Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of African Earth Sciences 45 (2006) 241–256
Journal of African Earth Sciences
www.elsevier.com/locate/jafrearsci

Geological Society of Africa Presidential Review, No. 11

The North–South Paleozoic to Quaternary trend of alkaline magmatism from Niger–Nigeria to Cameroon: Complex interaction between hotspots and Precambrian faults

Vincent Ngako [a], Emmanuel Njonfang [b,*], Festus Tongwa Aka [c,1], Pascal Affaton [d], Joseph Metuk Nnange [a]

[a] *Institut de Recherches Géologiques et Minières (IRGM), B.P. 4110, Yaoundé, Cameroon*
[b] *Laboratoire de Géologie, Ecole Normale Supérieure, Université de Yaoundé I, B.P. 47 Yaoundé, Cameroon*
[c] *Institute of Mining and Geological Research (IRGM) Ekona, P.O. Box 370 Buea, Cameroon*
[d] *CEREGE, Europôle de l'Arbois, B.P. 80, 13545 Aix-en-Provence Cedex 04, France*

Received 16 February 2005; received in revised form 10 March 2006; accepted 16 March 2006
Available online 11 May 2006

Abstract

The alkaline magmatism from Niger–Nigeria to Cameroon forms large scale magmatic provinces across the African plate. It displays a N–S trend from Aïr in Niger to Jos Plateau in Nigeria changing southeastwards towards Cameroon. We have compiled recent petrological, geochemical and structural data on these magmatic provinces. The data show that although there is a general age decrease from one province to another (407 ± 8 Ma in Aïr to $\leqslant 66$ Ma in Cameroon), there is no age migration in any given province, except in the Nigeria province (Younger Granites) where a rough NE–SW age decrease is observed. The relationship between these different magmatic provinces that share similar geochemical data, added to the SW–NE parallel trends of Nigeria, Benue Trough and Cameroon Line, is difficult to explain in terms of a simple northward motion of the African plate over a single hotspot. In the light of recent tectonic models, we suggest complex interaction between, on the one hand, at least two mantle plumes acting in succession (including the St. Helena mantle plume) and, on the other hand, lithospheric fractures that induce oblique alignments of new magmatic complexes.

Keywords: Pan-African orogeny; West-Central Africa; Alkaline magmatism; Mantle plume; Hotspot; Lithospheric fractures

Contents

* Corresponding author. Tel.: +237 231 65 23.
E-mail addresses: enjonfan@uycdc.uninet.cm (E. Njonfang), akatongw@misasa.okayama-u.ac.jp (F.T. Aka).
[1] Present address: Institute for Study of the Earth's Interior, Okayama University at Misasa, Tottori-ken 689-0193, Japan.

1464-343X/$ - see front matter
doi:10.1016/j.jafrearsci.2006.03.003

1. Introduction

After the Pan-African orogenesis in Western Africa (Fig. 1) around 600 Ma, geologic evolution is characterized by the emplacement of Mesozoic ring complexes in Central Nigeria, the formation of the Benue Trough (BT) during the Cretaceous, and the emplacement of ring complexes in Cameroon during the early Cenozoic, followed by volcanic activity since the Eocene. Although the tectonic origin of the BT has been linked to the opening of the South Atlantic Ocean (Benkhelil, 1989; Popoff, 1988; Brunet et al., 1988), the relationship between its evolution and Phanerozoic

