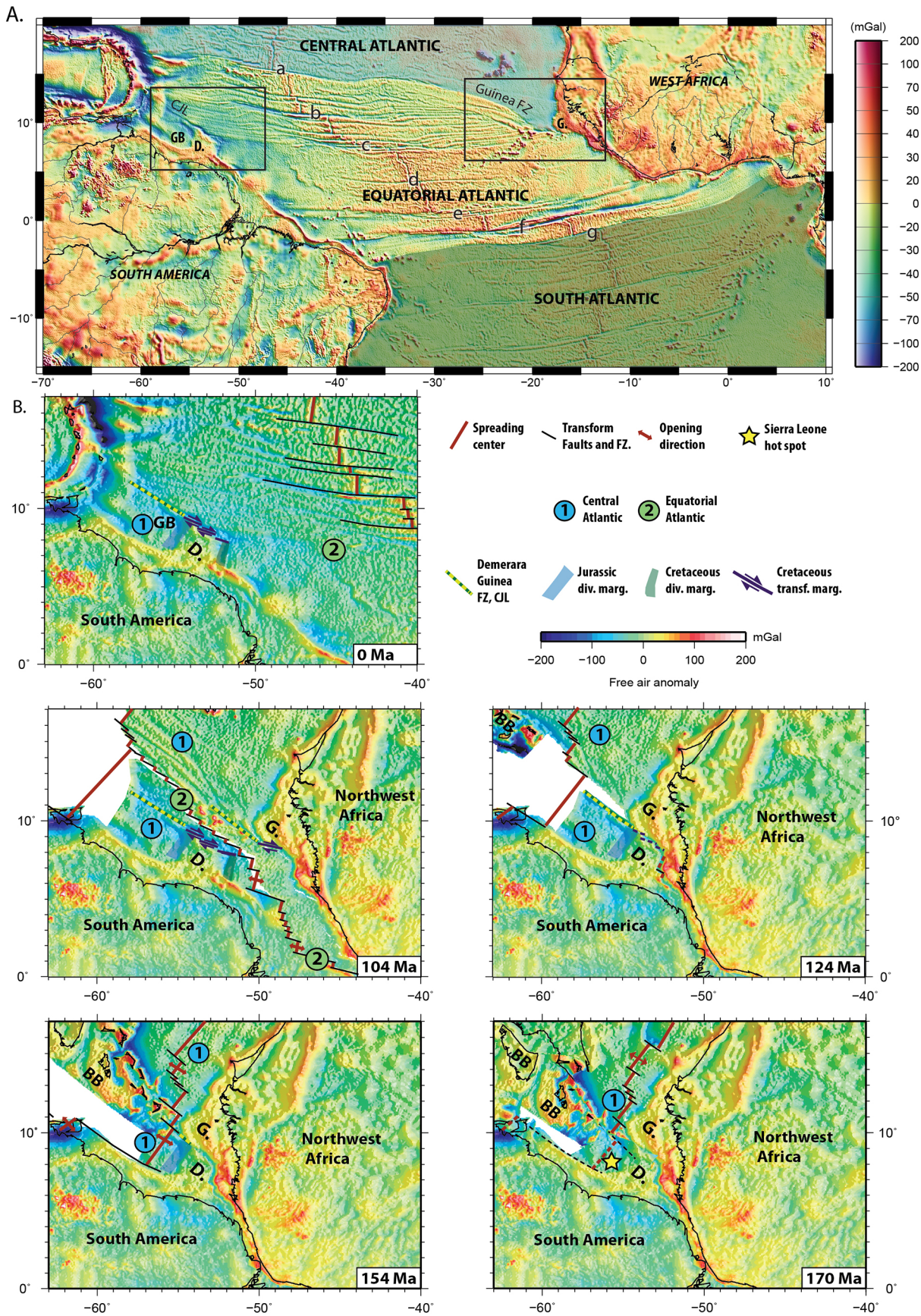


Figure 1

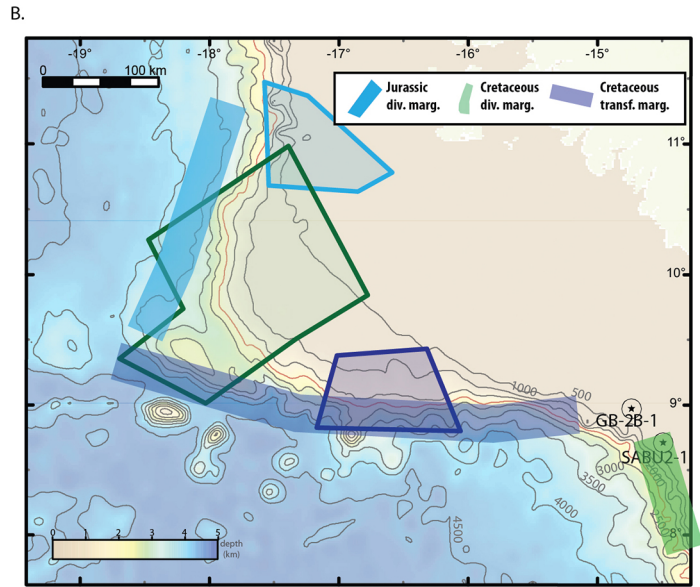
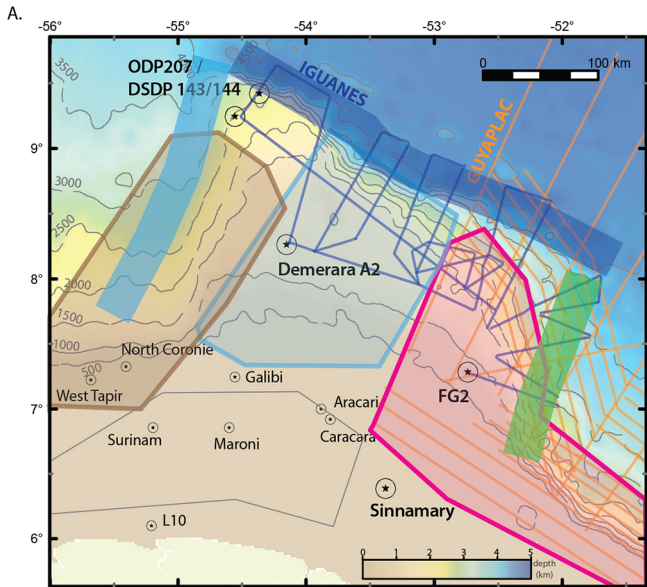


