Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of African Earth Sciences 43 (2005) 275–282
Journal of African Earth Sciences
www.elsevier.com/locate/jafrearsci

Phanerozoic geological evolution of the Equatorial Atlantic domain

Christophe Basile [a,*], Jean Mascle [b], René Guiraud [c]

[a] Laboratoire de Géodynamique des Chaînes Alpines, CNRS UMR 5025, Observatoire des Sciences de l'Univers de Grenoble, Université Joseph Fourier, 1381 rue de la Piscine, BP 53, 38041 Grenoble Cedex, France
[b] Geosciences Azur, CNRS UMR 6526, Observatoire océanologique de Villefranche, BP 48, La Darse, 06235 Villefranche-sur-Mer, France
[c] Laboratoire Dynamique de la Lithosphère, case 060, Université Montpellier 2, 34095 Montpellier Cedex 5, France

Received 19 June 2004; accepted 18 July 2005
Available online 2 November 2005

Abstract

The Phanerozoic geological evolution of the Equatorial Atlantic domain has been controlled since the end of Early Cretaceous by the Romanche and Saint Paul transform faults. These faults did not follow the PanAfrican shear zones, but were surimposed on Palæozoic basins. From Neocomian to Barremian, the Central Atlantic rift propagated southward in Cassiporé and Marajó basins, and the South Atlantic rift propagated northward in Potiguar and Benue basins. During Aptian times, the Equatorial Atlantic transform domain appeared as a transfer zone between the northward propagating tip of South Atlantic and the Central Atlantic. Between the transform faults, oceanic accretion started during Late Aptian in small divergent segments, from south to north: Benin-Mundaú, deep Ivorian basin-Barreirinhas, Liberia-Cassiporé. From Late Aptian to Late Albian, the Togo-Ghana-Ceará basins appeared along the Romanche transform fault, and Côte d'Ivoire-Parà-Maranhão basins along Saint Paul transform fault. They were rapidly subsiding in intra-continental settings. During Late Cretaceous, these basins became active transform continental margins, and passive margins since Santonian times. In the same time, the continental edge uplifted leading either to important erosion on the shelf or to marginal ridges parallel to the transform faults in deeper settings.

Keywords: Equatorial Atlantic; Rifting; Transform margin

1. Introduction

In the African and South American lithospheric plates, the Equatorial Atlantic domain is a peculiar area where both Phanerozoic structures and geological evolution have been controlled by few but very long transform faults, still active since their initiation at the end of Early Cretaceous. From south to north, there are the Chain, Romanche and Saint Paul fracture zones (Fig. 1). The continental basins that appeared along these transform faults are the Benue and Potiguar basins (Chain), Togo-Ghana and Ceará basins (Romanche), the Côte d'Ivoire and Pará-Maranhão basins (Saint Paul) (Fig. 1). Between these transform faults, short segments of conjugated divergent margins are from south to north Benin-Mundaú, deep Ivorian basin -Barreirinhas, Liberia-Cassiporé (Fig. 1).

Unfortunately, this area has been relatively poorly investigated for several reasons:

- as for many sedimentary basins, there are few aerial outcrops, especially along the African margin;
- the continental margins are mainly of transform-types, thus very narrow and potentially less interesting than wide divergent margins for oil prospection;
- vertical seismic lines does not provide good images of the numerous strike-slip faults;
- the geodynamic framework is poorly constrained because the oceanic accretion started during the Cretaceous quiet magnetic period, because the present position below the magnetic equator prevails good quality magnetic measurements, and finally because the

* Corresponding author. Tel.: +33 47 651 4069; fax: +33 47 651 4058.
E-mail address: cbasile@ujf-grenoble.fr (C. Basile).

1464-343X/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.jafrearsci.2005.07.011

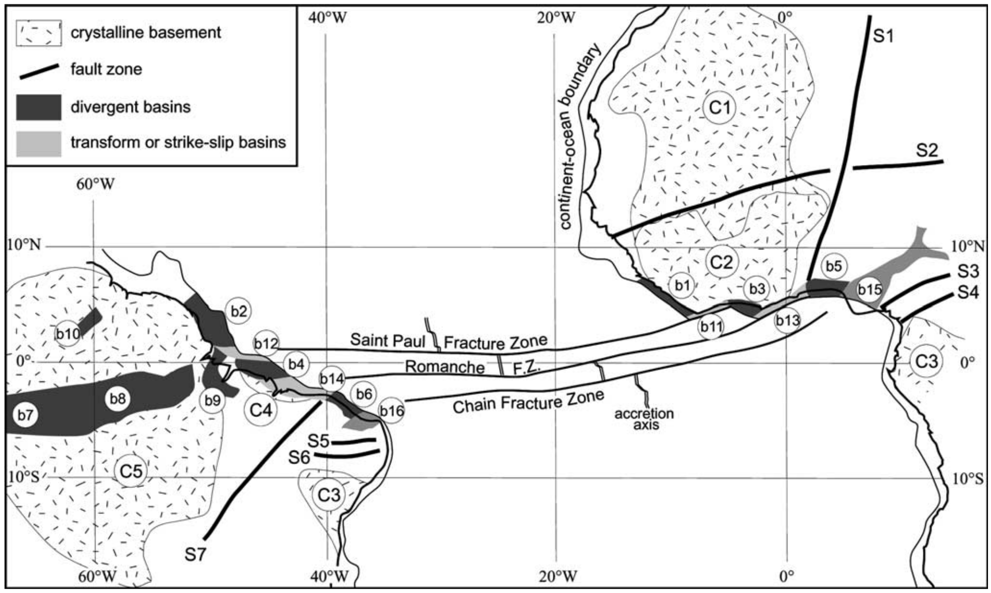

Fig. 1. Main structures in Equatorial Atlantic. Brazilian basins from Milani and Thomaz Filho (2000); cratons and intracontinental shears modified from Villeneuve and Cornée (1994). C1: West African craton; C2: Eburnean shield; C3: Sâo Francisco craton; C4: Sâo Luis craton; C5: Guyana craton. S1: Kandi lineament; S2: Guinean-Nubian lineaments; S3: South Adamaoua shear zone; S4: Sanaga shear zone; S5: Patos shear zone; S6: Pernambuco shear zone; S7: Trans-brazilian fault zone. Conjugated divergent basins: b1 (Liberia) and b2 (Caciporé); b3 (deep ivorian basin) and b4 (Barreirinhas); b5 (Benin) and b6 (Mundaú). Intracontinental divergent basins: b7 (Solimões), b8 (Amazonas), b9 (Marajó), b10 (Tacutu). Conjugated transform continental margins: b11 (Côte d'Ivoire) and b12 (Pará-Maranhão); b13 (Ghana-Togo) and b14 (Ceará). Strike-slip basins: b15 (Benue), b16 (Potiguar).

numerous and wide fracture zones make the correlation of magnetic anomalies uneasy (e.g. Campan, 1995).