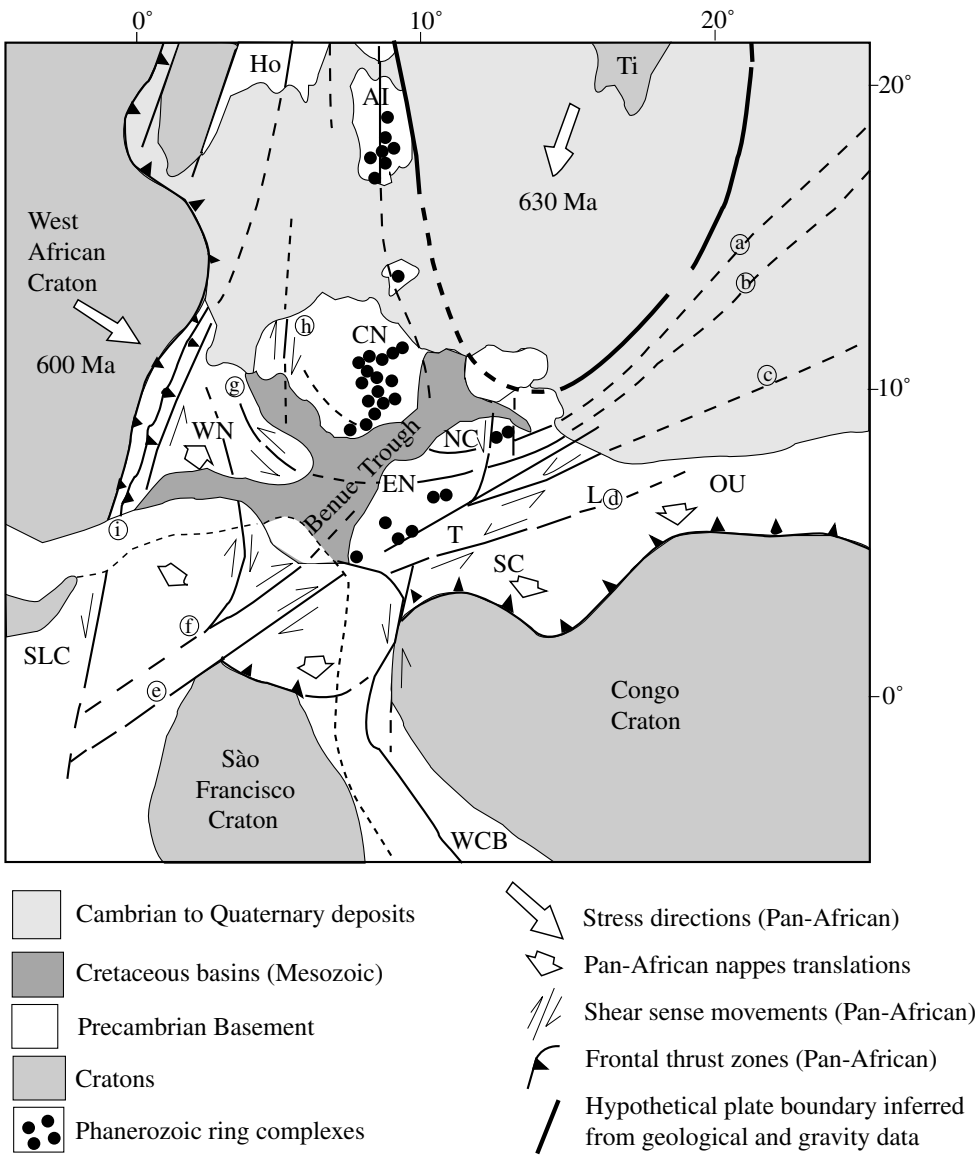

Fig. 1. Continental structures of Western Gondwana after Pan-African tectonic evolution (redrawn and modified from Toteu et al., 1991). Shear Zones: (a) Balche; (b) Buffle Noir; (c) Central Cameroon Shear Zone (CCSZ); (d) Sanaga Fault; (e) Pernambuco fault; (f) Patos; (g) Okene; (h) Zungeru (Birnin Gwari); (i) Kandi-Sobral. Symbols – Ho: Hoggar; AI: Aïr; T: Tibati; L: Lom; WCB: West Congolian Belt; WN: Western Nigeria; CN: Central Nigeria; EN: Eastern Nigeria; NC: Northern Cameroon; SC: Southern Cameroon; OU: Oubanguides; SLC: São Luis Craton.