Figure 2

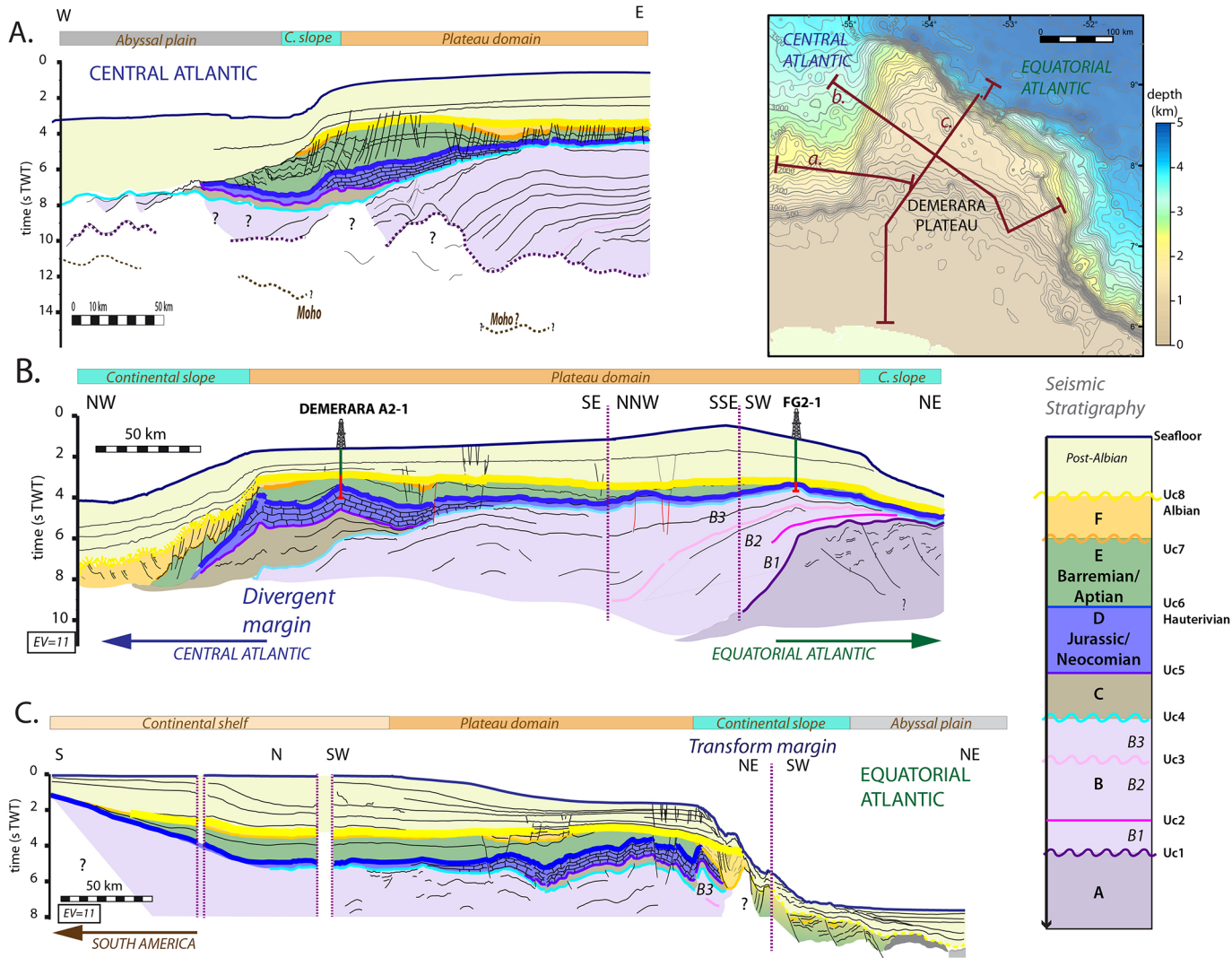


Figure 3



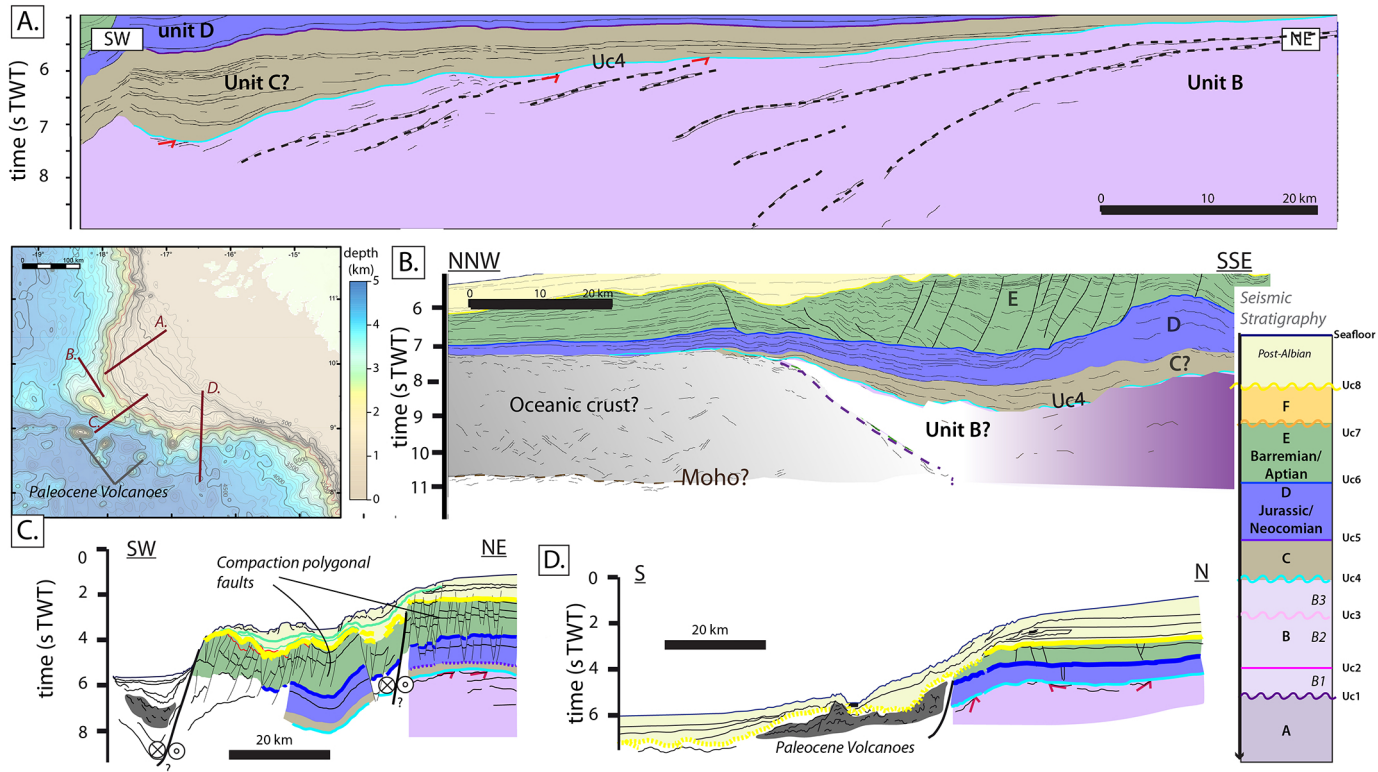
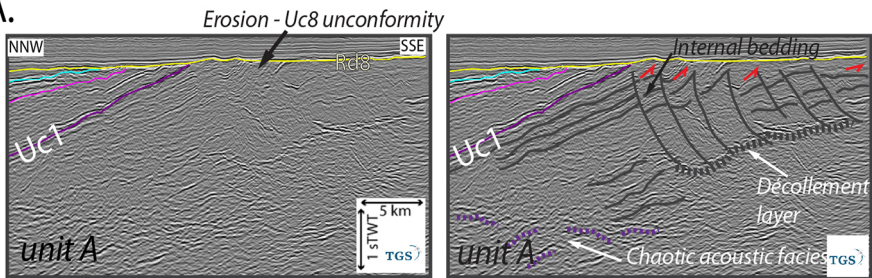
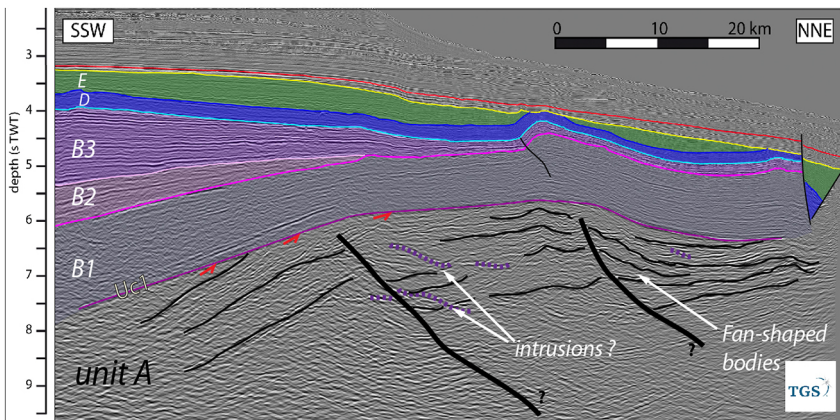


