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Initiation of transform continental margins: the Cretaceous margins of the Demerara plateau

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Abstract :

During the end of the lower Cretaceous, the connection between the South and the Central Atlantic accretionary axis led to the oblique opening of the Equatorial Atlantic, and to the separation of Africa and South America by alternating transform and rift margins. At the western end of the Equatorial Atlantic, we investigate the structure of the Cretaceous margins surrounding the Demerara plateau, north of French Guiana and Suriname. These margins were previously described as transform northward and divergent eastward. From the bathymetry and deep structures, we propose to divide the northern transform into three margin segments, with two transform segments separated by a divergent one. These two transform margins are very different, the north-western one being linear and associated with a steep and erosive continental slope, the north-eastern one consisting of several faults and ridges en echelon disposed. In between, the divergent margin appear to be a pull-apart basin localised by structures inherited from the previous Jurassic rifting. Additionally, the eastern divergent margin can have been localised by a thermal anomaly tentatively related to a hotspot. It is proposed that the deformation has been first localised in divergent (rift) basins, subsequently connected by transform faults. The structure of the transform fault varies with the offset between adjacent rift basins: large offset forms a linear transform, short (less than 200 km) offset forms en echelon structures.

Introduction

The question of initiation of transform faults came with their very first definition. Wilson (1965) introduced the concept of transform faults and transform continental margins as lithospheric plate boundaries inherited from ‘lines of old weakness’. In Wilson’ seminar paper, this was specifically exemplified by the separation of South America from Africa. This inherited origin has been used in any model of formation where the continental separation line follows a step-like configuration, alternating transform and divergent segments (e.g. among many others Le Pichon and Hayes, 1971; Scrutton, 1979; Mascle and Blarez, 1987; Basile 2015), although this inheritance is most of the time not explicitly stated. According to Wilson (1965), transform faults are inherited from continental structures; rifts and subsequent divergent margins are considered as secondary features, which do not exist originally but appear to connect the inherited transform segments.

However, field data hardly support this assumption of inheritance of transform faults. Some oceanic transform faults are in line with, or connected to older structures (Wright, 1976; Attoh et al., 2005; Bellahsen et al., 2013). But most frequently, transform faults crosscut inherited continental lithospheric structures (e.g. Basile et al. 2005 for the Equatorial Atlantic). Furthermore, if transfer zones are often observed in continental rifts, this is not the case for transform faults. On the contrary, there are examples where the formation of transform faults can be proven to be post-rift (Taylor et al. 2009). The best example is found in the Woodlark basin where both the rift and oceanic structures are well-preserved and imaged. In this example (Taylor et al., 2009), en echelon rift segments formed during continental rifting. These segments were separated by undeformed or poorly deformed transfer zones. Transform faults only appeared after oceanic accretion started, and connected the tips of adjacent accretion axes.

Therefore, two conceptions of transform fault formation are in opposition (Basile and Braun, 2016; Nemčok et al., 2016):

- Wilson’s model, where divergent segments connect inherited transform during continental rifting.
- Taylor’s model, where transform segments are formed post-rift and connect divergent segments at the time of oceanic accretion.

The aim of this paper is to present new data on the structure and formation of the Cretaceous transform margins north of Demerara plateau, offshore French Guiana and Suriname, in order to discuss the influence of inherited structures on their formation. The Demerara plateau is well suited to address this question, because its lithospheric structure is mainly inherited from Jurassic magmatism emplaced during the Central Atlantic rifting (Reuber et al., 2016; Basile et al., 2020; Museur et al., 2021; Graindorge et al., this volume).

Geological and geodynamical setting of the Demerara plateau

The Demerara plateau is a submarine bathymetric high located north of French Guiana and Suriname, offshore of South America (Figure 1). It is a typical Transform Marginal Plateau, with a flat but deep (> 1500 m below sea level) bathymetric surface within the continental margin, and bounded northward by a transform margin (Loncke et al., 2020).

The structure of the plateau is inherited from two main geodynamical stages:

- A Jurassic stage: during the opening of the Central Atlantic Ocean, the Demerara area is located at the southern end of the continental rift (Klitgord and Schouten, 1986; Nemčok et al., 2015). At that time, the Demerara plateau was contiguous to the Guinea plateau (Benkhelil et al., 1995). Together, they formed a divergent margin bounded westward by the newly accreted oceanic crust (Figure 2A). This margin has recently been described and interpreted as a Jurassic magmatic margin (Reuber et al., 2016; Museur et al., 2021). Below the Jurassic post-rift sediments, the main part of the crustal thickness is composed of up to 21 km of westward dipping stratigraphic units (Seaward Dipping Reflectors (SDRs), dipping toward the Jurassic oceanic crust) (Reuber et al., 2016). These SDRs represent approximately 80% of the thickness of the crust below the post-rift sediments, not taking into account the probable contribution of magmatic intrusions and underplating in the lower part of the crust (Museur et al., 2021). This magmatism was interpreted as formed above the Sierra Leone hotspot from 180 to 170 Ma (Basile et al., 2020).
Regarding the Jurassic rifting, the SDRs are syn-rift deposits. They are overlain by a post-rift carbonate platform that developed mainly along the western edge of the margin from the Callovian to the Neocomian. During Barremian-Aptian, the detrital input increased in the sedimentation, and led to the formation of a thick sedimentary wedge on the western slope of the margin, that eventually collapsed in a gravitational structure westward (Nemčok et al., 2015, Mercier de Lépinay, 2016; Casson et al., 2021).
- A Cretaceous stage: the Equatorial Atlantic Ocean opened as a connection between the northward propagating South Atlantic Ocean and the Jurassic Central Atlantic (Figure 2B). This rift zone formed numerous E-W right-lateral transform faults, including the one North of the Demerara plateau, and also divergent boundaries such as the one located to the East of the Demerara plateau (Figure 1). This rifting episode is Aptian in age and pulled apart the Guinea plateau from the Demerara plateau (Basile et al., 2005). The syn-rift units filled few tilted blocks, overlain by post-rift Albian sediments (Sapin et al., 2016). A late Albian regional sub-aerial erosional unconformity affects the entire plateau (Gouyet et al., 1994; Erbacher et al., 2004 ; Basile et al., 2013 ; Mercier de Lépinay, 2016). This unconformity represents the last period when the plateau was located at shallow water depth. Above it, Upper Cretaceous and Cenozoic pelagic sediments record the deepening of the Plateau (Erbacher, et al., 2004; Casson et al., 2021).

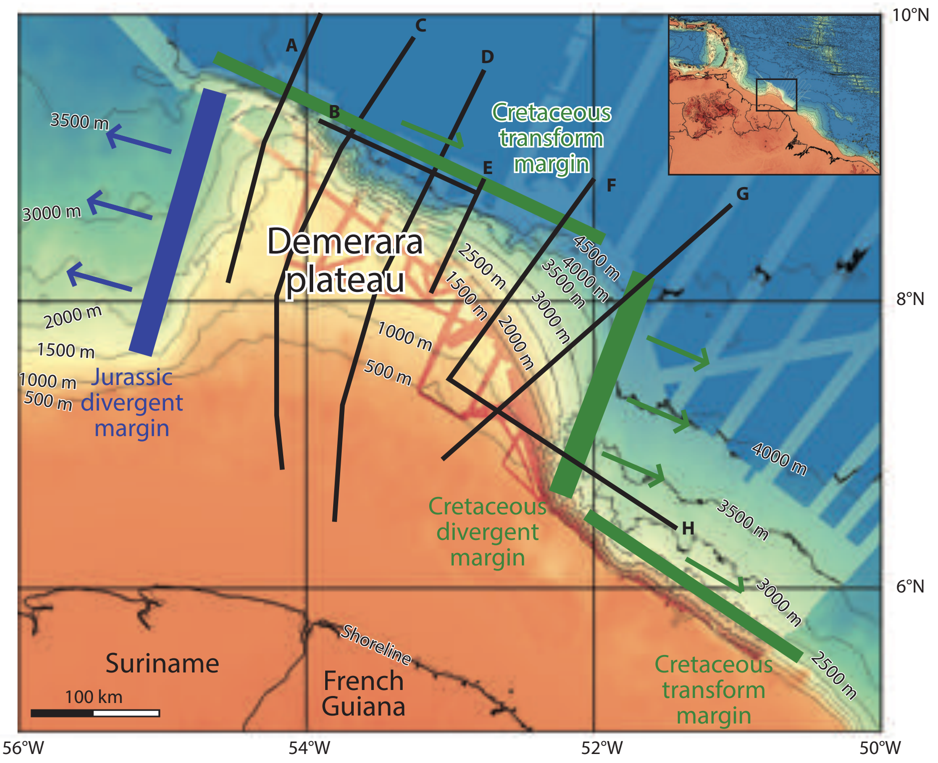

Figure 1 : Topographic map (from Etopo1 for the background, and in lighter colors IGUANES, DRADEM and MARGATS cruises: Loncke et al., 2015; Basile et al., 2017; Graindorge and Klingelhoefer, 2016). Isobaths every 500 m. A to H : locations of the seismic lines shown in Figure 4. Inset: location of the studied area on the Northern margin of South America.

