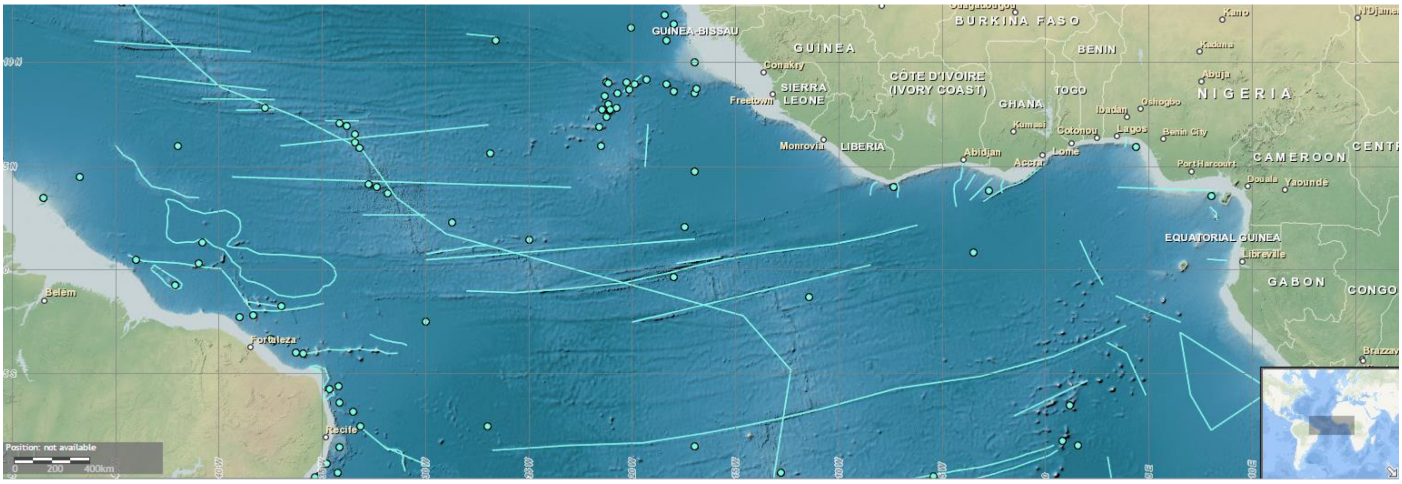
Fast-Track Brazil

May, 2019.

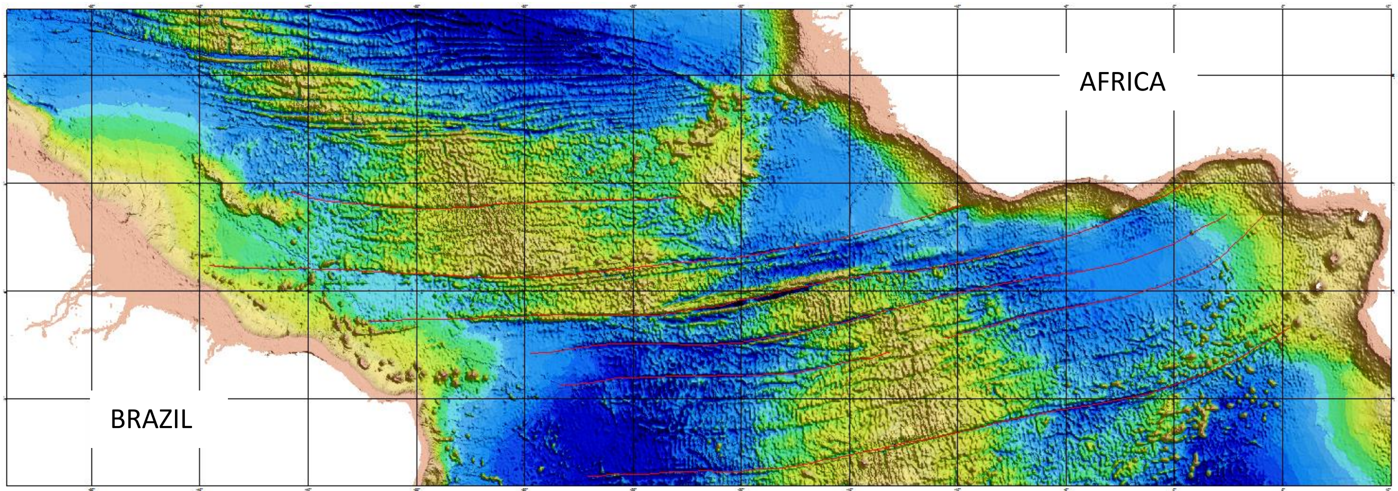
1. After a review over on-line GEBCO Gazetteer it was observed that **Fernando de Noronha Fracture Zone** and **Charcot Fracture Zone** are not represented on-line GEBCO Gazetteer.