Figure 4

A.



B.



C. Uc1 isodepth map

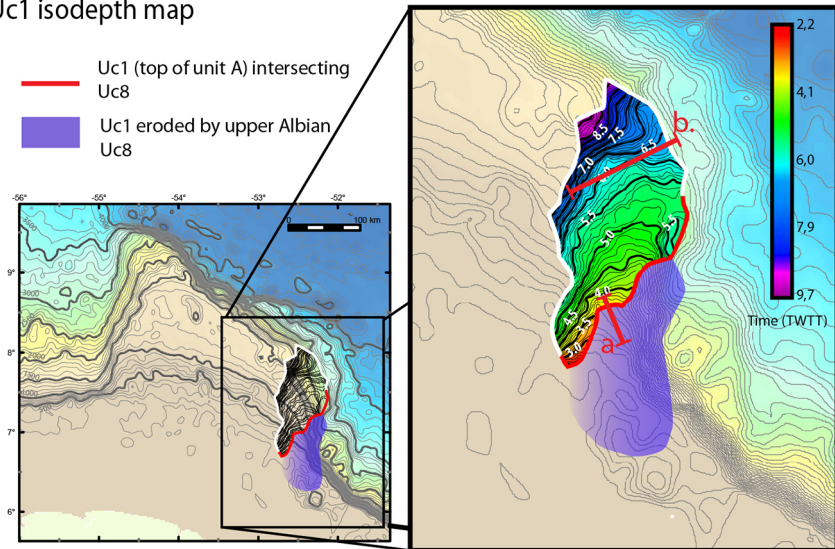
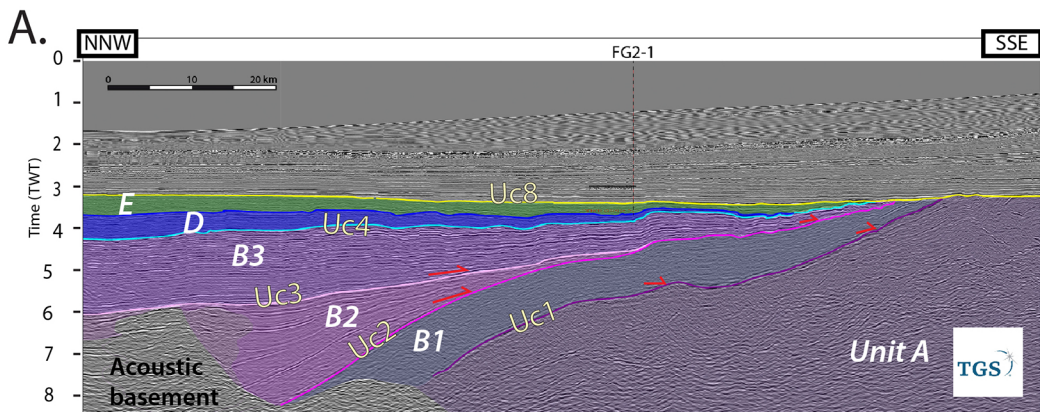
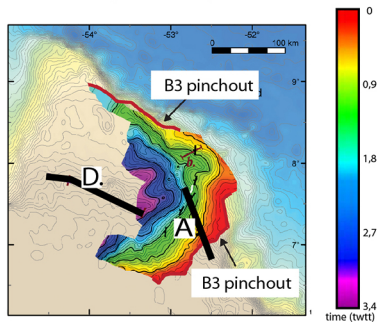