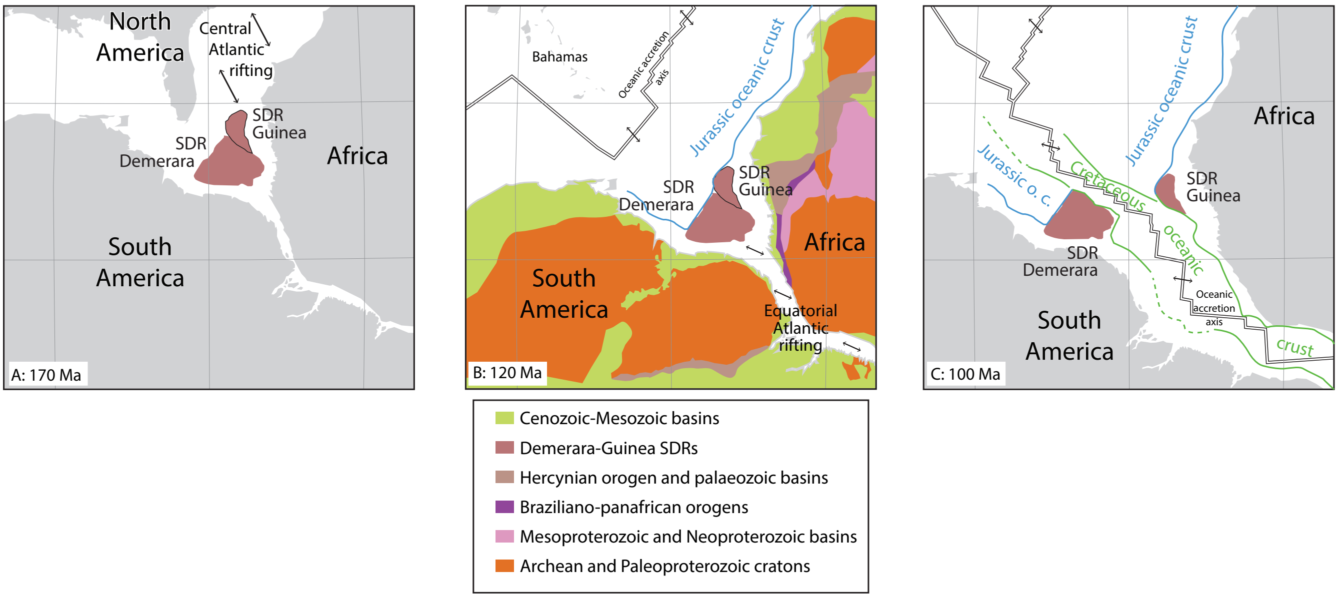

Figure 2: The two stages of margin formation around the Demerara and Guinea plateaus (modified from Basile et al., 2020). 2A presents the reconstitution at 170 Ma, during the Central Atlantic riftin; 2B presents the reconstitution at 120 Ma, during the rifting of the Equatorial Atlantic, and after the Jurassic opening of the Central Atlantic; 2C (100 Ma) presents the reconstitution after the opening of the Equatorial Atlantic. The blue line (2B and 2C) represents the edge of the Central Atlantic Jurassic oceanic crust, the green line (2C) the edge of the Equatorial Atlantic Cretaceous oceanic crust (dashed for the part that has been subducted below the Lesser Antilles, and below the Amazon delta); these boundaries were drawn from the vertical gravity gradient from Sandwell et al., 2014. Figure 2B displays the present-day onshore geology on the tectonic reconstruction at 120 Ma.

The Cretaceous transform and divergent margins North and East of the Demerara plateau

The Cretaceous margin of the Demerara plateau can be divided into four segments, based on bathymetric and structural observations (Loncke et al., 2015). From West to East, they are (Figure 3):

- <u>The north-western transform segment</u>.

At a large scale, this 100 km-long segment is linear and strikes WNW-SSE (N108°). It represents a steep and planar slope (15° in average) between the edge of the plateau (2800 m-deep) and the abyssal plain which is located 1700 m deeper. At a smaller scale, numerous canyons erode the slope.

On seismic lines (e.g. Figure 4A), there is no sedimentary cover on the continental slope, which extends below the sediments of the abyssal plain down to a deep trench striking parallel to the bathymetric scarp. This trench is interpreted as the trace of the vertical transform fault at the continent-ocean boundary. While slightly faulted and folded, the sedimentary succession of the Demerara plateau does not appear to be strongly affected by the transform fault: in this segment no thinning or thickening, nor uplift or subsidence of sedimentary units can be observed towards the transform. The plateau seems to have been simply cross-cut in its entire thickness by the transform fault, and the lower Cretaceous sedimentary units of the plateau outcrop on the slope where they were dredged (Fox et al., 1970; Basile et al., 2017; Girault 2017).

- <u>The northern pull-apart basin</u>.

This 150 km-long segment is curved, striking NW-SE (N146°) in its western part, and WNW-ESE (N118°) in its eastern part. In section, the continental slope is convex. The average slope is 5° between the edge of the plateau (1400 m deep) and the talus of the abyssal plain at 4300 m depth. The lower part of the slope is steeper, reaching 8° on average.

In seismic lines, the slope appears to be covered by sediments, with numerous sliding structures (mass-transport deposits downslope, gravitational fault scarps upslope: Loncke et al., 2015). Along an E-W seismic line (Figure 4B), typical structures of a rifted margin are observed below the slope, and the progressive deepening and crustal thinning are associated with tilted blocks bounded by ocean-ward (eastward) dipping normal faults. Two of these tilted blocks are located below the sediments of the abyssal plain: their top is deeper than 6 km below sea level, indicating a very thin crust and/or exhumed mantle. It is noteworthy that the stretched crust mainly consists of Jurassic and lower Cretaceous SDRs and sediments. Older structures may be present in the deeper layer, that may represent lower continental crust, but it is very likely that these structures were overprinted by the magmatic event that fed the Jurassic SDRs.