Analyzing the Digital Terrain Model - DTM together with the Free-Air model we may better define these features in order to update de GEBCO Gazetteer shape files dataset.

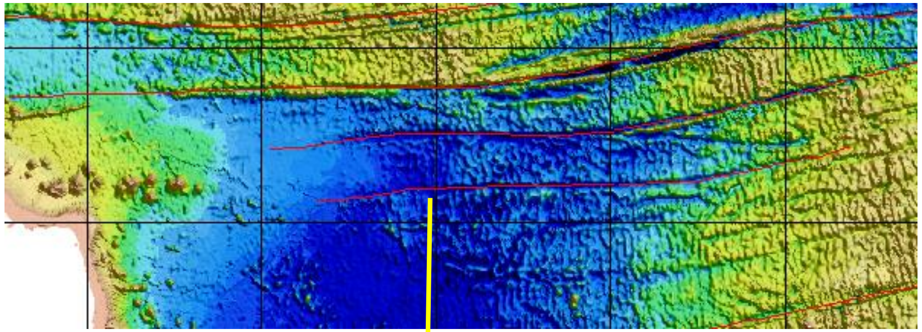
On-line GEBCO Gazetteer Map



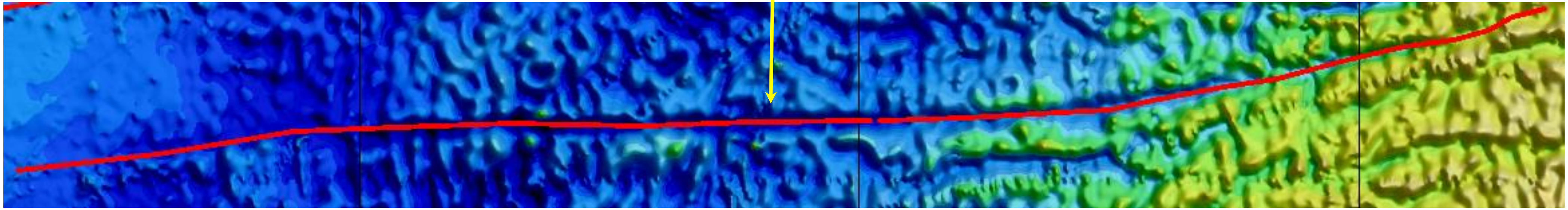
Digital Terrain Model - DTM between Brazil and Africa and the Fracture Zones in red lines



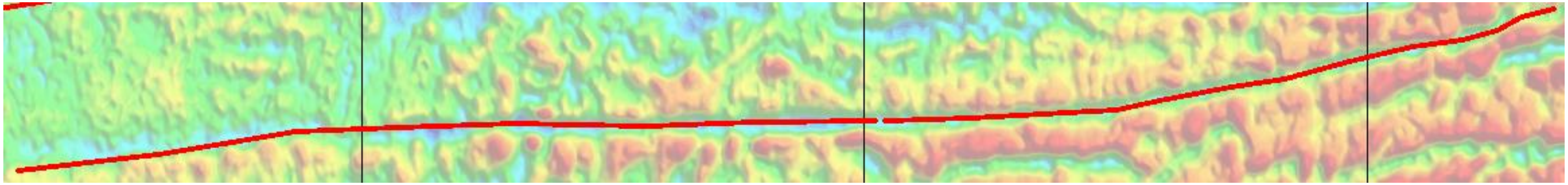
Fernando de Noronha Fracture Zone (not represented on-line GEBCO Gazetteer)