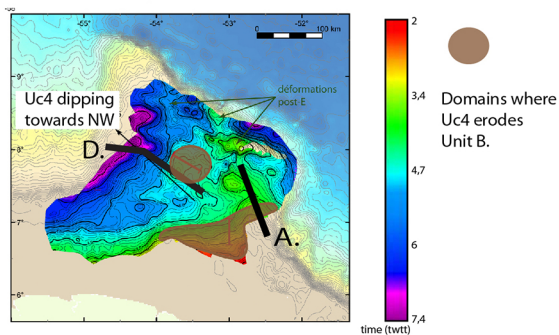
Figure 5



**B.** Isopach map of unit B3



**C.** Uc4 (top of unit B) isochron



**D.**

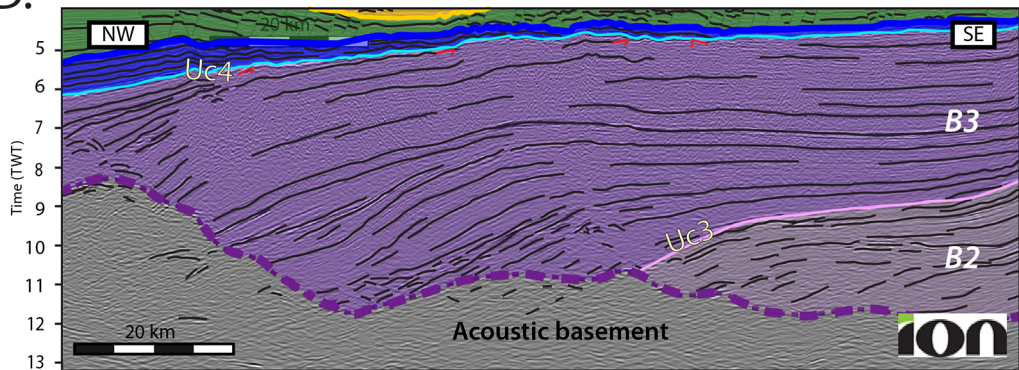
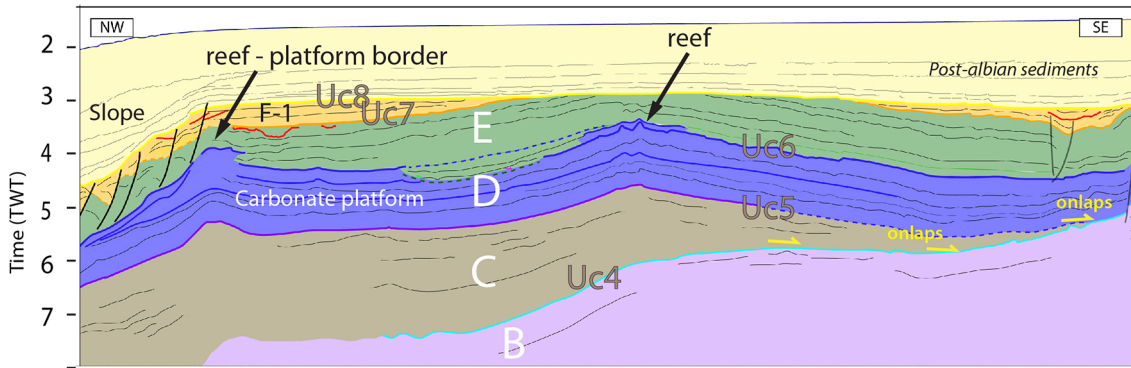
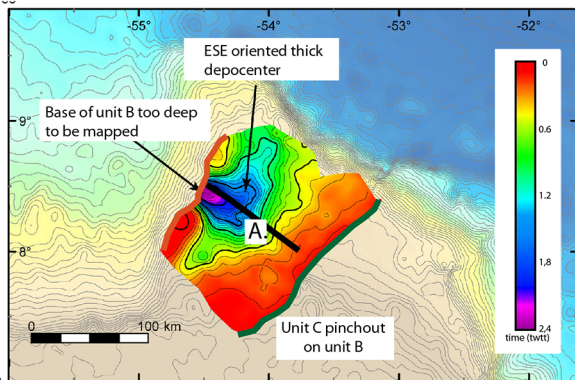


Figure 6

A.



B. Isopach map of unit C



C. Isopach map of unit D

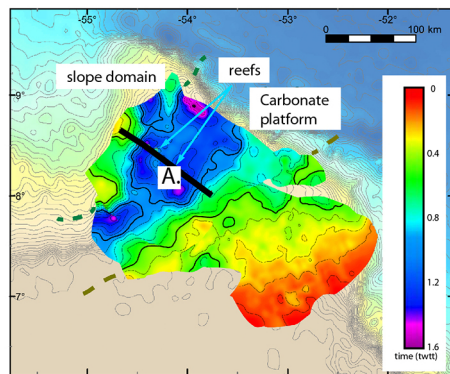


Figure 7

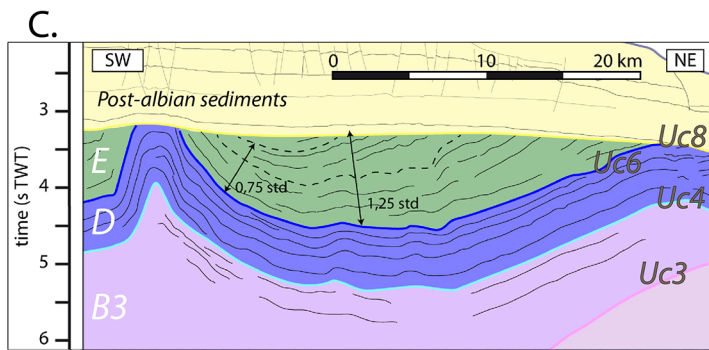
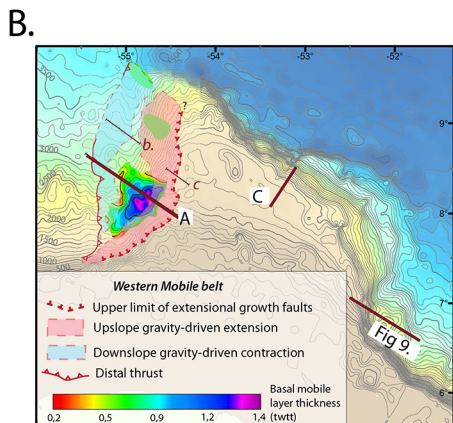
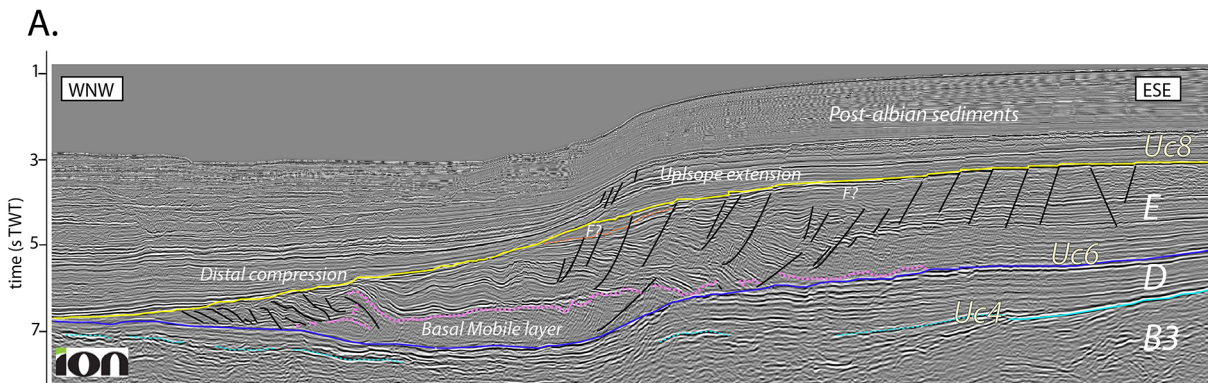