Most of the available geological informations on the continental shelf come from drill-holes and seismic lines performed by the oil industry. During the seventies, the scientific exploration was focused on the survey of fracture zones in the deep basins and dedicated to a first investigation of continental margins (Fail et al., 1970; Arens et al., 1971; Delteil et al., 1974; Emery et al., 1975). From the eighties, investigations were focused on the Côte d'Ivoire-Ghana margin, in the central part of the African equatorial margin, and along the intersection of the Romanche fracture zone with the deep Ivorian divergent basin (review in Basile et al., 1996). These investigations culminated with four scientific drill-holes performed during Ocean Drilling Program Leg 159 along this margin (Mascle et al., 1996).

From this data set, we describe in this paper the geological evolution from a pre-rift reconstruction (Fig. 2a) to the present day stage.

2. Latest Proterozoic to Triasic: pre-rift

The Equatorial Atlantic margins extend over an assemblage of Proterozoic to earliest Palæozoic tectonic domains, that mainly result from the PanAfrican-Braziliano orogeny (Black, 1984) which occurred between ca. 720 and 520 Ma (Villeneuve and Cornée, 1994; Caby, 2003; Guiraud et al., this issue). This fold-thrust belt developed around the West African craton, the Guyana craton, the Sâo Luis craton-Eburnean shield and the Sâo Francisco craton (Fig. 2a). It was associated with major strike-slip fault zones which rejuvenated during Phanerozoic times and more or less influenced the development of the Equatorial Atlantic, as the central African fracture zone (Cornacchia and Dars, 1983; Black, 1984), the Kandi-Transbrazilian fracture zone (Guiraud and Alidou, 1981; Caby, 1989), and the Guinean-Nubian lineaments (Guiraud et al., 1985) (Fig. 2a).

Erosion and tectonic quiescence followed the PanAfrican-Braziliano orogeny. It resulted in a large sedimentary area trending WSW to ENE from northeastern Brazil to West Africa. In Ghana (Kjemperud et al., 1992) (Figs. 3 and 4a) and Côte d'Ivoire basins (Tucker, 1992) as in Brazil (Solimões, Amazonas and Parnaíba basins, Milani and Thomaz Filho, 2000), continental terrigenous sedimentation took place from Ordovician times (Fig. 2a). These basins registered marine invasions between middle Devonian and Early Carboniferous, when large marine platforms extended from the Proto-Pacific Ocean over South America during global sea level highstands (Isaacson and Díaz Martínez, 1995; Williams, 1995). Marine sediments included sandstones, silts, shales, carbonaceous shales and limestones. Poorly dated Late Carboniferous to Triassic continental sandstones overlaid the marine Carboniferous. The total thickness of the preserved Palæozoic series can reach 1000–1200 m (Fig. 4a).

3. Late Triassic to Jurassic: rifting in the Central Atlantic

The Late Triassic rifting in the Central Atlantic extended southward in northern Brazil: Late Triassic