(Paleozoic to Quaternary) magmatic activity in Western Africa is still unclear. Among the major unanswered questions related to this magmatic evolution are: the generalized abnormal thickness of the continental crust (less than 35 km in Western Africa, Fig. 2); the evolution of the BT into an abandoned rift; the difference in emplacement ages of ring complexes in Niger, Nigeria and Cameroon; and finally, the restriction of present volcanic activity to Mount Cameroon (last eruption in 2000). The broad southward age migration, added to the remarkable similarity in shape/size (Fitton, 1980, 1983) and geochemical features (Coulon et al., 1996) of the BT and the Cameroon Line (CL) suggests a possible relationship between these magmatic provinces and the same mantle plume. However, recent geochronological data in the Aïr province (Moreau et al., 1994) and in the CL (Marzoli et al., 2000) do not show age migration within a given magmatic province as formerly proposed and widely discussed by Déruelle et al. (1991, and references therein). Aka et al. (2004) even show that Plio-Quaternary volcanism (⩽6 Ma) has been synchronous on the whole CL. The absence of space–time variation within a given magmatic province renders the relationship between one province and the other unclear. For instance, the early magmatic evolution in the BT is difficult to relate with the Cretaceous to Present activity on the CL. It is noteworthy that since the review of various hypotheses of the tectono-magmatic origin of the CL by Déruelle et al. (1991), the following views are still discussed: (1) a (failed) continental rifting (Guiraud et al., 1992; Guiraud and Maurin, 1992; Wilson and Guiraud, 1992) probably produced directly by a thermal anomaly in the asthenosphere; (2) rejuvenation of Precambrian faults (Moreau et al., 1994); (3) hot line or thermally anomalous linear zone in the Earth's mantle (Meyers et al., 1998).

We have compile more recently available petrologic, geochemical and structural data on the different magmatic provinces. Here we interpret and discuss the data in the light of recent tectonic models that explain the origin of some linear intraplate magmatic chains and propose alternative explanations to classical hotspot models. We suggest