Figure 8

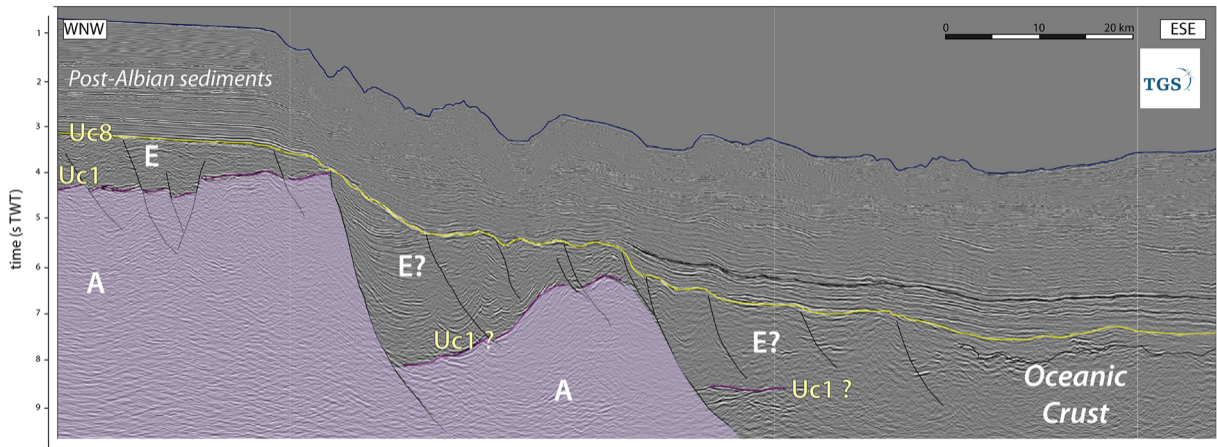


Figure 9

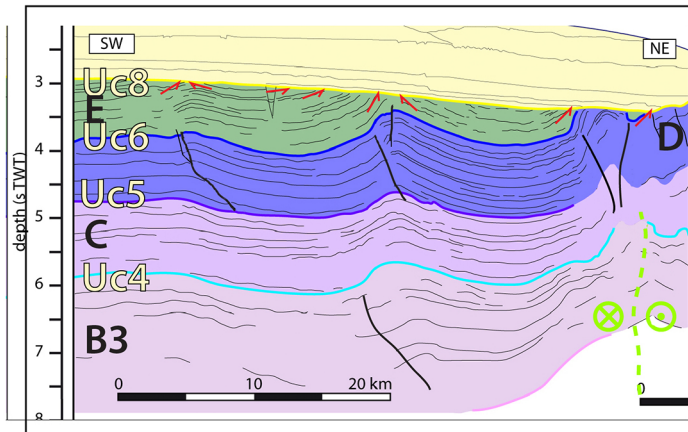
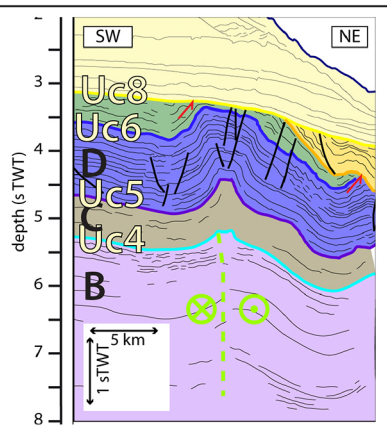
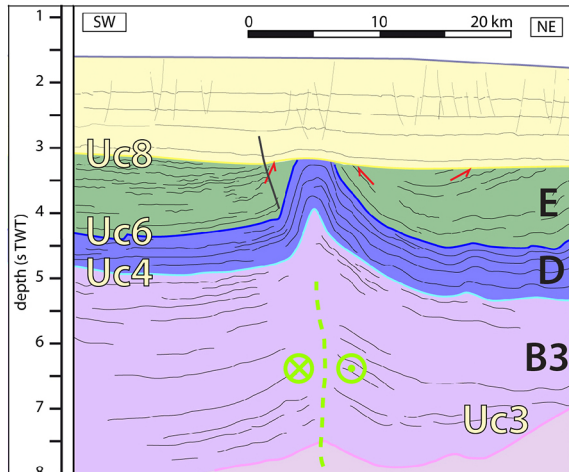
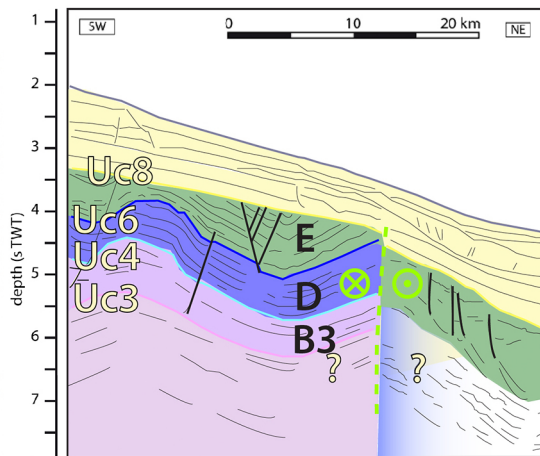
**A.****B.****C.****D.**