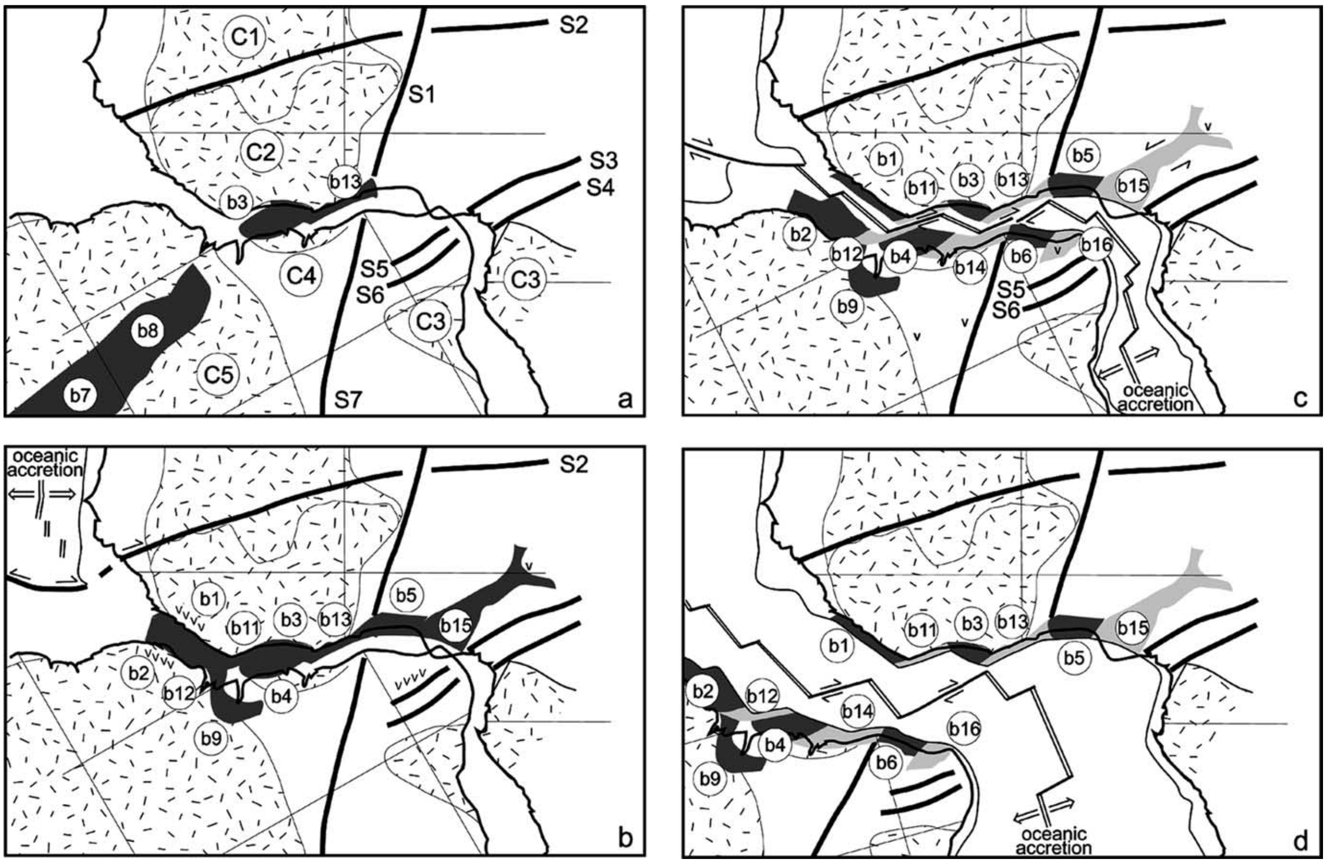

Fig. 2. Geodynamic evolution of the Equatorial Atlantic. Same legend as for Fig. 1: (a) Pre-rift (latest Proterozoic to Triasic) reconstitution. Continental fit after Unternehr et al. (1988), modified from Campan (1995). Africa is supposed fixed. (b) Oxfordian reconstitution. V indicates Early Liassic volcanism in Guyana, Liberia, NE Brazil and Benue basin. (c) Late Aptian reconstitution. Plate boundaries modified from Campan (1995). V indicates Early Cretaceous volcanism in NE Brazil, Potiguar and Benue basins. (d) Santonian reconstitution. Plate boundaries modified from Campan (1995).

terrigeneous continental formations have been drilled in the offshore Caciporé (Brandão and Feijó, 1994) and Marajó basins (Milani and Thomaz Filho, 2000). The orientation of rifting in this northern area has been likely controlled by the PanAfrican Rokelides belt trend. This rifting stage was followed in the earliest Lias (around 200 Ma) by the development of the Central Atlantic Magmatic tholeiitic Province (Wilson and Guiraud, 1998; Burke et al., 2003). This province extended southward over the western part of the future Equatorial Atlantic. Tholeiitic volcanism occurred either intercalated within the sediments in Caciporé, Marajó, Solimões and Amazonas basins, or in NNW–SSE trending dykes in the western edge of Caciporé basin (Milani and Thomaz Filho, 2000), French Guyana (dated 196-200 Ma: Deckart et al., 1997), and Liberia (186-201 Ma: Mauche et al., 1989).

While oceanic accretion started during the Jurassic in Central Atlantic, the Guinean-Nubian/Ouachita-Wichita fault zone (Fig. 2b) acted as a transfer zone between the divergent area northward and an almost stable area southward. South of this fault zone indications of plate divergence are restricted to limited subsidence and some volcanism. Liassic to Tithonian continental sandstones and shales deposited along the NW–SE trending Liberia basin (Martin, 1982). Late Jurassic continental terrigenous formations also deposited offshore Côte d'Ivoire (Martin, 1982), in Ghana (Martin, 1982), Benin (Dray et al., 1989) and in upper Benue (Guiraud, 1993) basins (Fig. 2b). In this equatorial area, the Mesozoic sedimentation seems to have been independent from the PanAfrican structures, but was probably localized over Devonian basins. Basalt flows occurred in the eastern Ghana basin during the Callovian (Akpati, 1978) (Fig. 3), in the Benue basin and in the western part of the Maranhão basin since 147 Ma (Popoff, 1988; Fodor et al., 1990; Maluski et al., 1995). Basaltic dykes intruded around the northwestern Brazil Potiguar basin during Middle Jurassic (Horn et al., 1988; Bellieni et al., 1992) (Fig. 2b). They are trending N70° to N80°E as the PanAfrican Adamaoua and Sanaga lineaments on the African side, or Patos and Pernambuco lineaments on the Brazilian side.

This Callovian to latest Jurassic local rejuvenation or initiation of basin sedimentation and magmatism must be underlined as it is synchronous with similar events occurring along the Central African Rift System, e.g. the upper Benue, the central Sudan or the Anza basin in Kenya (cf. Guiraud et al., this issue). These different clues witness of a change in the paleo-stress field that affected the

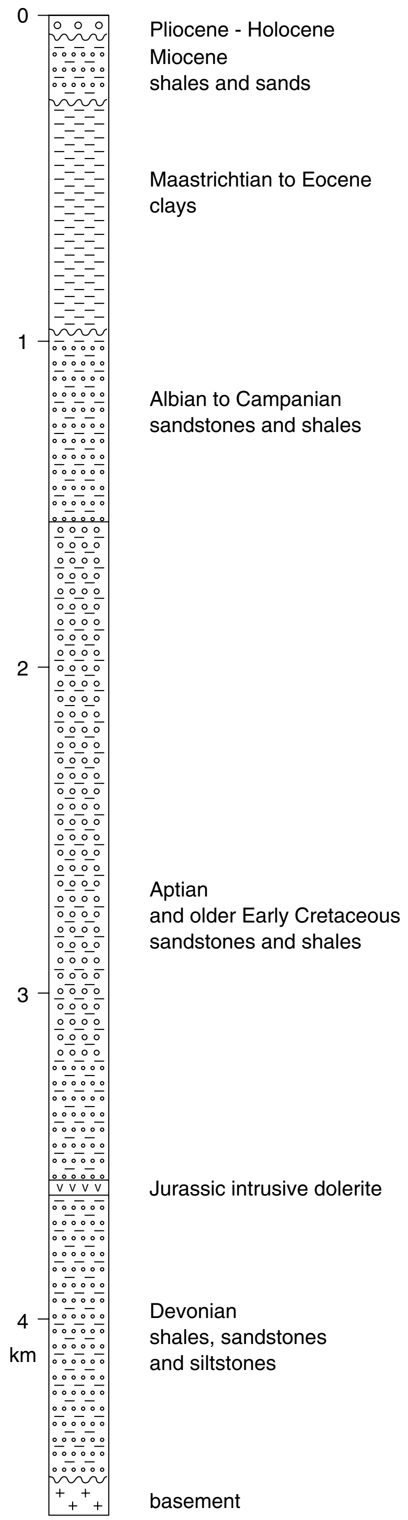

Fig. 3. Composite stratigraphic framework of Keta basin (Ghana margin) (from Akpati, 1978).