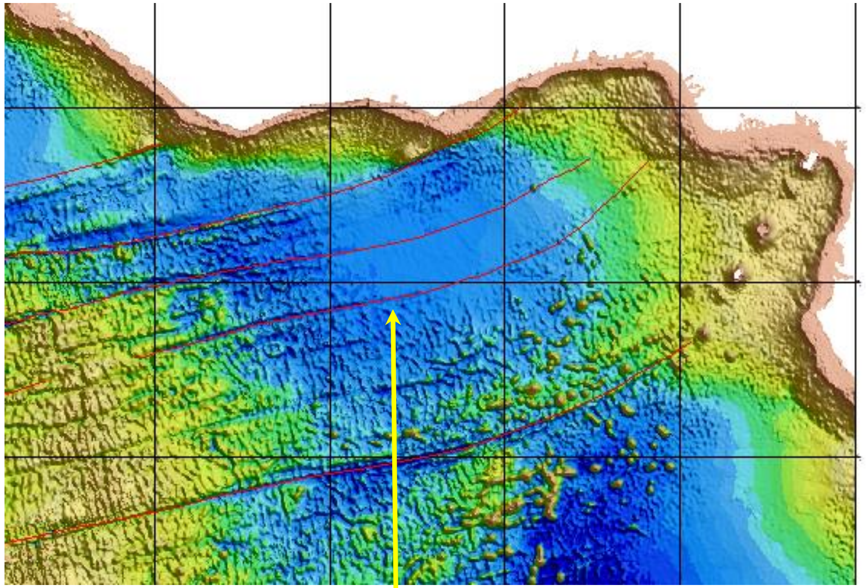
Digital Terrain Model - DTM



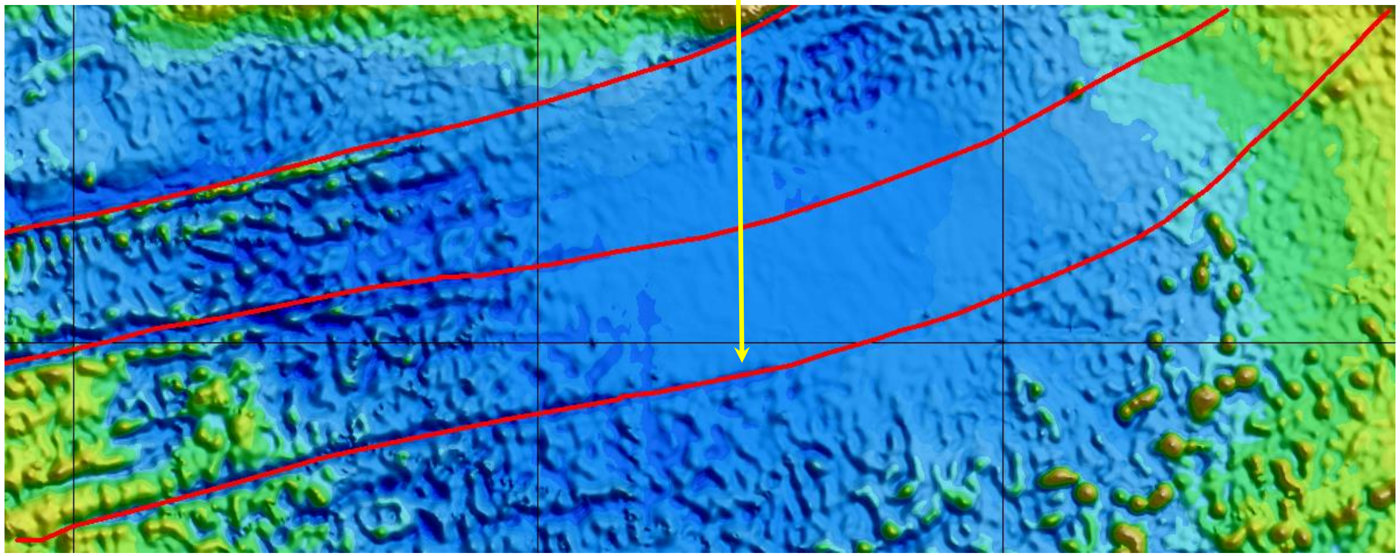
Free-Air model



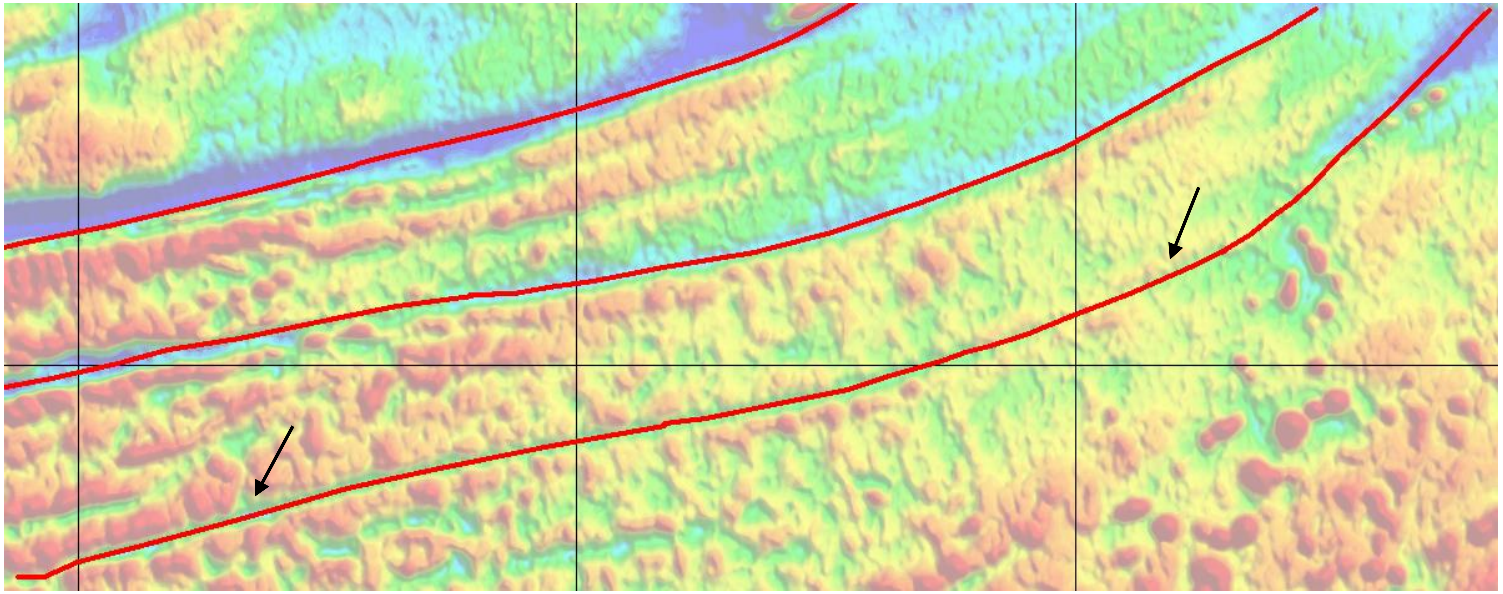
1.7. Charcot Fracture Zone (not represented on-line GEBCO Gazetteer)



Digital Terrain Model - DTM



Free-Air model



THE TECTONIC FABRIC OF THE EQUATORIAL ATLANTIC AND ADJOINING CONTINENTAL MARGINS: GULF OF GUINEA TO NORTHEASTERN BRAZIL (*)

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ABSTRACT – Fracture zones are very prominent and generally linear basement features which bound segments of oceanic crust and offset the mid-oceanic ridge. Major fracture zones offset the Mid-Atlantic Ridge in the equatorial region by distances ranging from 300 to 900 km. Saint Paul's, Romanche, Chain, Jean Charcot/Fernando de Noronha, and Ascension Fracture Zones were mapped from the African to the Brazilian coast across the equatorial Atlantic. Each of these fracture zones displays a ridge and trough morphology that can be traced laterally (when available data permitted) from the offset region of the Mid-Atlantic Ridge to the continental margins on either side of the Atlantic. Mapping of the basement features (ridges and troughs) in the equatorial Atlantic reveals that a marked east–west basement fabric exists for the entire ocean floor and that the Mid-Atlantic Ridge axis is asymmetrically located toward west. The fracture zones in the equatorial Atlantic vary considerably in width (⩾50 km), complexity, trend, and morphology along their strikes. They extend nearly continuously from the Brazilian shield to the West African shield and divide the ocean floor into segments bounded by linear ridges and intervening troughs. In the continental shelves, horst and graben structures occur laterally along the continuation of fracture-zone trends and half-graben(*) basins occur in the continental shelves in the crustal segments between these fracture-zone trends. The fracture-zone trends were established at the onset of rifting; these trends did not necessarily originate along old weakness zones in the Precambrian shields and platforms.

Marginal fracture ridges which occur in the continental margin of the equatorial Atlantic are very prominent physiographic features which are lateral continuations of the transverse ridges of fracture zones in mid-ocean. The very high relief and the youthfulness of volcanism in some of the marginal ridges suggest that tectonic adjustments have been taking place along fracture zones at distances far from the offset region of the Mid-Atlantic Ridge axis.