Figure 10

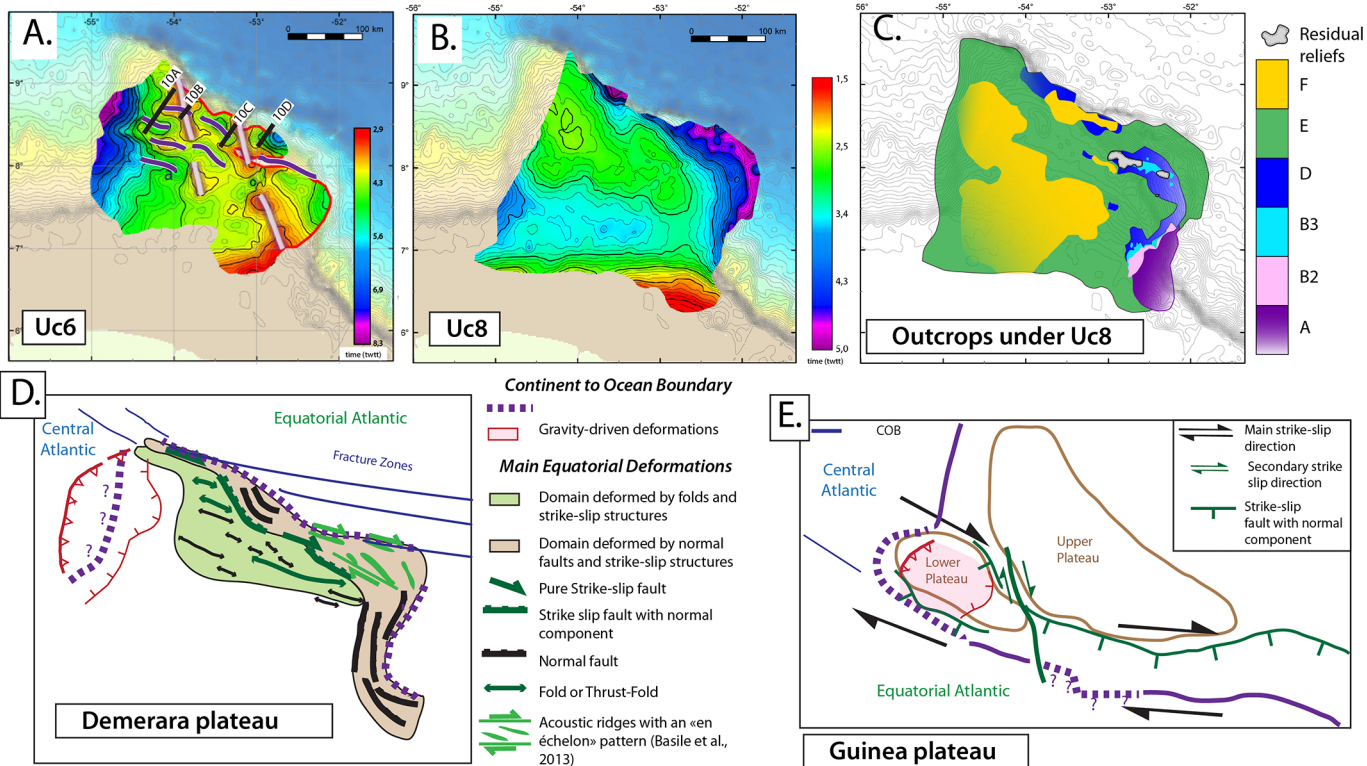
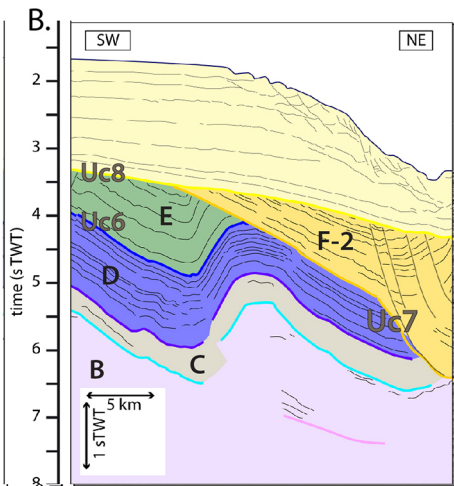
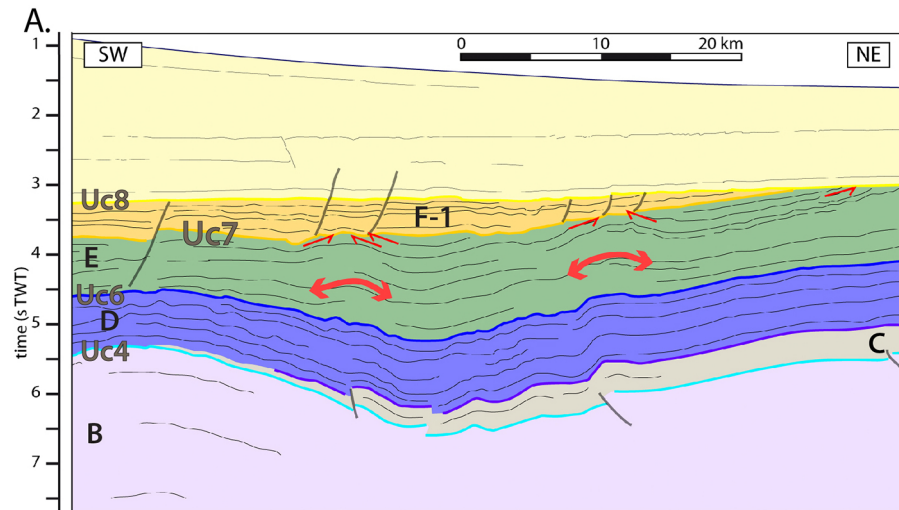


Figure 11





**C. Isopach map of F (s TWT)**

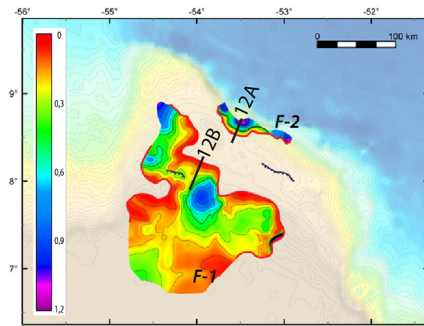
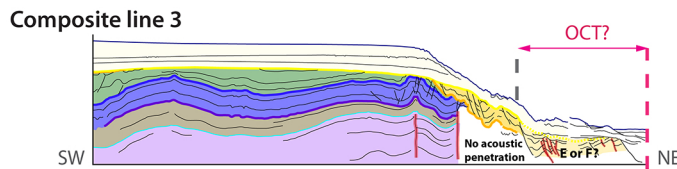
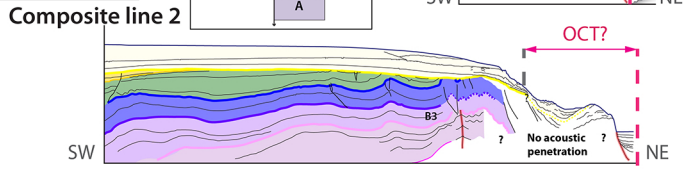
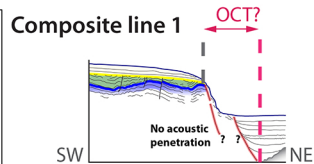
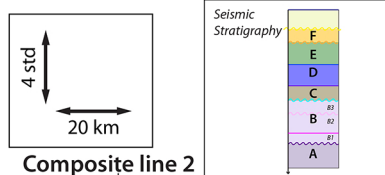
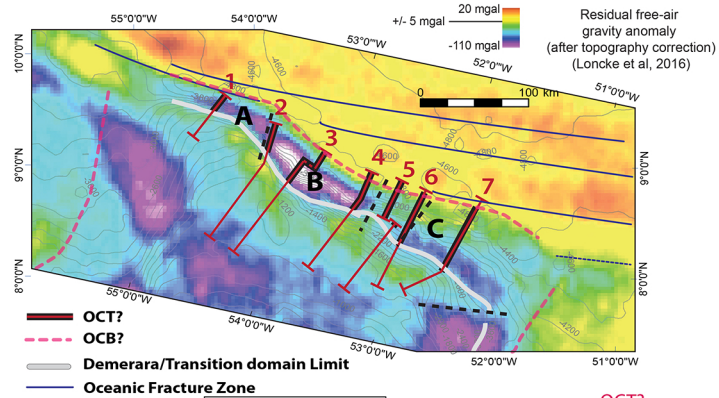
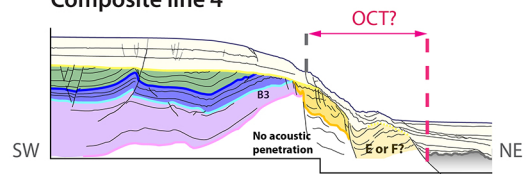