African-Arabian/south American plates, characterized by the occurrence of local tensional regimes which represent far-field effects of the opening of the Central Atlantic ocean and the Somali basin (western Indian Ocean). They predate the strong rifting activity that occurred since earliest Cretaceous times.

4. Late Berriasian to Late Aptian: rifting in the South and Equatorial Atlantic

During the Early Cretaceous, a new rift axis appeared in the South Atlantic, in relation with the emergence of the Paraná plume. The volcanic activity of the plume head started 138 Ma ago (Stewart et al., 1996), with a main magmatic episode between 134 and 129 Ma (Peate, 1997). Volcanism occurred in and around the Paraná area, as far as north Brazil in the East Maranhão (115–122 Ma: Fodor et al., 1990) and Potiguar basins (130–140 Ma: Bellieni et al., 1992), and in the Benue basin (Maluski et al., 1995; Coulon et al., 1996) (Fig. 2c). From 130 to 120 Ma, rifting propagated northward to the Benue area, and across Africa to the Tethys realm (Guiraud and Maurin, 1991, 1992). Syn-rift sedimentation started in intracontinental basins since the Berriasian in the Potiguar basin (Araripe and Feijó, 1994) and probably along the Patos lineament in the Araripe (Baudin and Berthou, 1996) and Rio do Peixe basins (Senant and Popoff, 1991; Françolin et al., 1994). During Early Barremian sedimentation started in the Benue Trough (Brunet et al., 1988), the Ghanaian Keta basin (Doyle et al., 1982) and Foz do Amazonas (Brandão and Feijó, 1994). During this first stage of rifting in the equatorial area, the Niger delta area appears as a triple junction between the South Atlantic rift, the Benue transtensional rift and the transform zone of en échelon equatorial basins (Fig. 2c). The rifting of the northeastern branch of the south Atlantic failed around 120 Ma, at the time of the final break up of Gondwana, when oceanic accretion started between Antarctica and India (Scotese et al., 1988). This incipient oceanic accretion imposed a kinematic plate reorganization (Nürnberg and Müller, 1991), and the connection between South and Central Atlantic by the en échelon Romanche and Saint Paul right-lateral transform faults, cross-cutting the PanAfrican structures but localized on previously subsiding areas.

During Aptian times, intracontinental siliciclastic sedimentation occurred in fluvial to lacustrine environments all along these two transform faults, in strongly subsiding basins controlled by strike-slip or transtensional faults (Zalan et al., 1985; de Caprona, 1992; Chierici, 1996; Mascle et al., 1996, 1998; Basile et al., 1998; Attoh et al., 2004) (Figs. 3, 4b, d and e). Between the two transform faults, the Côte d'Ivoire area represented a pull-apart structure, dominated by ENE-WSW extension and tilted blocks in the central part of the deep Ivorian basin (Blarez and Mascle, 1988; Basile et al., 1993; Sage, 1994). However, most crustal thinning and associated subsidence was localized along the curved coastal fault (de Caprona, 1992; Chierici, 1996), which was the termination of St Paul transform fault in the extensional area. Similarly, horsetail splay occurred at the connection between the Romanche transform fault and the southern side of the rifted Ivorian basin (Basile et al., 1993).

5. Late Aptian to Late Albian: post-rift, intracontinental transform

Rifting in the equatorial divergent basins stopped when the first oceanic crust accreted during the Cretaceous quiet magnetic zone (Fig. 2c). Starting accretion correlates with a Late Aptian post-rift unconformity observed in the deep Ivorian basin (Basile et al., 1993; Basile et al., 1998) (Fig. 4b) and in the conjugated Ceará basin (Zalan et al., 1985) (Fig. 4d and e). However, between the divergent accretion axis, deformation was still active along the transform fault. Intracontinental rapidly subsiding basins (Ghana: Attoh et al., 2004; Côte d'Ivoire: de Caprona, 1992; Brazil: da Costa et al., 1990) developed along the transform faults, probably in structures similar to those developed during Cenozoic times along the Dead Sea transform fault. Sedimentation was still siliciclastic (Fig. 3), probably feeded by the erosion of uplifted shoulders along