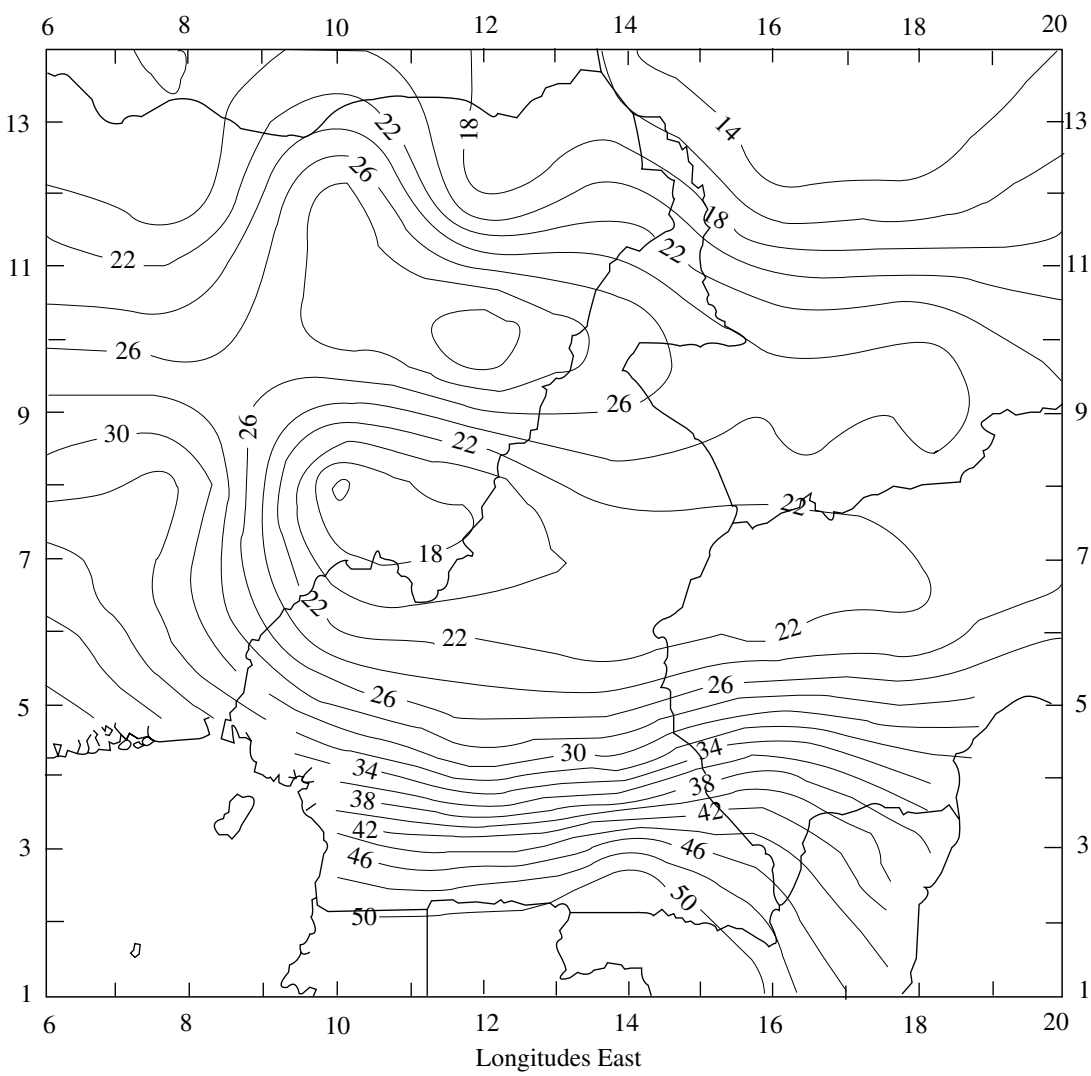

Fig. 2. Map of crustal thickness (in km) in Central Africa based on gravity data (after Poudjom Djomani et al., 1995).

that the origin of magmatic provinces and local reverse age migration within a few of them, result from fundamental differences of crustal development of hotspot related magma in a continental and an oceanic domains.

2. The main magmatic provinces and magmatic activity

In this paper, we define a magmatic province as a broad geographic area (linear or not), characterized by intrusive and/or volcanic bodies, the ages of which approximately correspond to the same geological period, namely Ordovician – Devonian (480–400 Ma), Carboniferous (330–260 Ma), Triassic–Jurassic (215–140 Ma), Cretaceous (147–106 Ma) and Tertiary (73–30 Ma), although overlapping ages are reported between some neighboring provinces.

2.1. The Niger–Nigeria Paleozoic to Mesozoic super province

The Niger–Nigeria super province (Fig. 3B) comprises from north to south, the Aïr anorogenic magmatic province (N. Niger), the Damagaram-Mounio province (S. Niger) and the Jos Plateau or "Younger Granite" province of Nigeria (Moreau, 1982; Bowden and Kinnaird, 1984; Cahen et al., 1984). Demaiffe and Moreau (1996) showed that the Aïr province is structurally and chronologically independent of the Damagaram-Mounio and the Younger Granite of Nigeria provinces.

A general review of the different types of Paleozoic ring complexes in the Aïr is given by Moreau et al. (1991, 1994), Demaiffe et al. (1991) and Demaiffe and Moreau (1996). The authors recognized 28 complexes among which the largest cone sheet in the world (the Meugueur-Meugueur, 65 km in diameter, Moreau et al., 1986) and one of the smallest intrusion (Tagueï, 0.8 km in diameter, Demaiffe et al., 1991). Most of the intrusions have a circular shape, but some are elliptical or semi-circular. They have been divided into three main types (Fig. 3C), based on the nature and abundance of rock-types (Moreau et al., 1991; Demaiffe et al., 1991). (1) the Taghouaji type is composed mainly of alkaline and peralkaline syenite and granite, with or without associated metaluminous granites (18 complexes); (2) the Goundaï type is composed mainly of acid volcanic rocks (rhyolitic tuffs and ignimbrites) with quartz syenite ring dykes (three complexes); (3) the Ofoud type (seven complexes) is characterized by a large proportion of basic rocks varying from troctolites and leucogabbros to true anorthosites, intruded by mildly to peralkaline syenites and granites (Brown et al., 1989; Demaiffe et al., 1991).