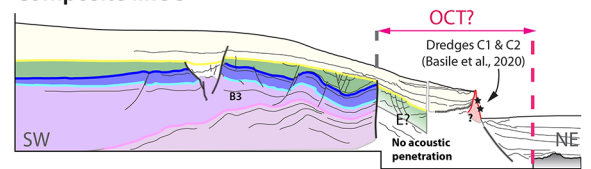
Figure 12



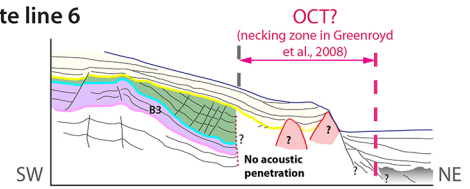
### Composite line 4



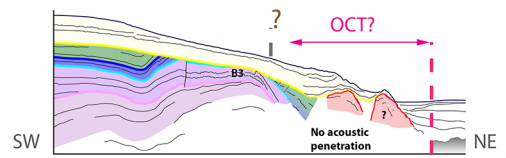
### Composite line 5



### Composite line 6



### Composite Line 7



SEGMENT A

SEGMENT B

SEGMENT B

SEGMENT C

Figure 13



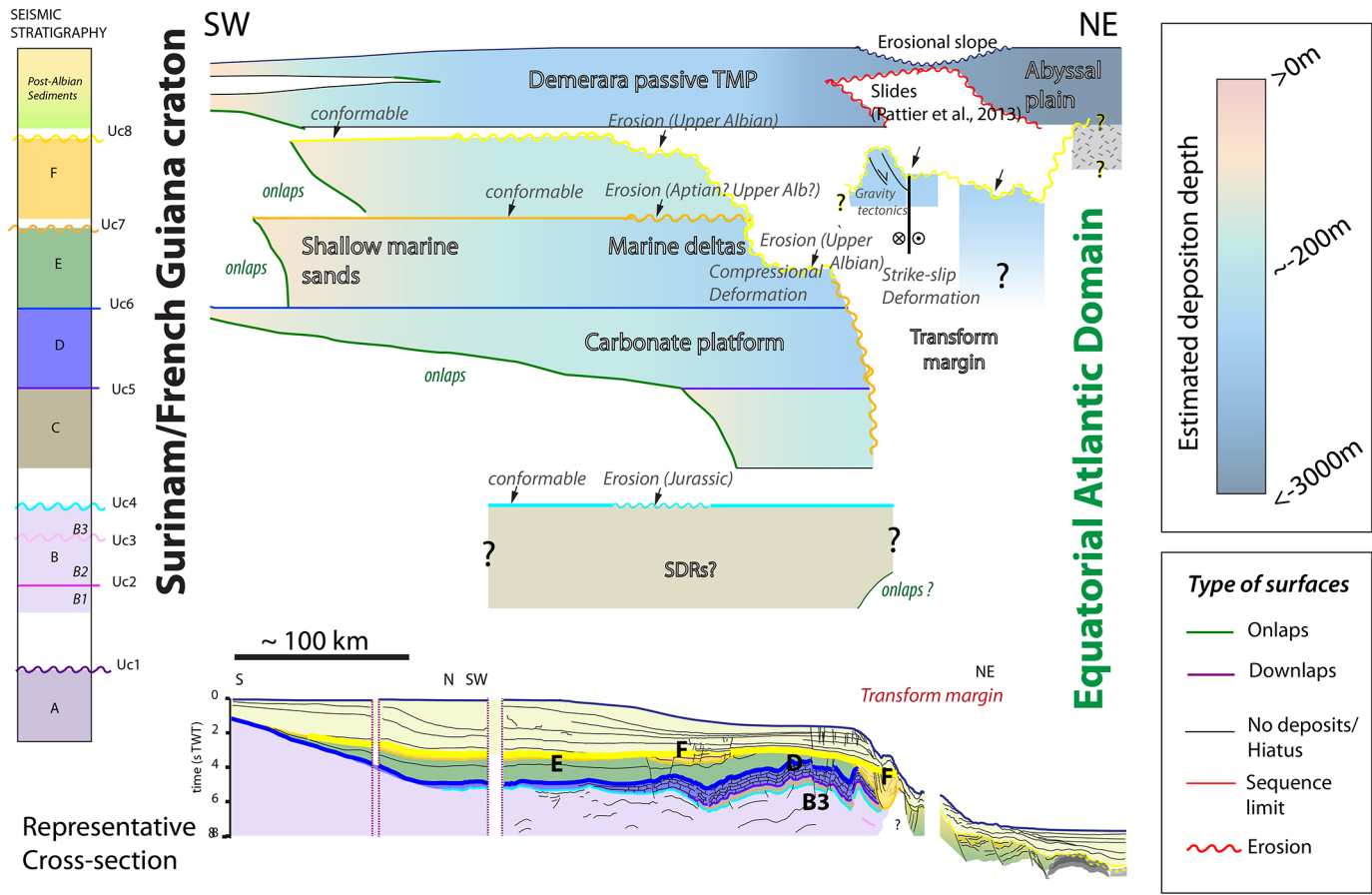


Figure 15

## Legend

Ocean-Continent boundary

### Unit B

- Distribution map of Unit B
- Unit B very thin/ not present (basement highs)
- Apparent dip direction within B
- Onlaps of unit B on unit A
- Uc4 is erosive (emersion?)
- Distribution map of Trias/Lower Lias evaporites

### Unit C:

- Distribution and thickness of unit C
- Maximum subsidence area (thermal subsidence?)
- Localized highly subsiding domains

### Unit D:

- Sands (continent/ proximal margin)
- Carbonates (neritic platform)
- Carbonate marls (paleo-slope)
- Platform border

### Unit E:

- Sands (continent/ proximal margin)
- Clays (platform and slope)
- Unit E thickness
- Proximal gravity-driven normal fault
- Distal gravity-driven thrust fault
- Syn-sedimentary deformation of unit E
- Crustal normal faults
- Barremian Volcanism