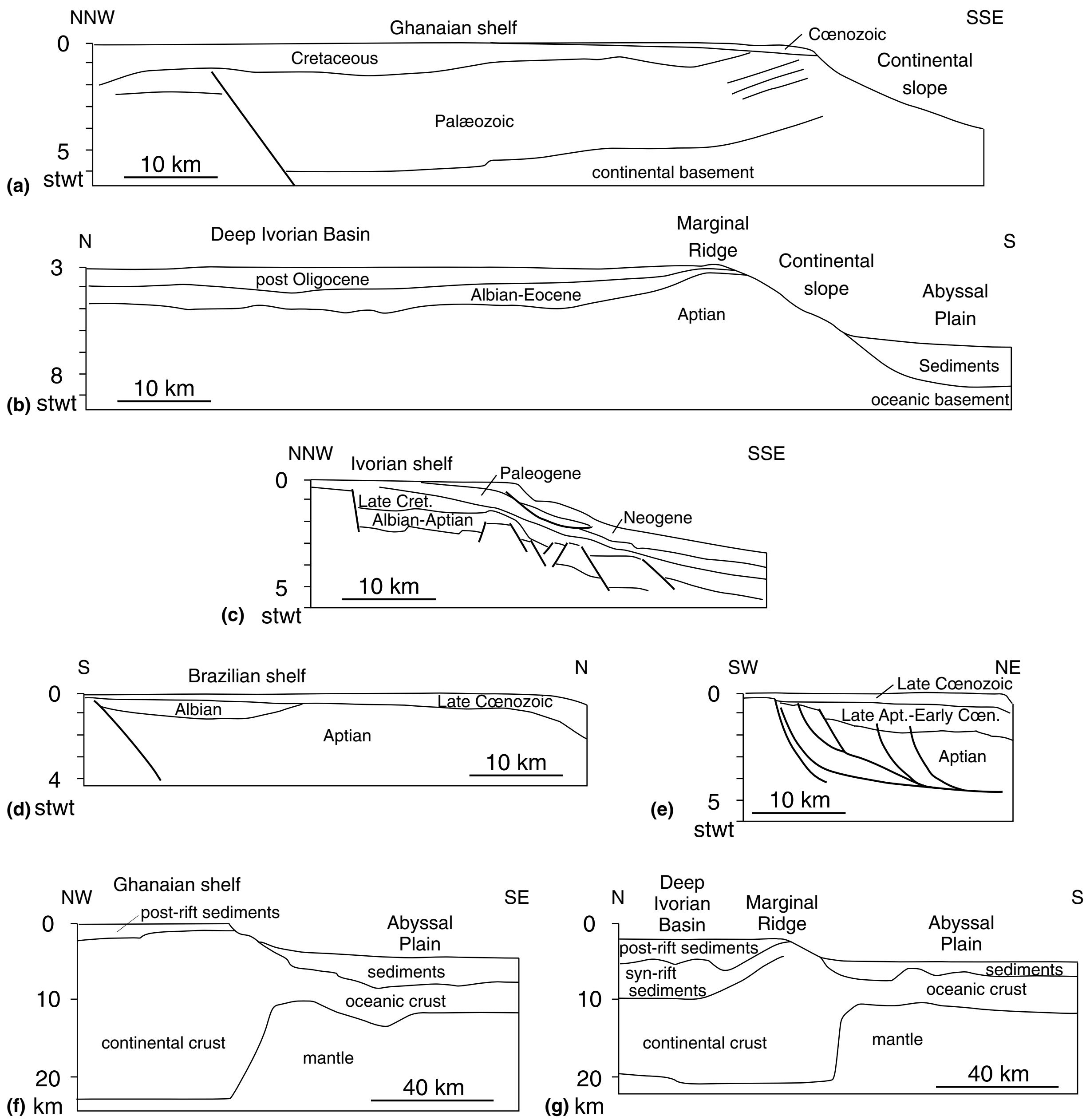

Fig. 4. Line drawing of seismic sections across continental margins in the Equatorial Atlantic. Same vertical (in second two-way travel time) and horizontal scales for (a)–(e), with vertical exaggeration three for water velocities. (a) Ghana margin (b13 in Fig. 1), modified from line 47 (Attoh et al., 2004). (b) Deep Ivorian Basin (b3 in Fig. 1) and Côte d'Ivoire-Ghana marginal ridge (b13 in Fig. 1), modified from line MT02 (Basile et al., 1996). (c) Côte d'Ivoire margin (b11 in Fig. 1), modified from figure 7–17 (de Caprona, 1992). (d) Ceará margin (b14 in Fig. 1), modified from line 53–280 (Zalan et al., 1985; da Costa et al., 1990). (e) Mundaú basin (b6 in Fig. 1), modified from lines 222–529 and 58–319 (da Costa et al., 1990). (f) and (g) are crustal sections of Ghana margin and Côte d'Ivoire-Ghana marginal ridge, respectively (same scales, vertical exaggeration 2.5). (f) modified from Edwards et al. (1997), in the area of (a); (g) modified from Sage (1994), along the same section as (b).

the transform basins. First marine influences appeared in the Equatorial area during Late Aptian (Koutsoukos, 1982; Mascle et al., 1996; Maisey, 2000), but open marine connection between South Atlantic and Central Atlantic oceans occurred only during Late Albian times, through narrow but locally deep basins (Pletsch et al., 2001).

While rigth-lateral transform faulting developed in the Equatorial Atlantic, left-lateral strike-slip faults were still active in the Benue trough (Guiraud, 1991), indicating that the Niger delta was still a triple junction up to Late Albian, even if displacements in the Benue area were probably very small when compared with displacements in the Atlantic area.

This intracontinental transform stage ended when the active transform fault brought into contact an oceanic lithosphere against a continental lithosphere. A second unconformity is associated to this event (Fig. 4c and d), expected to have been diachronous along the transform fault, and older on the eastern termination of the transform faults on the African side (respectively on the western end on the Brazilian side) (Mascle and Blarez, 1987). Consequently, the ages of the unconformity vary along the margin, but are not younger than Late Albian, as at the African westernmost end of the Romanche transform, in the Côte d'Ivoire-Ghana marginal ridge area (Basile et al., 1998).

6. Latest Albian to Late Santonian: active transform margin

This stage started everywhere on the Equatorial continental margins by a diachronous unconformity that sealed the deformation. However, the reconstructions of the oceanic opening imply that transform faults were still active at that time between continental and oceanic lithospheres. This implies that the active transform zone shifted from the continental edge to the continent-ocean boundary, and that the deformation ceased on the continental margin (e.g., Basile et al., 1993; Basile et al., 1998). One of the most striking event at this stage is the uplift of the continental edge along the transform continent-ocean boundary. Where the continental crust was thinned and deep, as in the deep Ivorian basin or in Liberia, this resulted in the formation of a marginal ridge parallel to the transform fault (Fig. 4b and g). Where the continental crust has not been thinned, the uplift resulted in tilting towards the continent and erosion (e.g. da Costa et al., 1990; Attoh et al., 2004) (Fig. 4a and f). Since Mascle and Blarez (1987) and Todd and Keen (1989), this uplift along transform continental margins has been mainly explained as a consequence of transient heat transfer from the hot oceanic lithosphere to the coldest continental one. However, two of the most important results of ODP Leg 159 are that uplift occured along the Côte d'Ivoire-Ghana marginal ridge since middle Albian times (Basile et al., 1998), i.e. during the intracontinental stage, and that there are no evidences of heating associated with the contact between oceanic and continental lithospheres (Basile et al., 1998; Wagner and Pletsch, 2001). Consequently, an alternate explanation has been proposed for transform uplift, based on the lithospheric flexure resulting from erosional unloading of the continental crust along the transform fault, when plate displacement brings into contact continental crust at sea-level against deeper thinned continental crust, then oceanic crust (Basile and Allemand, 2002).