Other important structural features which are intimately related to rifting in the equatorial Atlantic and which are examined in detail in the present study are the Marajó System of Grabens, the Benue Trough, and the Cameroon Structural Trend. The Marajó System of Grabens (in the Amazon area of Brazil) originated from the southward propagation of the rifting direction that was probably associated with the opening of the North Atlantic Ocean. The Benue Trough in Africa is flanked by fracture-zone directions that imprinted a horst-and-graben setting in the basin. Folding in the Benue Trough is probably caused by vertical tectonism associated with the uplift and differential tilting of buried basements horsts. This vertical tectonism may have been caused by adjustments to changes in transform motion between the African and South American plates. The Cameroon Trend is a horst-like feature whose origin may be associated with the breakup of the continents and is probably linked with the reactivation of a Precambrian lineament that is represented in both sides of the Atlantic by the Pernambuco Lineament in Brazil and by the Ngaoundéré Fault Zone in West Africa. The tectonic reactivation of this lineament caused the occurrence of magmatism and the development of horst-like features that acted as a physiographic barrier to salt deposition in the South Atlantic during the Aptian. To the north of the lineament no salts were deposited, whereas a large salt basin existed to the south. The Cameroon Volcanic Line has been reactivated since the Late Mesozoic by complex magmatism (granites, basalts, and alkaline rocks) and block faulting. On the Brazilian side, the Pernambuco Lineament was also reactivated in the Late Mesozoic. The Cameroon Trend is apparently a landward continuation of the Ascension Fracture Zone.

The remarkable geological fit of Africa and Brazil in the equatorial Atlantic suggests that the rifting and subsequent drifting of the two continents did not involve appreciable crustal distortion of the two continents.

KEY WORDS: Brazil; Gulf of Guinea; Brazilian Continental Margin; African Continental Margin; Equatorial Atlantic Ocean; Structural geology; Physiography; Tectonism; Sedimentary processes; Fracture zones; Plate tectonics; South Atlantic evolution; Atlantic type continental margin; Geological history.

(*) *Here, the term "half-graben" does not have the meaning of an* asymmetric graben. *As used in this context, it means a* rifted pull apart basin. – (The Editor)

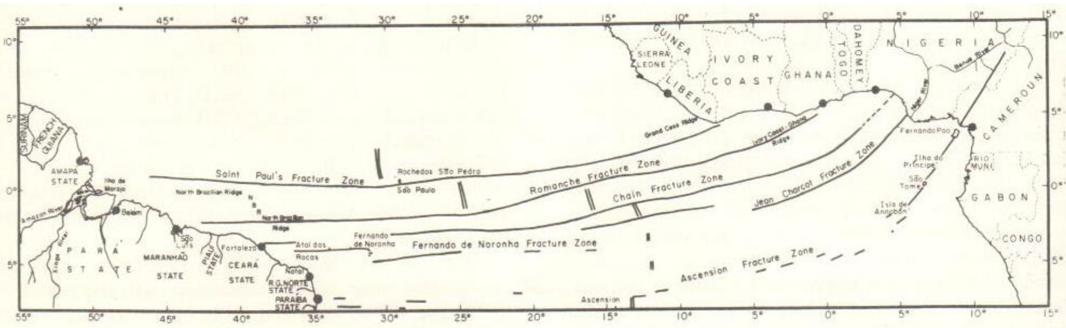

Fig. 1

The equatorial Atlantic and the fracture zones studied in this work.

2.4 – *FERNANDO DE NORONHA/JEAN CHARCOT FRACTURE ZONE*

The discovery by French workers of an important lineament to the south of Chain Fracture Zone, which consisted of a buried ridge in the continental rise of the Gulf of Guinea, led to the speculation that this lineament represented a fracture zone in mid-ocean (DELTEIL *et alii,* 1974). The lineament, the Jean Charcot Ridge, is not only a prominent ridge, as seen in profile 6, but also marks a pronounced basement level change. This implies that the ridge indeed corresponds to a fracture zone trend (Figs. 3 and 4, profiles 9, 11-15, and 20). Seismic profiles are not available between 5^{o}W and 12^{o}W longitudes, but profiles 36 and 37 (Figs. 3 and 4) suggest that a prominent fracture zone, to the south of Chain Fracture Zone, may well correspond to the Jean Charcot lineament in mid-ocean. This last assertion is in agreement with the so-called Charcot Fracture Zone shown in EMERY *et alii* (1975).