In the Younger Granites of Nigeria, over 50 intrusions forming a series of high-level anorogenic complexes have been recognized (Badejoko, 1986; Orajaka, 1986). These circular or elliptical intrusions have an average diameter of 10–25 km. Each of the ring-complexes began as a chain of volcanoes (Bowden and Kinnaird, 1984). Volcanic rocks

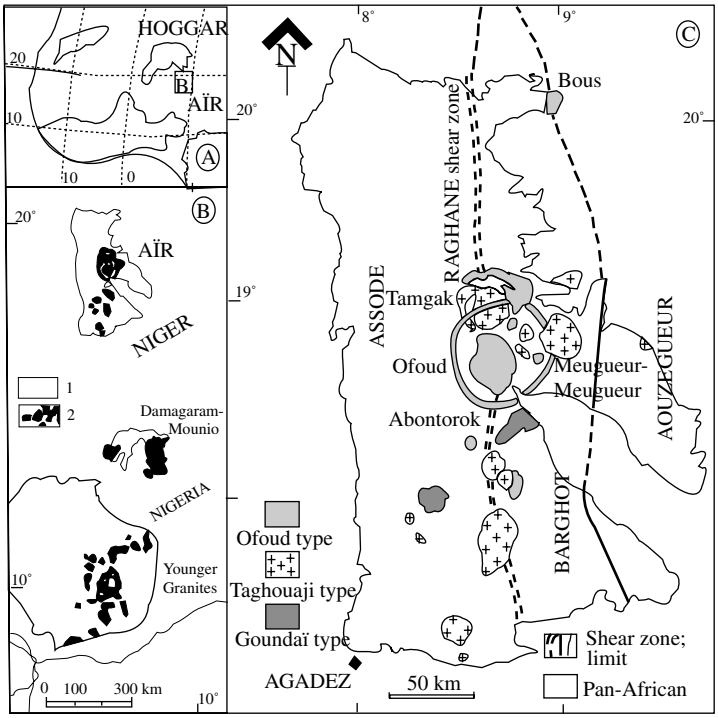

Fig. 3. (A) The Aïr province in West Africa. (B) Geographic localisation of the Aïr (N. Niger), Damagaram-Mounio (S. Niger) and Younger Granites (Nigeria) alkaline provinces. 1: Pan-African basement; 2: Phanerozoic Ring-complexes. (C) Geological sketch map of Aïr (After Demaiffe and Moreau, 1996).

commonly occur, especially in the northernmost complexes (Rahaman et al., 1984). Basic intrusive rocks represent less than 1% of the total area of the province (against 40–80% in the Aïr) and include monzonites and monzogabbros (basaltic lavas are more common). Anorthosites occur only as xenoliths in a doleritic dyke near Jos (Wright, 1975). There are several distinctive granite types (Kinnaird, 1985): (i) peralkaline granites and related syenites (with alkali or calcic amphibole); (ii) peraluminous biotite alkali feldspar granites and biotite syenogranites; (iii) metaluminous fayalite and hornblende-bearing granites and porphyries with amphibole or biotite.

2.2. The Benue Trough

The magmatic province of the BT constitutes a spatial link between the alkaline to peralkaline province of Nigeria to the North and the CL to the South. Detailed account of its petrology and geochemistry can be found in Baudin (1991) and the main characteristics in Maluski et al. (1995) and Coulon et al. (1996). Two principal magmatic domains are recognized, northern and southern Benue. In the northern domain, magmatism is characterized by transitional alkaline basalts and transitional tholeiitic basalts; acidic magmatism (rhyolites and granophyres) of