This stage ended when the oceanic accretion took place against the transform margin (Fig. 2d). As for the beginning of this stage, this end is diachronous as the accretion axis moved along the transform fault. The last contact between the continental lithosphere and the accretion axis occurred during Late Santonian (84 Ma) (Fig. 2d), and was coeval with a major kinematic change for the African plate (Guiraud and Bosworth, 1997).

7. Post-transform evolution: passive continental margin

From Late Santonian to present times, the continental margins experienced continuous subsidence, increased above previous basins by differential compaction, and reduced above the previously uplifted continental edges. In the deep parts of the margins, changes in sedimentation indicate an increasing influence of deepwater circulation, probably as the consequence of the establishment of a N–S circulation through the Equatorial Atlantic gateway (Pletsch et al., 2001). In the shallower parts, the Oligocene unconformity (e.g. Chierici, 1996) (Figs. 3, 4b and c), known in all West African coastal basins, appears as the most important event in the sedimentary section, and was probably related to a main sea-level fall. Anyway, because of their very steep continental slopes, the transform margins of the Equatorial Atlantic were not widen as divergent margins during the post rift stage: progradation of the shelf break by sedimentary accumulation is restricted to the narrows divergent basins as the Mundaú or deep Ivorian basins; along transform margins, shelf sediments by-passed through the continental slope directly to the abyssal plain.

Acknowledgement

We thank T. Pletsch for constructive review.

References

Akpati, B.N., 1978. Geologic structure and evolution of the Keta basin, Ghana west Africa. Geol. Soc. Am. Bull. 89, 124–132.

Araripe, P.T., Feijó, F.J., 1994. Bacia Potiguar. B. Geoci. Petrobrás 8 (1), 127–141.

Arens, G., Delteil, J.R., Valery, P., Damotte, B., Montadert, C., Patriat, P., 1971. The continental margin of the Ivory Coast and Ghana. Inst. Geol. Sci. London, Rep. 70, 61–78.

Attoh, K., Brown, L., Guo, J., Heanlein, J., 2004. Seismic stratigraphic record of transpression and uplift on the Romanche transform margin, offshore Ghana. Tectonophysics 378, 1–16.

Basile, C., Allemand, P., 2002. Erosion and flexural uplift along transform faults. Geophys. J. Int. 151, 646–653.

Basile, C., Mascle, J., Popoff, M., Bouillin, J.P., Mascle, G., 1993. The Ivory Coast-Ghana transform margin—a marginal ridge structure deduced from seismic data. Tectonophysics 59, 1–19.

Basile, C., Mascle, J., Sage, F., Lamarche, G., Pontoise, B., 1996. Pre-cruise and site surveys: a synthesis of marine geological and geophysical data on the Côte d'Ivoire-Ghana transform margin. In: J. Mascle, G.P. Lohmann, P.D. Clift et al. (Eds), Proceedings of the Ocean Drilling Program, Initial reports, vol. 159, 47–60.

Basile, C., Mascle, J., Benkhelil, J., Bouillin, J.P., 1998. Geodynamic evolution of the Côte d'Ivoire-Ghana transform margin: an overview of Leg 159 results. In: Mascle, J., Lohmann, G.P., Moullade, M. (Eds), Proc. ODP, Sci. Results, vol. 159, 101–110.

Baudin, F., Berthou, P.Y., 1996. Environments de dépôt de la matière organique des sédiments aptiens-albiens du bassin d'Araripe (NE du Brésil). Bull. Centres Rech. Explor.-Prod. Elf Aquitaine 20 (1), 213–227.

Bellieni, G., Macedo, M.H.F., Petrini, R., Piccirillo, E.M., Cavazzini, G., Comin-Ghiaramonti, P., Ernesto, M., Macedo, J.W.P., Martins, G., Melfi, A.J., Pacca, I.G., De Min, A., 1992. Evidence of magmatic activity related to Middle Jurassic and Lower Cretaceous rifting from northeastern Brazil (Ceará-Mirim): K/Ar age, palaeomagnetism, petrology and Sr–Nd isotope characteristics. Chem. Geol. 97, 9–32.

Black, R., 1984. The Pan-African event in the geological framework of Africa. Pangea 2, 6–16.

Blarez, E., Mascle, J., 1988. Shallow structures and evolution of the Ivory Coast and Ghana transform margin. Mar. Pet. Geol. 5, 54–64.

Brandão, J.A.S.L., Feijó, F.J., 1994. Bacia da Foz do Amazonas. Boletim de Geociências da Petrobras 8 (1), 91–99.

Brunet, M., Dejax, J., Brillanceau, A., Congleton, J., Downs, W., Duperon-Laudoueneix, M., Eisenmann, V., Flanagan, K., Flynn, L., Heintz, E., Hell, J., Jacobs, L., Jehenne, Y., Ndjeng, E., Mouchelin, G., Pilbeam, D., 1988. Mise en évidence d'une sédimentation précoce d'âge Barrémien dans le fossé de la Bénoué en Afrique occidentale (Bassin du Mayo Oulo Léré, Cameroun), en relation avec l'ouverture de l'Atlantique sud. C. R. Acad. Sci. Paris 306, 1125–1130.

Burke, K., MacGregor, D.S., Cameron, N.R., 2003. Africa's petroleum systems: four tectonic 'Aces' in the past 600 million years. In: Arthur, T.J., MacGregor, D.S., Cameron, N.R. (Eds.), Petroleum Geology of Africa: New Themes and Developing Technologies, 207. Geological Society, London, pp. 21–60, Special publications.

Caby, R., 1989. Precambrian terranes in Benin, Nigeria and northeast Brazil and the late Proterozoic south Atlantic fit. Geol. Soc. Am. Special Paper 230, 145–158.

Caby, R., 2003. Terrane assembly and geodynamic evolution of central-western Hoggar: a synthesis. J. African Earth Sci. 37, 133–159.

Campan, A., 1995. Analyse cinématique de l'Atlantique équatorial: implications sur l'évolution de l'Atlantique Sud et sur la frontière de plaques Amérique du Nord/Amérique du Sud. Ph.D. Thesis, Université Pierre et Marie Curie, Paris, 352pp.

de Caprona, G.D., 1992. The continental margin of western Côte d'Ivoire: structural framework inherited from intra-continental shearing. Ph.D. Thesis, Göteborg Universitet, Geologiska Institutionen, 69, 150pp.