Fernando de Noronha seamount chain was visualized as a continuous ridge when Lamont-Doherty Geological Observatory made geophysical surveys in the continental margin of northern Brazil. The lineament of Fernando de Noronha together with the North Brazilian Ridge confined the sedimentation of a part of the northeastern Brazilian margin (GORINI & BRYAN, 1974). Further studies demonstrated that the guyots, volcanic islands, seamounts, and basement highs of Fernando de Noronha Ridge were continuous with a fracture zone to the east of 31^{o}W, hence named as Fernando de Noronha Fracture Zone (Figs. 3 and 4, profiles 49, 50, 52-54, 56-58, 60, and 62) – (GORINI *et alii,* 1974). The fracture zone was mapped as far east as 25^{o}W and it could not be followed farther eastward because of a lack of closely spaced crossings. Profile 43 shows a topographically complex zone between two markedly distinct basement levels, thus suggesting a fracture zone. This fracture zone is correlated laterally to the probable fracture zone depicted in profile 39 and may also correspond to the fracture zone seen in profiles 36 and 37. Consequently, Fernando de Noronha Fracture Zone is believed to be in the same lineament on the Brazilian side as the Jean Charcot Fracture Zone on the African side: both have the same relative positions with respect to Chain Fracture Zone on either side of the Atlantic (Fig. 7). However, as it will be discussed later, in the early rifting history of Brazil and Africa the two lineaments had distinct geographic locations.

Continental Margin in the Northern Part of the Gulf of Guinea

Jean-Raymond Delteil, Pierre Valery, Lucien Montadert, Catherine Fondeur, Philippe Patriat, and Jean Mascle

Coast-Ghana Ridge and the Liberian Ridge, from the standpoint of origin and structure; it may also be compared with the continental margin of South Africa at the Agulhas fracture zone (Talwani and Eldholm, 1973).

The Benin 4 profile (Fig. 9) reveals that the structural framework of the central portion of the marginal basin is linked to the existence of a substratum uplift bounding two compartments: one west and south compartment, containing the series described above for the deep basin; together with a north and east compartment in which correlations indicate a considerable thinning of the post-Early Cretaceous series and the presence of a thick sedimentary series (noted J-Ci), which is ascribed to the early Mesozoic, but which probably contains Paleozoic formations. It should be recalled that the continental shelf of Ghana exhibits a Paleozoic and Mesozoic basin distinguished by a horst-and-graben architecture generally caused by NE- or NW-trending faults (Cudjoe and Khan, 1973). Observations carried out on the northern compartment of profile 4 appear to indicate a structural framework of this type, consequently suggesting geological continuity with the Ghanaian shelf from the horst mentioned

CONTINENTAL MARGIN OFF THE NIGER DELTA

The Chain fracture zone has been identified as the southern extremity of the Benin 7 (Fig. 11) and Benin 8 profiles as well as the Walda 54 and 55 profiles. It corresponds to an uplift in the oceanic substratum separating two compartments distinguished by a sedimentary cover which is thicker in the north than in the south. However, the throw is low (0.5 sDT). On the other hand, a substantial magnetic anomaly is observable above the structure.

The seismic profiles located off the Niger Delta, particularly Walda 45, Walda 46 (Fig. 12), and Walda 51 (Fig. 13) reveal the existence of a highly characteristic structure at the level of the oceanic basement, about 150 km south of the Chain fracture zone.

As noted, this structure exhibits a significant variation in sediment thicknesses, with substantial thinning toward the south. This structural unit also coincides with a significant magnetic alignment clearly observable between 2°W and 5°E. These criteria and their relation to a structural axis parallel in direction to the Romanche and Chain

fracture zones have led the authors to its definition as a new fracture zone, for which the name "Charcot" is proposed.

It appears that this fault was overlapped at the southern extremity of the Benin 9 profile (Fig. 14) by 3°N and 5°E, as the same magnetic anomaly is found here. However, in this profile, the substratum structure is obscured by the complex "diapiric" phenomena of the continental slope off the Niger Delta.

Its possible prolongation toward the continent was not studied. The existence of a gravimetric high (Hospers, 1965, 1971) in the region of the mouths of the Niger should be recalled. However, the existence of a relationship between these two structures cannot be positively affirmed.

From the standpoint of oceanic tectonics, it should be noted that the Charcot fracture appears to exceed the Chain fracture in importance by its influence on the sedimentation in the eastern region of the Gulf of Guinea. On the other hand, it cannot be positively identified in the direction of the Mid-Atlantic Ridge and at the central rift.