The N-S seismic sections present a very different pattern (Figures 4C and 4D). The edge of the continental slope is located above a basement ridge. Because the SDR units onlap this ridge, this structure was in place during the Jurassic, and defines the northern edge of the main SDR depocenter. On top and north of this ridge, a thick unit of Cretaceous syn-rift sediments overlies on an erosional surface, indicating that this area was uplifted, then subsided during the rifting (Mercier de Lépinay, 2016). Finally, a steep north-dipping fault separated the plateau from deeper blocks that presently lie below the abyssal plain. In map view, the steep fault trends WNW-ESE, follows the basement ridge, and connects to the western-most normal fault in the E-W section (Figure 3). Despite poor coverage by seismic lines in this area, one can postulate that the other normal faults bounding the tilted blocks are connected to this main fault in a horsetail termination: the vertical displacement between the plateau and the deep tilted blocks is accommodated by several normal faults north-westward, and by a single steep fault south-eastward.

This mapping results in a non-cylindrical structure, where the most prominent structure is inherited from the Jurassic rifting, and acts as a transtensive fault, oblique to the relative displacement direction. This main fault defines the western and southern edges of a pull-apart basin, with normal faults accommodating oblique divergence to the west, between strike-slip faulting northward and a transtensive fault southward (Figure 3).

- The north-eastern transform segment. Whereas the limit between the north-western transform and northern pull-apart segments can be precisely defined from the bathymetric, structural and sedimentary data, both the western and eastern boundaries of the north-eastern transform segment may be a subject of discussion. The main structure in this area is a 50 km-long basement ridge underlining the edge of the plateau, and with a very steep (60°) northern slope. The basement of this so-called 60° ridge consists of Jurassic magmatic rocks, supposed to be a part of the SDR package (Basile et al., 2020). Unfortunately, the stratigraphic connection between the 60° ridge and the Demerara plateau cannot be observed on the available seismic lines (Figure 4E). This ridge trends N113°, very close to the N118° of the transtensive fault bounding southward the pull-apart basin. However, these two structures are not in line, but left-laterallly en echelon located (Figure 3). A third structure appears eastward on the same line: it consists of two parallel, NW-SE (N141°) striking ridges culminating at 3700 and 4300 m depths, respectively. The higher ridge has been named Bastille ridge, and undated volcanic rocks reworked in a carbonate platform were dredged on its side (Basile et al., 2020). In seismic section (Figure 4F), these two ridges appear as the crest of two tilted blocks bounded by northeastward dipping normal faults, the crest of the Bastille plateau having been flattening by an horizontal erosional surface.

Together, these three structures define a trend parallel to the trend of the north-western transform margin. Consequently, we propose that they all belong to a transform margin segment, the westward transtensive fault being both part of the transform segment and the southern boundary of the pull-apart basin. Similarly, the Bastille plateau is at the outer corner of the transform segment (Basile, 2015), at the intersection with the eastern Demerara margin.