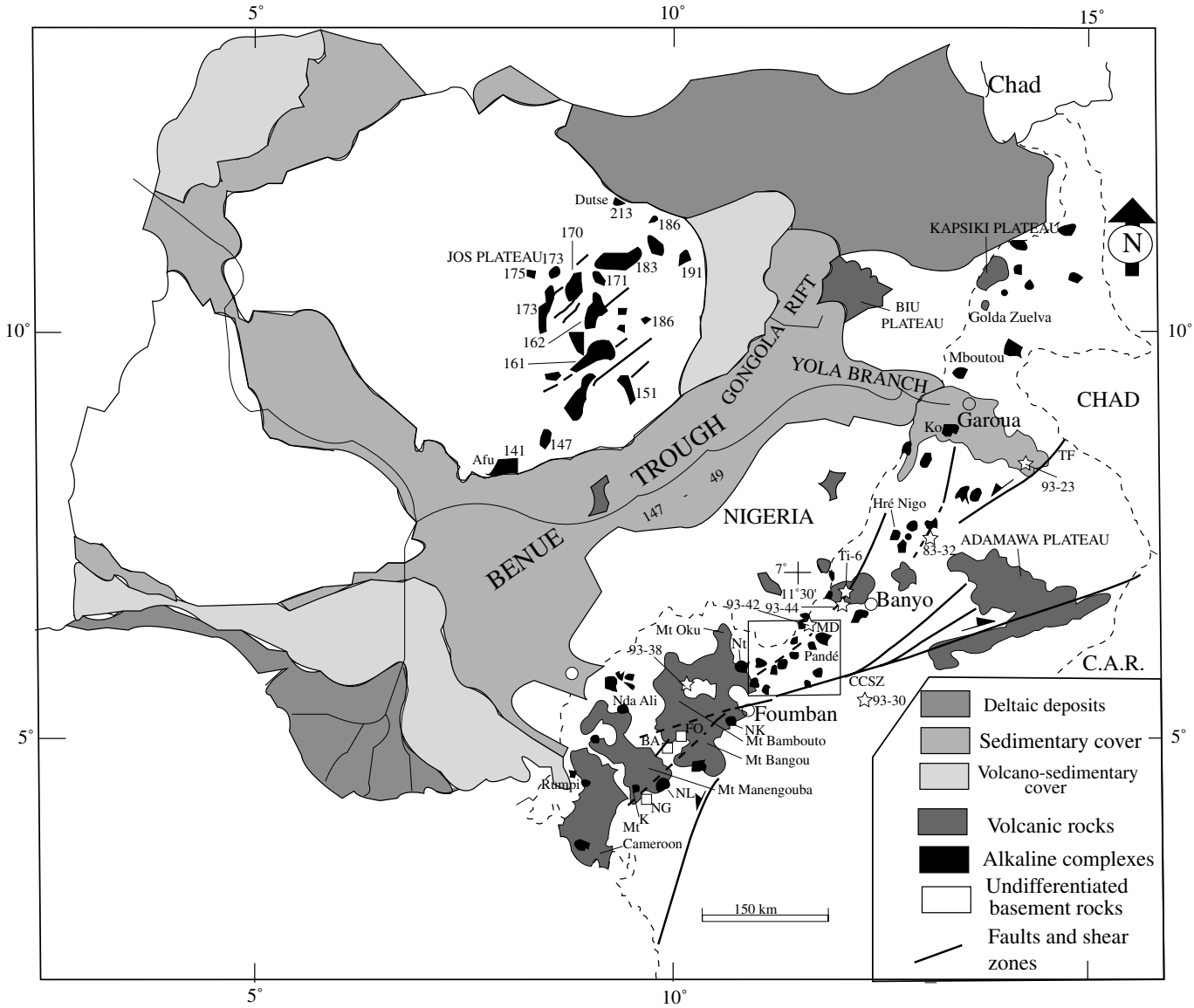

Fig. 4. A compilation of Cameroon and Nigeria geological maps showing the location of ring-complexes of Nigeria and Cameroon and volcanic massifs of the Cameroon Line. K: Koupé; NL: Nlonako; NK: Nkogam; Nt: Ntumbaw; Ko: Kokoumi; MD: Mayo Darlé. Age range of magmatic activity in the Benue Trough after Maluski et al. (1995). Note the rough NE–SW decrease of ages in the Younger Granites of Nigeria (numbers are in million years, after Rahaman et al., 1984) and the location of some syntectonic Pan-African granitoids along the Cameroon Line: Stars (Toteu et al., 2001); NG: Ngondo complex (Tagne Kamga et al., 1999); BA: Bandja complex (Nguiessi Tchankam et al., 1997); FO: Fomopéa complex (Kwékam, 1993). CCSZ: Central Cameroon Shear Zone; TF: Tcholliré Fault; Arrows: sense of displacement. Nigerian faults and shear zones after Rahaman et al. (1984) and Ferré et al. (1998). C.A.R.: Central African Republic.

peralkaline nature is also present. In the southern Benue, several magmatic districts exhibit alkaline or tholeiitic affinities. Alkaline rocks include: basalts, dolerites, rhyolites, trachytes, phonolites, phonotephrites, tephriphonolites, camptonites and nepheline syenites. Only doleritic sills display a clear mineralogical tholeiitic affinity and correspond chemically to quartz tholeiites.