The main feature of the margin resides in the development of relatively intense diapiric tectonics visible on the Benin 9 profile (Fig. 14), which appears to persist at the foot of the continental shelf at a depth of about 3,500 m. The origin of this diapiric activity has been debated, and has been attributed by some authors to a salt diapir origin (Pautot et al., 1973; Mascle et al., 1973)

GENERAL STRUCTURE OF THE GULF OF GUINEA

Substratum of the Basin

The deep structure of the Gulf of Guinea in the area under consideration is illustrated by the isochronous map at the substratum level in Figure 15. This map leads to the following observations:

1. The equatorial fracture zones extend to the internal portion of the Gulf of Guinea.
2. These fractures, whose positions have been clarified with respect to previous data, cause a division into parallel compartments. From north to south, the oceanic substratum exhibits a stepwise structure mounting toward the south. This agrees with the offsets observed at the Mid-Atlantic Ridge, implying that the substratum is more ancient on the northern than on the southern block for a given meridian, and that the subsidence has thus been more pronounced. This is probably accentuated by the damming effect of the fracture zones. In any given compartment, a deepening of the basement toward the continental margin is indeed observable. By comparison with the bathymetric map, it may be deduced that the sediment thickness is greatest north of the Romanche and off the Niger.
3. The orientation of the seismic profiles did not permit clarification of any noteworthy structural fault perpendicular to the fracture zones. The magnetic E-W line between the Romanche and the

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Role of Equatorial Fracture Zones on Fluid Migration across the South Atlantic Margins

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Abstract

The continental margin basins of Brazil and West Africa share very similar tectono-stratigraphic megasequences that are recognizable in petroliferous basins, as a result of the Late Jurassic-Early Cretaceous rifting of the South Atlantic basins. A number of oil families present along the South Atlantic conjugated margins are composed of genetically related oils of mixed provenance. Motion of tectonic plates and their configurations which depend so much on the nature of the boundaries and their orientations strongly influence fault tectonics within both continents The tectonic evolution of the plates leads to the formation of fracture zones parallel to the direction of plate motion. The Middle Benue Trough of Nigeria and by extension, the whole Benue Trough, is bound by two offshore transform faults (the Chain and the Charcot Fracture Zones). These faults are asymmetric longitudinally with an oblique transverse fault bounding the basin, and have been outlined by the presence of magnetic lineation. Five E-W profiles across the Middle Benue Trough were selected for the application of Werner deconvolution and subjected to harmonic analysis. The magnetic dataset was used in concluding that the Equatorial Fracture Zones (EFZ) in the South Atlantic Ocean extending from South America into the Gulf of Guinea are mainly responsible for long distance migration of marine hydrocarbons from the West Africa margin to the offshore of Brazil.

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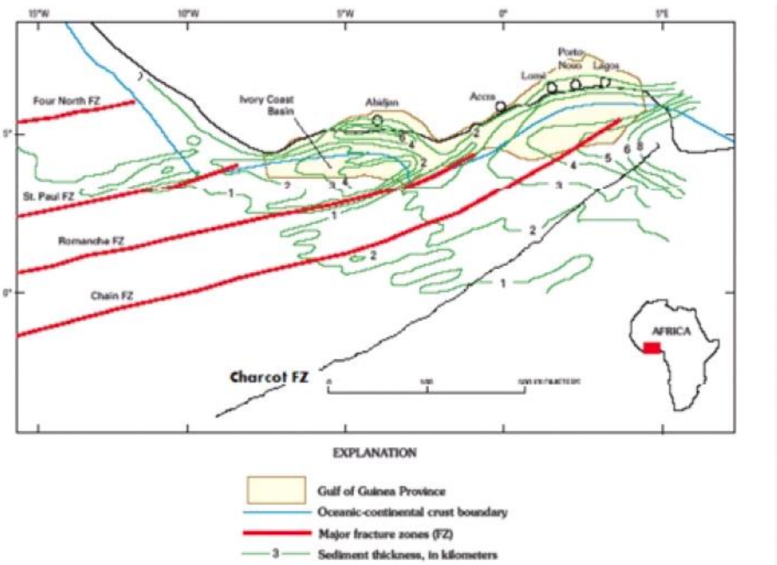
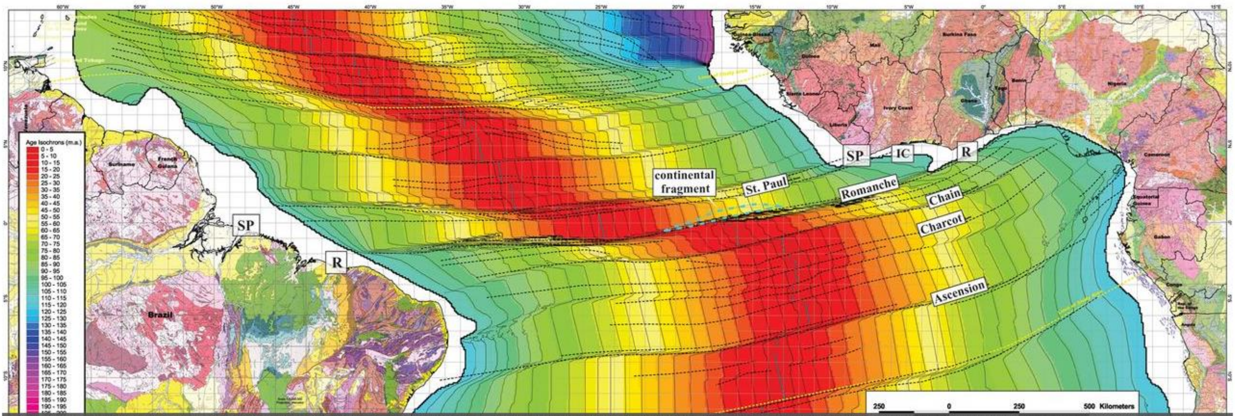