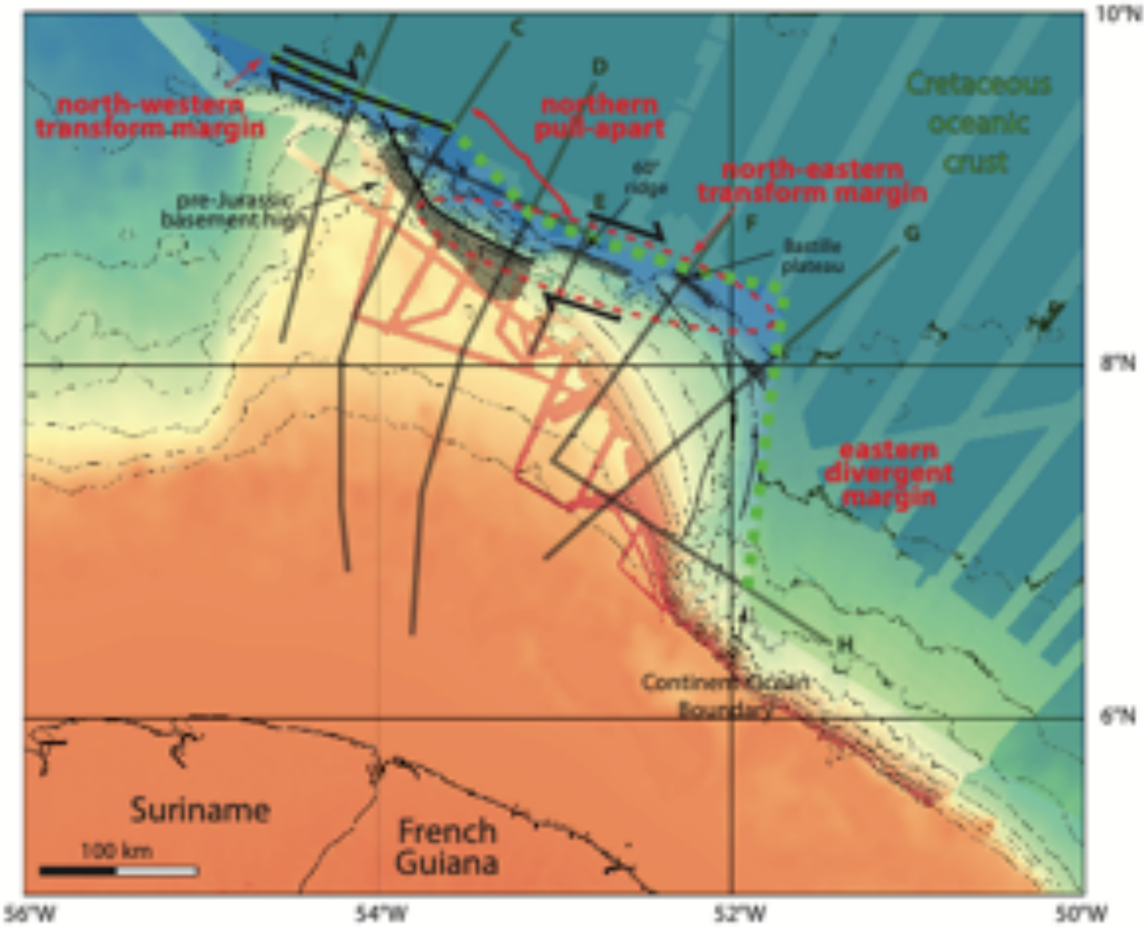

Figure 3 : Schematic structural map of the Cretaceous margins of the Demerara plateau.