2.3. The Cameroon Line

The CL, made up of an oceanic (Annobon, São Tomé, Principé and Bioko) and a continental (Mounts Etindé, Cameroon, Manengouba, Bambouto, Oku, Ngaoundéré, Bui and Mandara mountains) sectors, is active since the Cenozoic. Its activity includes emplacement of plutonic complexes (more than 60) in the continental sector and volcanic eruptions (Fig. 4). Volcanic rocks are usually aligned and in places associated with the plutonic complexes. The plutonic complexes are small in size (mostly 5–10 km in diameter) and except for four complexes in North and South-west Cameroon, they are mainly constituted of granites or syenites, to which subordinate intermediate and basic rocks are sometimes associated (Kambou et al., 1989; Njonfang et al., 1992; Njonfang and Moreau, 2000). The Mboutou, Kokoumi and Nigo complexes, in North Cameroon comprise basic rocks (Jacquemin et al., 1981; Parsons et al., 1986; Ngounouno et al., 2001; Kamdem et al., 2002). The Ntumbaw complex in NW Cameroon (Ghogomu et al., 1989) contains predominantly intermediate rocks. Syenites are mostly saturated and granites oversaturated; both displaying mineralogical and geochemical characteristics of alkaline to peralkaline rocks. The Kokoumi complex is entirely undersaturated with a gabbro – nepheline monzosyenite – nepheline syenite series (Ngounouno et al., 2001). It is also particular in that the plutonic series is cut by lamprophyric dykes (Ngounouno et al., 2001).

Volcanic rocks are more varied mostly undersaturated in the oceanic part and undersaturated to oversaturated in the continental part. At the continent–ocean boundary (COB), Bioko and Mount Cameroon are mainly basaltic. Etindé located to the intermediate southwestern flank of Mt. Cameroon is made up entirely of undersaturated lavas (Nkoumbou et al., 1995). The other continental massifs are usually bimodal. Mafic lavas comprise basanites, alkali basalts, hawaiites and mugearites and the silicic lavas comprise benmoreites, trachytes, phonolites and/or rhyolites (Déruelle et al., 1991; Nono et al., 1994; Marzoli et al., 2000; Ngounouno et al., 2000; Kagou Dongmo et al., 2001; Nkouathio et al., 2002). Data from the oceanic sector of the CL (Déruelle et al., 1991, and references therein; Lee et al., 1994) indicate basanite to hy-normative basalt, tristanite and trachyte in Annobon; basalt to trachyte and phonolite with no compositional gap in São Tomé; nephelinite, basanite, tristanite, trachyphonolite, phonolite and alkali basalt in Principé and basanite to hy-basalt in Bioko. In Principé, the oldest rocks (31 Ma) are basal hyaloclastite breccias that contain fragments of fresh tholeiite. Aka et al. (2004) noted a geographic control on the distribution of $^{3}He/^{4}He$ ratios along the CL, with high-μ OIB-like values on the continent/ocean boundary zone (Bioko, Mount Cameroon and Etinde) increasing to mantle (MORB-like) values in its oceanic (towards Annobon) and continental (towards Ngaoundéré) terminals. Even though a review of the CL volcanism by Déruelle et al. (1991) suggests that it is entirely alkaline in nature, some transitional affinities have recently been described in the Mbam, Bangou, Bambouto and Oku volcanic centers in the West and Northwest Cameroon (Moundi et al., 1996; Marzoli et al., 2000; Fosso et al., 2005).

Some mafic lavas of the CL are rich in ultramafic xenoliths (Lee et al., 1996; Aka et al., 2004). These occur in both the continental sector as in Oku and Nyos (Nana et al., 2001; Temdjim et al., 2004) and in the oceanic sector as in São Tomé (Caldeira and Munhá, 2002).