Figure 10: Sketch map showing major Fracture Zones (FZ), sediment thickness, and oceanic-continental crust boundary for the Gulf of Guinea Province [44].



Flow lines represented by oceanic fracture zones interpreted on top of the magnetic stripe anomaly-based age of oceanic crust (modified from Müller *et al.* 1997 and Nemčok *et al.* 2013*a* and references therein). Note a change in the spreading vector in the vicinity of the Romanche transform margin (R) from the Albian NE–SW direction to the Thanetian ENE–WSW direction. SP, St Paul transform margin

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Figure extracted from the SUMMARY OF RECOMMENDATIONS OF THE COMMISSION ON THE LIMITS OF THE CONTINENTAL SHELF IN REGARD TO THE SUBMISSION MADE BY GHANA ON 28 APRIL 2009.

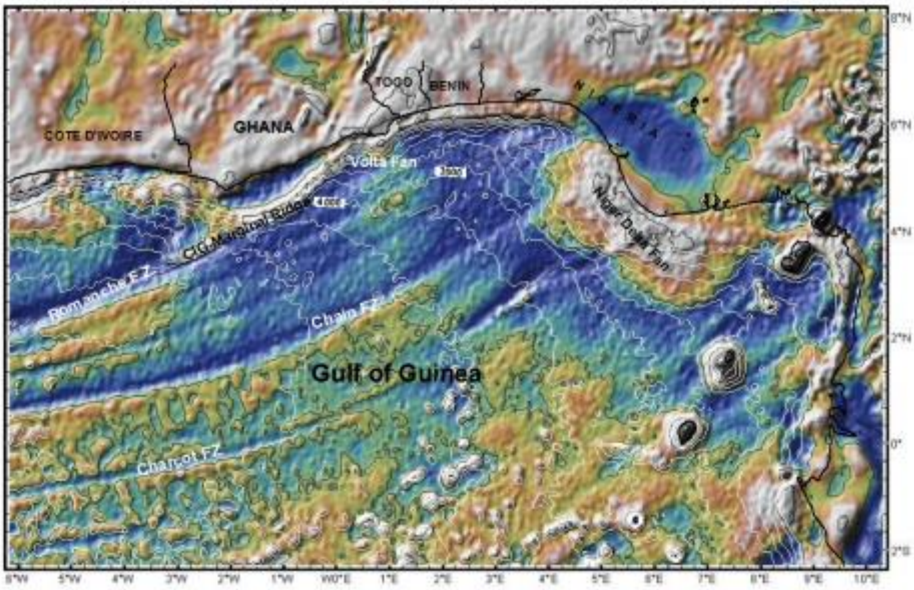

Figure 2: Satellite derived free-air gravity map of the Gulf of Guinea with bathymetric contours in white (source: GeoMapApp, Lamont-Doherty Earth Observatory). The transform margin is characterised by the Côte d'Ivoire-Ghana Marginal Ridge, and aligned with the Romanche Fracture Zone. Other important fracture zones are the Chain and Charcot Fracture Zones.