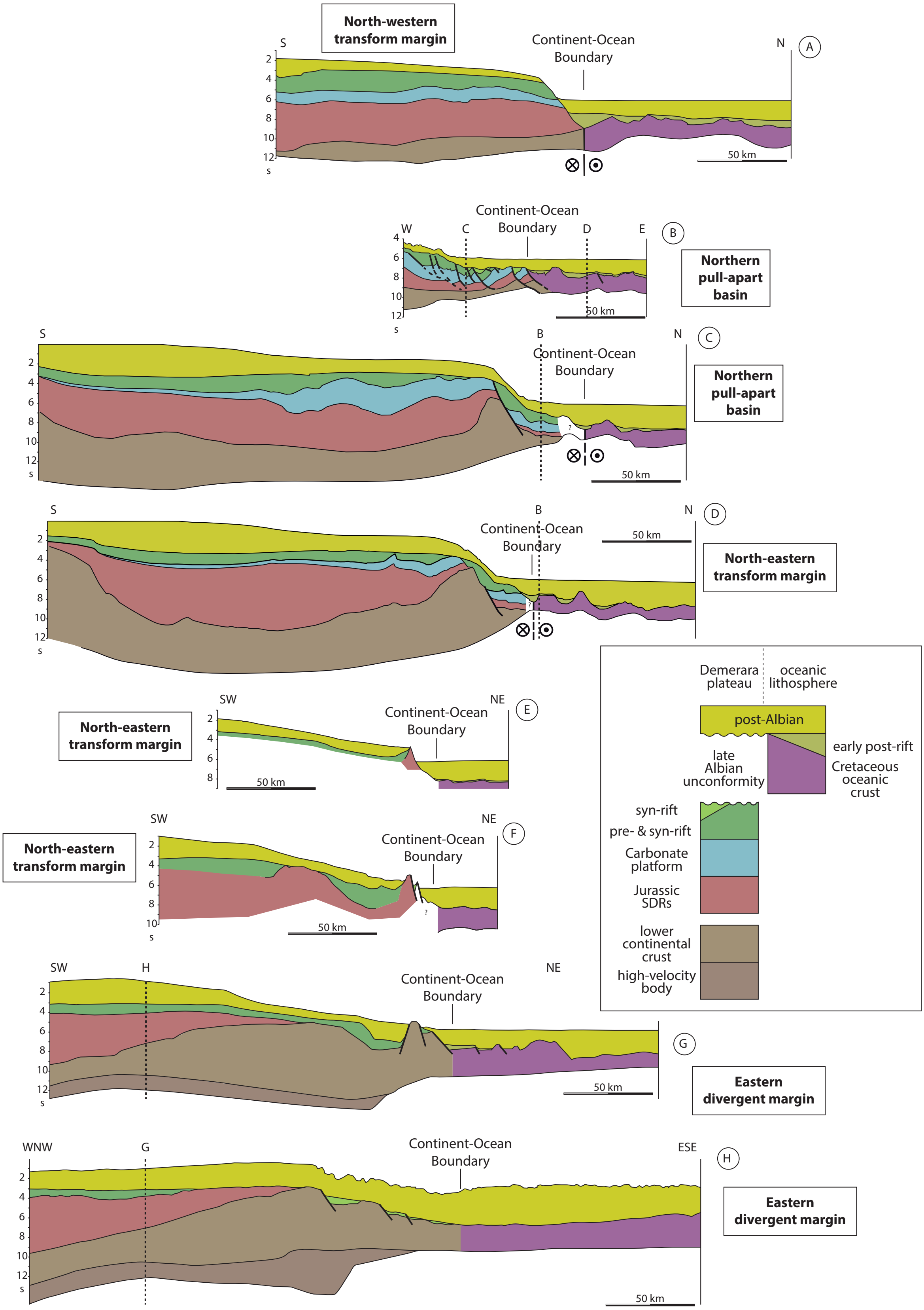

Figure 4: Seismic lines across the Cretaceous margins of the Demerara plateau. Location Figures 1 and 3. All sections are displayed at the same vertical and horizontal scales (vertical exaggeration 7.4 in water). Lines A to D are interpreted from ION-GXT sections; line E is from IGUANES cruise (Loncke et al., 2015); lines F to H are from MARGATS cruise (Graindorge and Klingelhoefer, 2016), the interpretation of G and H also using wide angle data (Museur et al., 2021).

- The eastern divergent margin.

The deep part of the eastern margin of the Demerara plateau is almost totally covered by sediments from both the distal part of the Amazon deep sea fan and from the eastern Guiana continental slope. Seismic lines poorly image this margin. A northern section is located across the Bastille plateau (cf. previous paragraph, Figure 4F), at the intersection with the north-eastern Demerara transform margin. A southern section is located at the intersection with the eastern Guiana transform margin (Sapin et al., 2016; Museur et al., 2021; Graindorge et al., this volume) (Figure 4H). In between, a central section crosses a NW-SE (N140°) trending ridge, culminating at 3700 m depth (Museur et al., 2021; Graindorge et al., this volume) (Figure 4G). This ridge appears on the seismic line as a horst bounded by two normal faults, very close to the oceanic crust.

The tectonic structures allow distinguishing two parts in the eastern margin: to the north, the Bastille plateau and the horst define a NW-SE trend, and are separated from the Demerara plateau by a deep graben. To the south, the continent-ocean boundary trends NNE-SSW (Basile et al., 2013), and presents few tilted blocks (Sapin et al., 2016). In both parts, the thinning of the crust between the Demerara plateau and the oceanic crust is very rapid, as it occurs in a 50 km-wide transition zone, and the first appearing oceanic crust is about 7 km thick, thicker than the Cretaceous oceanic crust observed eastward (4 km) (Figure 4G), or below the Amazon deep sea fan (Watts et al. 2009).

The continent-ocean transition occurs in an area devoid of Jurassic SDRs. These SDRs thicken westward, and thin eastward, but they also were strongly eroded by the Cretaceous syn-rift uplift, which increased from west to east. This syn-rift uplift can explain the erosional surfaces observed in the deep horsts such as the Bastille plateau, that are indeed too deep (3.7 km below sea level) to be explained by thermal subsidence alone. Surprisingly, while the Cretaceous divergent margin formed in the proximal part of the Jurassic magmatic margin (i.e. where the SDRs vanished towards the continent), the lower part of the crust consists of a high velocity (>7 km/s) body very similar to magmatic underplating as observed in the distal part of many magmatic margins (Museur et al. 2021; Graindorge et al., this volume).

Discussion

- A template for the chronology of Cretaceous deformations

Compressive deformation (folds and thrusts) has been widespread described over the whole Demerara plateau (Gouyet et al., 1994; Basile et al., 2013; Mercier de Lépinay, 2016; Reuber et al., 2016) as along the Guinea plateau (Benkhelil et al., 1995; Mercier de Lépinay, 2016). These compressive deformations postdate the Cretaceous syn-rift units in the eastern divergent margins (Basile et al., 2013), but predate the syn-rift units along the northern Demerara margin (Mercier de Lépinay, 2016). The post-rift (break-up) unconformity is Aptian in age along the eastern divergent (Sapin et al., 2016). Later on after the break up, the late Albian erosional surface flatten the reliefs, even if locally few reactivated structures can cross this erosional surface (Basile et al., 2013).

From this chronology, one can infer that the formation of the eastern divergent margin predated the formation of the northern margin. However, it has to be kept in mind that the complex spatial repartition and trends of compressive deformations (along the northern transform margin as along the divergent eastern margin: Mercier de Lépinay, 2016) does not allow to interpret the compressive deformation as resulting from a single tectonic event, and consequently it is possible that the compressive deformations are not coeval everywhere in the plateau.

- Segmentation of the Cretaceous margin

During the Cretaceous opening of the Equatorial Atlantic Ocean, two divergent (pull-apart and East Demerara) and two transform segments (north-western and north-eastern) appeared between the Demerara and Guinea plateaus. They are only very few seismic lines that cross the southern transform border of the Guinea plateau, and this area has been strongly overprinted during the Paleogene by numerous volcanic seamounts (Bertrand et al., 1993; Benkhelil et al., 1995; Olyphant et al., 2017). Consequently, a direct comparison between the two conjugated transform margins remains a challenge, and we present here only the segmentation of the Demerara Cretaceous margins.