Chierici, M.A., 1996. Stratigraphy, palaeoenvironments and geological evolution of the Ivory Coast-Ghana basin. Géologie de l'Afrique et de l'Atlantique Sud: Actes Colloques Angers 1994, 293–303.

Cornacchia, M., Dars, R., 1983. Un trait structural majeur du continent africain. Les linéaments centrafricains du Cameroun au Golfe d'Aden. Bull. Soc. Géol. France 7 (25), 101–109.

da Costa, I.G., Beltrami, C.V., Alves, L.E.M., 1990. A evolução tectono-sedimentar e o habitat do óleo da bacia do Ceará. B. Geoci. Petrobrás 4 (1), 65–74.

Coulon, C., Vidal, P., Dupuy, C., Baudin, P., Popoff, M., Maluski, H., Hermitte, D., 1996. The Mesozoic to early Cenozoic magmatism of the Benue Trough (Nigeria); geochemical evidence for the involvement of the St Helena plume. J. Petrol. 37 (6), 1341–1358.

Deckart, K., Féraud, G., Bertrand, H., 1997. Age of Jurassic continental tholeiites of French Guyana, Surinam and Guinea: implications for the initial opening of the Central Atlantic Ocean. Earth Planet. Sci. Lett. 150, 205–220.

Delteil, J.R., Valery, P., Montadert, C., Fondeur, C., Patriat, P., Mascle, J., 1974. Continental margin in the northern part of the gulf of Guinea. In: Burk, C.A., Drake, C.L. (Eds.), Geology of Continental Margins. Springer, New York, pp. 297–311.

Doyle, J.A., Jardiné, S., Doerekamp, A., 1982. *Afropollis*, a new genus of early angiosperm pollen, with notes on the Cretaceous palynostratigraphy and paleoenvironments of northern Gondwana. Bull. Centres Rech. Explor.—Prod. Elf-Aquitaine 6 (1), 39–117.

Dray, M., Giachello, L., Lazzarotto, V., Mancini, M., Roman, E., Zuppi, G.M., 1989. Etude isotopique de l'aquifère crétacé du bassin côtier béninois. Hydrogéologie 3, 167–177.

Edwards, R.A., Whitmarsh, R.B., Scrutton, R.A., 1997. The crustal structure across the transform continental margin off Ghana, eastern equatorial Atlantic. J. Geophys. Res. 102 (B1), 747–772.

Emery, K.O., Uchupi, E., Phillips, J., Bowin, C., Mascle, J., 1975. Continental margin off Western Africa: Angola to Sierra Leone. Am. Assoc. Petrol. Geol. Bull. 59, 2209–2265.

Fail, J.P., Montadert, L., Delteil, J.R., Valery, P., Patriat, P., Schlich, R., 1970. Prolongation des zones de fractures de l'océan Atlantique dans le golfe de Guinée. Earth Planet. Sci. Lett. 7, 413–419.

Fodor, R.V., Sial, A.N., Mukasa, S.B., McKee, E.H., 1990. Petrology, isotope characteristics, and K-Ar ages of the Maranhão, northern Brazil, Mesozoic basalt province. Contrib. Mineral. Petrol. 104, 555–567.

Françolin, J.L.B., Cobbold, P.R., Szatmari, P., 1994. Faulting in the Early Cretaceous Rio do Peixe basin (NE Brazil) and its significance for the opening of the Atlantic. J. Struct. Geol. 16 (5), 647–661.

Guiraud, M., 1991. Mécanisme de formation du bassin Crétacé sur décrochements multiples de la Haute Bénoué (Nigéria). Bull. Centres Rech. Expor.—Prod. Elf Aquitaine 15 (1), 1011–1067.

Guiraud, M., 1993. Late Jurassic rifting—early Cretaceous rifting and late Cretaceous transpressional inversion in the upper Benue basin (NE Nigeria). Bull. Centres Rech. Expor.—Prod. Elf Aquitaine 17 (2), 371–383.

Guiraud, R., Alidou, S., 1981. La faille de Kandi (Bénin), témoin du rejeu fini-crétacé d'un accident majeur à l'échelle de la plaque africaine. C. R. Acad. Sci. Paris 293, 779–782.

Guiraud, R., Bosworth, W., 1997. Senonian basin inversion and rejuvenation of rifting in Africa and Arabia: synthesis and implications to plate-scale tectonics. Tectonophysics 282, 39–82.

Guiraud, R., Bosworth, W., Frizon de Lamotte, D., Thierry, J., this volume. Phanerozoic geological evolution of Northern and Central Africa. Journal of African Earth Sciences, doi:10.1016/j.jafrearsci.2005.07.017.

Guiraud, R., Issawi, B., Bellion, Y., 1985. Les linéaments guinéo-nubiens: un trait structural majeur à l'échelle de la plaque africaine. C. R. Acad. Sci. Paris 300, 17–20.

Guiraud, R., Maurin, J.C., 1991. Le rifting en Afrique au Crétacé inférieur: synthèse structurale, mise en évidence de deux étapes dans la genèse des bassins, relations avec les ouverture océaniques péri-africaines. Bull. Soc. Géol. France 162, 811–823.

Guiraud, R., Maurin, J.C., 1992. Early Cretaceous rifts of western and central Africa: an overview. Tectonophysics 213, 153–168.

Horn, P., Muller-Shonius, D., Schult, A., 1988. Potassium-Argon ages on a Mesozoic tholeitic dike swarm in Rio Grande Do Norte, Brazil. Rev. Bras. Geosci. 18 (1), 50–53.

Isaacson, P.E., Díaz Martínez, E., 1995. Evidence for a middle-late Paleozoic foreland bazin and significant paleolatitudinal shift, Central Andes. In: Tankard, A.J., Suárez, R.S., Welsink, H.J. (Eds.), Petroleum Basins of South America, 67. AAPG Memoir, pp. 231–249.

Kjemperud, A., Agbesinyale, W., Agdestein, T., Gustafsson, C., Yükler, A., 1992. Tectono-stratigraphic history of the Keta basin, Ghana with emphasis on late erosional episodes. In: Géologie Africaine: Coll. Géol. Libreville, recueil des Communications 6–8 May 1991, pp. 55–69.