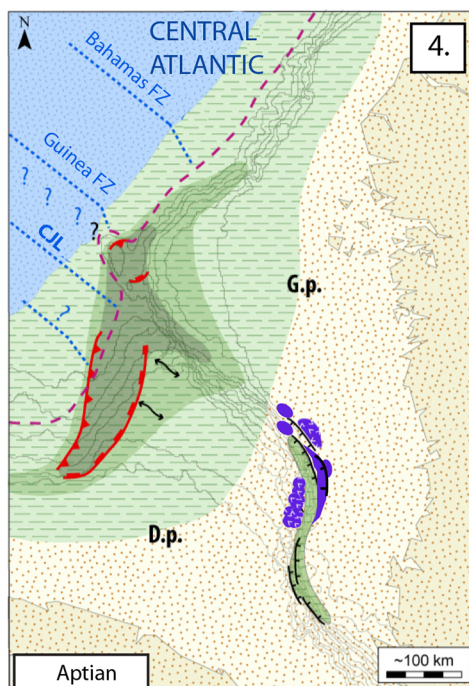
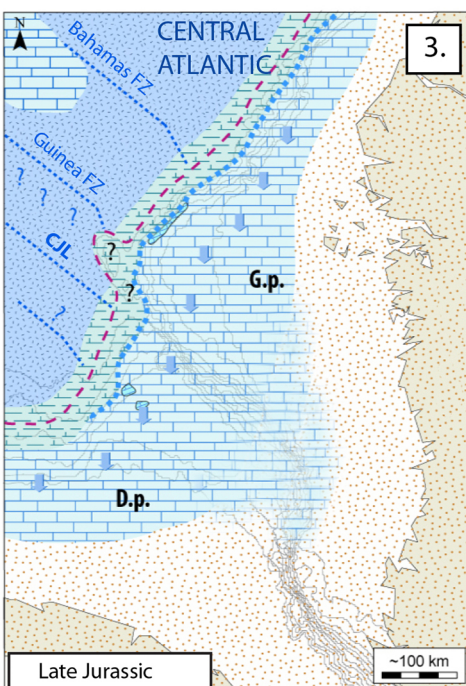
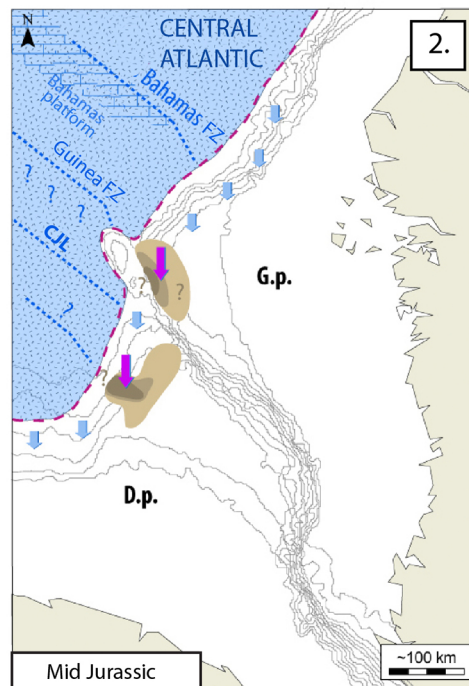
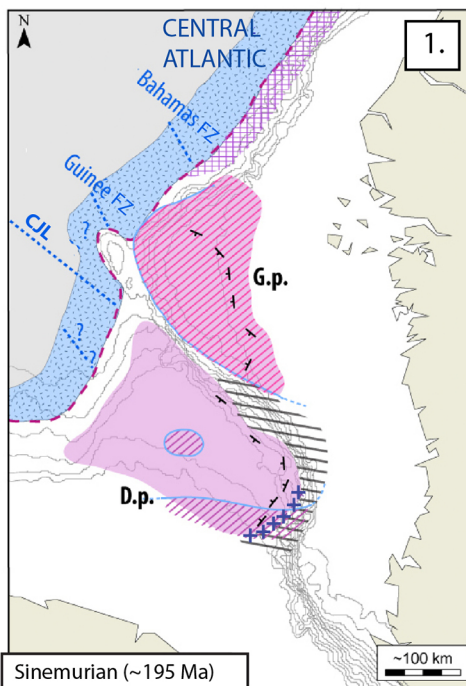


Figure 16

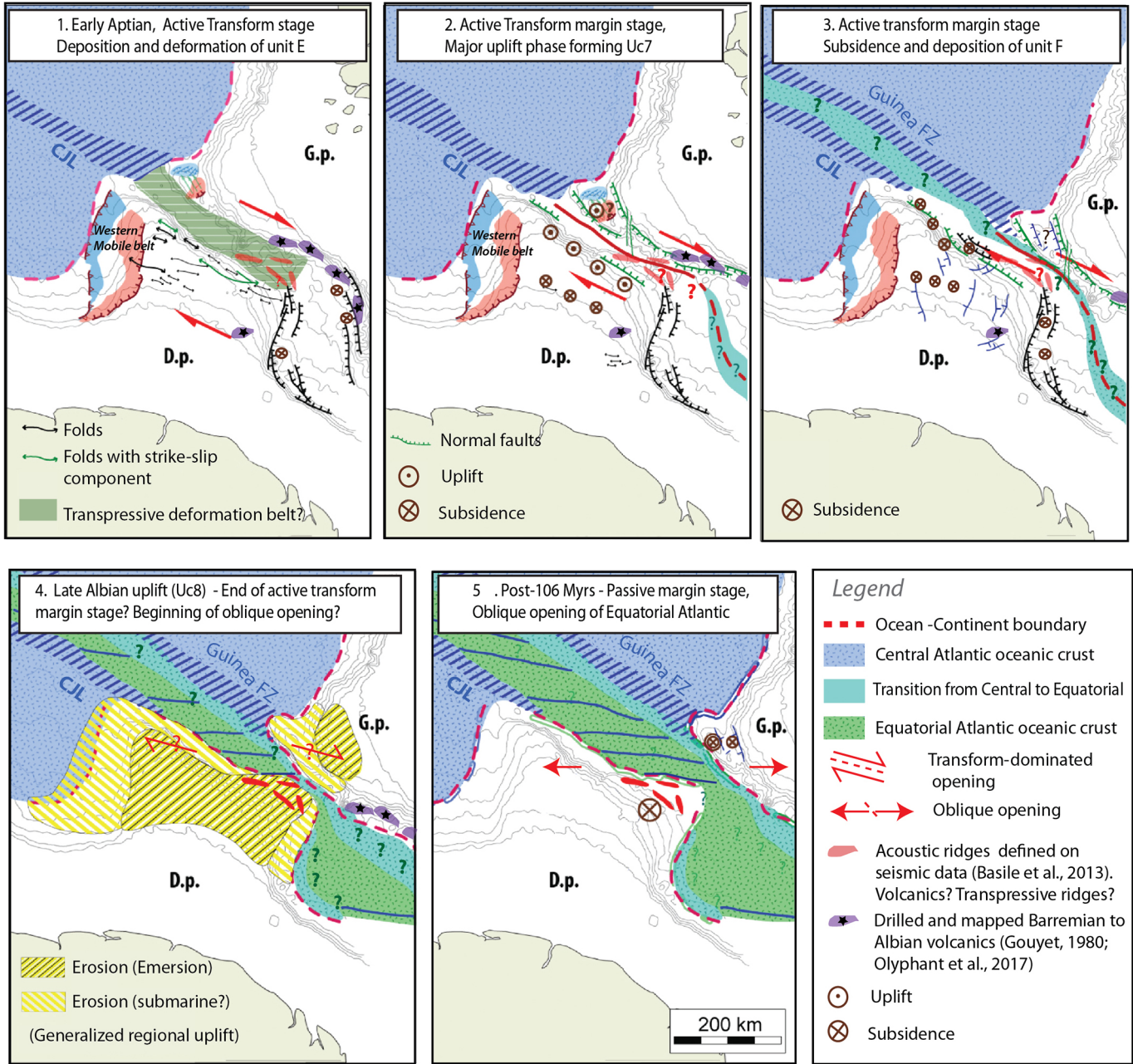


Figure 17