- The transform margins

The northwest transform segment presents classical features of a transform margin (Basile, 2015): the continental slope is steep and linear, and associated with a deep trough at the continent-ocean boundary. On the contrary, the northeast segment, while sharing the same trend, does not present a linear and continuous structure, but en echelon faults or ridges. This structural difference may be due to the offset accommodated by each of these segments: the northwest transform is supposed to be the termination of a long transform connecting the Demerara plateau to the oceanic accretion axis of the Central Atlantic Ocean, possibly 1000 km westward. On the contrary the northeast segment is only 150 km-long between the northern pull-apart and the eastern divergent margin. The increase localisation of deformation with the amount of displacement in strike-slip fault zones has been widely documented, from a single strike-slip fault (e.g. Tchalenko, 1970; Naylor et al.,1986 for field work and analogic experiments) to intra-continental transform faults (Norris and Toy, 2014), even if we lack systematic studies on this topic specifically for transform margins and intra-oceanic transform faults.

The north-western transform is well-imaged by seismic lines, and does not show any evidence of relationship with inherited structures. The north-east transform, while poorly imaged by seismic lines, does not exhibit inherited structures either.

- The divergent margins

The two divergent segments are a pull-apart north of Demerara, and the East Demerara divergent margin. The southern border fault of the pull apart appears as a normal fault westward and as a transtensive fault southward. Westward, the normal fault superimposes onto the northern slope of a basement ridge, which was previously onlapped by the Jurassic SDRs. This basement ridge may be older than the Jurassic, but given the thickness (more than 20 km) of the SDRs at their depocenter, it is more likely a Jurassic structure that accommodated laterally the differential subsidence of the Jurassic margin. Eastward, the border fault becomes more vertical and is supposed to accommodate mainly strike-slip displacement as a transtensive fault. Here, the border fault stands aside from the basement ridge, suggesting that inherited structures control the localisation of the border fault in the divergent part rather than in the strike-slip one.

There is no evidence that the East Demerara margin has any relationship with Precambrian structures as they are known onshore (Delor et al., 2003). There is some coincidence in between the Cretaceous and the Jurassic structures, as this rifted margin follows (in trend as well as in location) the eastern boundary of the SDRs (Mercier de Lépinay, 2016). However, the lack of SDRs can hardly be considered as an inherited structure, as there are no observed or inferred structures associated with the proximal (closest to the continent during the Jurassic rifting) limit of SDRs.

- An hypothetic lower cretaceous hotspot?

Another interpretation of the structure of the East Demerara margin may be to relate the location of this rifted segment to a hypothetic hotspot. Basile et al. (2020) proposed that the Jurassic magmatism of the Demerara and Guinea plateau may have been induced by the Sierra Leone hotspot, that later on (during the upper Cretaceous) formed the conjugate Sierra Leone and Ceara rises at the oceanic accretion axis. In this kinematic reconstitution, the Sierra Leone hotspot was close to, but northwest of the Demerara plateau during Aptian times. However, some indications may suggest an alternative or additional hotspot location east of Demerara at the same time: Barremian-Aptian basalts were drilled on eastern Demerara (Gouyet et al., 1994: few tens of meters drilled at the bottom of the hole, that are on seismic lines indistinguishable from the underlying SDRs); on the conjugate margin Aptian basalts were also drilled offshore Guinea, together with Albian (106 Ma old) basalts (up to 0.5 seconds thick on seismic lines) (Olyphant et al., 2017), also genetically related to the syenites (104 Ma old) that form the Los islands offshore Conakry (Moreau et al., 1996). While no Cretaceous SDRs were described, the Aptian and Albian volcanics and volcaniclastic deposits are widespread on the African margin (Olyphant et al., 2017). The second clue is the huge regional uplift of the Demerara plateau, observed during the Cretaceous rifting. This uplift brought at sea level tilted blocks as the Bastille plateau, likely lying on a 15 km-thick crust (if the crustal thickness is assumed to be similar to the horst at the same depth : Figure 10 in Museur et al., 2021). From the geometry of the late Albian unconformity (Mercier de Lépinay, 2016), the maximum uplift is not related to the transform margins nor to the folded parts of the plateau, but appears to occur on the eastern margin of Demarara, and decreases westward. Both the amount of uplift (close to one kilometre), the affected area (several hundreds of kilometres in diameter) and the timing of vertical motions (post-rift uplift followed by a rapid subsidence) are compatible with a hotspot swell (King and Adam, 2014).

Finally, a high velocity layer is observed at the base of the crust of the Cretaceous margin (Museur et al., 2021, Figure 4G and H); such a layer is commonly observed in the distal part of magmatic divergent margins. It may be related to the Jurassic magmatic margin, despite his location in the proximal part of the Jurassic margin. Alternatively, it may be related to a Cretaceous hotspot location, in the distal part of the Cretaceous divergent margin.

With the present-day data set, it is not possible to prove the relationship between a hotspot and the East Demerara divergent margin. If this hotspot existed, it should be considered as a twin of the Sierra Leone hotspot, about 500 km eastward, comparable to the Tristan and Gough (Hoernle et al., 2015) hotspot pair today. If it was the case, this twin hotspot may not have been active more recently than the Cenomanian (95 Ma), because no associated bathymetric trace can be observed in the Sierra Leone abyssal plain.