Koutsoukos, E.A.M., 1982. Geohistória e paleúcologia das bacias marginais de Florianópolis e Santos. XXXI Congresso Brasileiro de Geologia (Salvador), Anais 5, 2369–2382.

Maisey, J.G., 2000. Continental break up and the distribution of fishes of Western Gondwana during the Early Cretaceous. Cretaceous Res. 21 (2–3), 281–314.

Maluski, H., Coulon, C., Popoff, M., Baudin, P., 1995. $^{40}Ar/^{39}Ar$ chronology, petrology and gedynamic setting of Mesozoic to early Cenozoic magmatism from the Benue Trough, Nigeria. J. Geol. Soc., London 152, 311–326.

Martin, G., 1982. Geologie des Küsten-gebietes von Nordwest-Africa südlich der Sahara. Neue erkenntnisse aus der erdölexploration. Giessener geol. Schriftenr. 30 (160S), 150.

Mascle, J., Blarez, E., 1987. Evidence for transform margin evolution from the Ivory Coast-Ghana continental margin. Nature 326 (6111), 378–381.

Mascle, J., Lohmann, G.P., Clift, P.D., et al., 1996. Proceedings of the ocean drilling program. Initial Rep. 159, 616.

Mascle, J., Guiraud, M., Benkhelil, J., Basile, C., Bouillin, J.P., Mascle, G., Cousin, M., Durand, M., Dejax, J., Moullade, M., 1998. A geological field trip to the Côte d'Ivoire-Ghana transform margin. Oceanolog. Acta 21 (1), 1–20.

Mauche, R., Faure, G., Jones, J.M., Hoefs, J., 1989. Anomalous isotopic compositions of Sr, Ar, and O in the Mesozoic diabase dikes of Liberia, West Africa. Contrib. Mineral. Petrol. 101, 12–18.

Milani, E.J., Thomaz Filho, A., 2000. Sedimentary basins of South America. In: Tectonic evolution of South America, Cordani, U.G., Milani, E.J., Thomaz Filho, A., Campos, D.A. (Eds), 31st International Geological Congress, pp. 389–449.

Nürnberg, D., Müller, R.D., 1991. The tectonic evolution of the South Atlantic from Late Jurassic to present. Tectonophysics 191, 27–53.

Peate, D.W., 1997. The Paraná-Etendeka Province. In: Mahoney, J.J., Coffin, M.F. (Eds.), Large Ignous Provinces: Continental, Oceanic and Planetary Flood Volcanism, 100. Geophysical Monograph, pp. 217–245.

Pletsch, T., Erbacher, J., Holbourn, A.E.L., Kuhnt, W., Moullade, M., Oboh-Ikuenobede, F.E., Söding, E., Wagner, T., 2001. Cretaceous separation of Africa and South America: the view from the West African margin (ODP Leg 159). J. South Am. Earth Sci. 14, 147–174.

Popoff, M., 1988. Du Gondwana à l'Atlantique sud: les connexions du fossé de la Bénoué avec les bassins du Nord-Est brésilien jusqu'à l'ouverture du golfe de Guinée au Crétacé inférieur. In: The west african connection, Soujy, J., Rodgers, J. (Eds), J. Afric. Earth Sci., Special Public., vol. 7 (2), pp. 409–431.

Sage, F., 1994. Structure crustale d'une marge transformante et du domaine océanique adjacent: exemple de la marge de Côte d'Ivoire-Ghana. Ph.D. Thesis, Université Pierre et Marie Curie, Paris, 340pp.

Scotese, C.R., Gahagan, L.M., Larson, R.L., 1988. Plate tectonic reconstructions of the Cretaceous and Cenozoic ocean basins. Tectonophysics 155, 27–48.

Senant, J., Popoff, M., 1991. Early Cretaceous extension in northeast Brazil related to the South Atlantic opening. Tectonophysics 198, 35–46.

Stewart, K.S., Turner, S., Kelley, C.J., Hawkesworth, C.J., Kirstein, L., Mantovani, M.S.M., 1996. 3-D^{40}Ar-^{39}Ar geochronology in the Paraná flood basalt province. Earth Planet. Sci. Lett. 143, 95–110.

Todd, B.J., Keen, C.E., 1989. Temperature effects and their geological consequences at transform margins. Can. J. Earth Sci. 26, 2591–2603.

Tucker, J.W., 1992. Aspects of the Tano basin stratigraphy revealed by recent drilling in Ghana. In Géologie Africaine: Coll. Géol. Libreville, recueil des Communications, 6–8 May 1991, pp. 153–159.

Unternehr, P., Curie, D., Olivet, J.L., Goslin, J., Beuzart, P., 1988. South Atlantic fits and intraplate boundaries in Africa and South America. Tectonophysics 155, 169–179.

Villeneuve, M., Cornée, J.J., 1994. Structure, evolution and palaeogeography of the West African craton and bordering belts during the Neoproterozoic. Precambrian Res. 69, 307–326.

Wagner, T., Pletsch, T., 2001. No major thermal event on the mid-Cretaceous Côte d'Ivoire-Ghana transform margin. Terra Nova 13, 165–171.

Williams, K.E., 1995. Tectonic subsidence analysis and Paleozoic paleogeography of Gondwana. In: Tankard, A.J., Suárez, R.S., Welsink, H.J. (Eds.), Petroleum Basins of South America, 62. AAPG Memoir, pp. 79–100.

Wilson, M., Guiraud, R., 1998. Late Permian to recent magmatic activity on the african-arabian margin of Tethys. In: MacGregor, D.S., Moody, R.T.J., Clark-Lowes, D.D. (Eds.), Petroleum Geology of North Africa, 132. Geological Society, London, pp. 231–263, Special publications.

Zalan, P.V., Nelson, E.P., Warme, J.E., Davis, T.L., 1985. The Piaui basin: rifting and wrenching in an Equatorial Atlantic transform basin. In: Biddle, K.T., Christie-Blick, N. (Eds), Strike-slip deformation, basin formation, and sedimentation. Spec. Publ. Soc. Econ. Paleontol. Mineral., vol. 37, pp. 143–158.