Conclusions

All together, we cannot propose any observation or argument to assess that the transform faults north of the Demerara plateau are inherited from older structures. On the contrary, the location of the pull-apart north of Demerara plateau is coincident with, and therefore appears to be controlled by a crustal-scale structure inherited from the Jurassic rifting. In this case, the lateral boundary of the very thick (> 21 km) depocenter of Jurassic SDRs appears to act as a weaker zone (Figure 5A and B). This also may be the case for the East Demerara divergent margin, which coincide with the eastern boundary of the SDRs, but an alternative hypothesis may be that this margin segment has been localised by a hypothetic hotspot and the induced weakening of the lithospheric mantle. In any case, the discontinuous structure of the north-east transform segment, that consists of several en echelon ridges, can be explained by the small offset (less than 200 km) between the two divergent segments. This difference in length and structure of the north-western and north-eastern transform segments is difficult to explain if it is assumed that the transform faults appear first. On the contrary, it is an additional argument to propose that these transform segments formed after the adjacent rift segments. These observations favor Taylor's model in the case of the Demerara plateau: during the Cretaceous rifting and subsequent oceanic accretion, the transform faults may be considered as secondary structures that connect the primary divergent rift segments (Figure 5B and C). Of course, it does not exclude that transform fault can appear re-using older structures, as far as they have the adequate location and geometry. But as the first appearing and developing structures are the divergent basins, they are the ones where inheritance is of primary importance. The location of divergent segments can be inherited, and determine obliquity (i.e. the angle between the line connecting two divergent basins and the relative displacement direction), and the length of connecting transform segments. Inheritance can be controlled by previous rift stages, or by a thermal anomaly (such as a hotspot) affecting the thickness and strength of the lithosphere.

Consequently, the numerical and analogue models that can be used to study these structures should not only induce the transform faults in the model setting (e.g. McClay and Dooley, 1995; Basile and Brun, 1999 for analogue models, Brune et al., 2014 for numerical models), but also allow transform faults to appear as a connection between the tips of offset rift or oceanic accretionary segments (e.g. Gerya, 2013a and b; Basile and Braun, 2016; Ammann et al., 2018; Duclaux et al., 2020).

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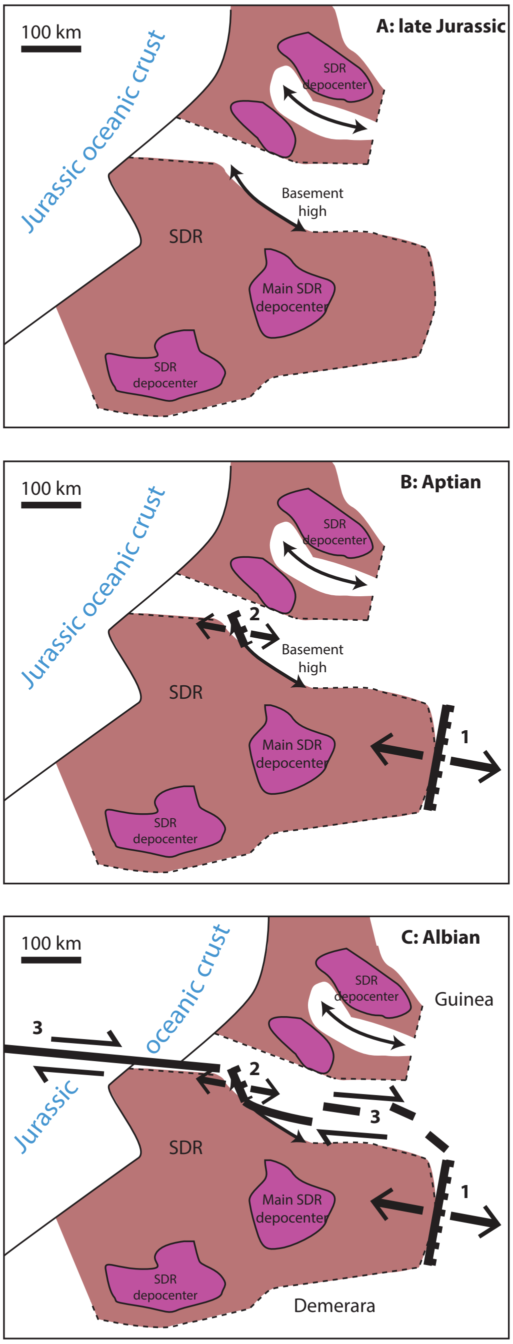

Figure 5: Interpretative sketch for the formation and segmentation of the Cretaceous margins around the Demerara plateau. 5A: structure after the Jurassic formation of the Central Atlantic. The initial SDR extension may extend beyond the dotted lines, that are the limits of available or interpretable seismic lines. 5B: Aptian rifting, supposed to start East of Demerara (1) before North of Demerara (2), although no direct correlation is available. 5C: Aptian to Albian formation of the transform faults (3).

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