3. Spatio-temporal evolution of magmatic activity

On the basis of ages decreasing from the Aïr ring complexes, North of Niger (480–400 Ma) to the Younger Granites of Nigeria in the South (215–140 Ma) through the Damagaram, South of Niger (330–260 Ma) (Bowden et al., 1976; Karche and Vachette, 1978), the Niger–Nigeria large magmatic province has been defined as a unique feature in the world of practically continuous within plate anorogenic volcanism and plutonism with progressive southern shift of centers of magmatic activity (Bowden and Karche, 1984). At the scale of the Aïr province alone, the ages would decrease from 487 Ma in the North to 407 Ma in the South (Bowden and Karche, 1984). But, new radiometric data (Rb/Sr method) on the same sample powders by Moreau et al. (1994) do not confirm this space–time migration model. Instead, the new results show that the emplacement of the Aïr ring complexes took place within a very short time at 407 ± 8 Ma, close to the Silurian–Devonian boundary or the lowest Early Devonian. In Nigeria, the ages in the Younger Granites, from Dutse (213 Ma) in the North to Afu (141 Ma) in the South, show that major local migrations of magmatic activity were concentrated along at least two ENE–WSW linear zones (Rahaman et al., 1984) (Fig. 4).

A detailed chronology of emplacement of volcanic rocks of the BT has been established using $^{40}Ar/^{39}Ar$ radiometric method and the following magmatic evolution is revealed (Maluski et al., 1995). (1) During the Late Jurassic to Albian period (147–106 Ma), magmatism probably occurred in the whole BT. It is particularly expressed in the northern Benue where it is represented by alkaline transitional basalts and associated peralkaline rhyolites (bimodal volcanism) and by tholeiitic transitional basalts. (2) Between 97 and 81 Ma, magmatism was concentrated in the southern Benue, was exclusively alkaline and predominantly intrusive. (3) During the period 68–49, the first magmatic products, also restricted to the southern Benue, were

alkaline and the last ones tholeiitic. As in the Aïr province (e.g., Moreau et al., 1994), no clear time–space age migration of magmatism in the BT is apparent.

Previous radiometric data (Rb/Sr and K/Ar methods) for the anorogenic plutonic complexes of the CL (see review by Kamdem et al., 2002) indicate that their emplacement occurred from the Paleocene (ca 67 Ma) to the Oligocene (ca 30 Ma). The oldest age was obtained on the Golda Zuelva granite in the north and the youngest on a Mt. Bana granite in the west (Lasserre, 1978). However the Nkogam and Mboutou complexes in the West and North gave 66 and 60 Ma, respectively (Lasserre, 1978; Caen-Vachette et al., 1987) pointing to the lack of time–space migration of plutonism. This conclusion is corroborated by the ages recently obtained for the Kokoumi complex, SW of Mboutou (39 Ma) and for the Hossere Nigo, west of Adamawa plateau (65 Ma) (Ngounouno et al., 2001; Montigny et al., 2004; Kamdem et al., 2002).

New radiometric data (K/Ar and $^{40}Ar/^{39}Ar$ methods) on volcanic rocks from the CL (Lee et al., 1994; Marzoli et al., 1999, 2000; Ngounouno et al., 2000; Aka et al., 2004; Montigny et al., 2004; Fosso et al., 2005) show that volcanic activity ranges from Upper Eocene (45 Ma) to the Present and not from Oligocene (30 Ma) as established for the distribution of volcano-capped swells along the line (Burke, 2001). The striking point is the SW younging volcanism in the oceanic sector from Principé (31 Ma) to Pagalu (5 Ma) islands (Lee et al., 1994). The oldest age so far obtained (45 Ma) on CL volcanic rocks is on Mt. Bangou, located southeast of Mt. Bambouto. Therefore, as for anorogenic complexes, it is difficult to consider volcanic activity along the CL in terms of a steady time–space migration, symptomatic of a hotspot reference frame as the Hawaiian Islands.

From the above synthesis, it is seen that alkaline magmatism in West-Central Africa shows a time–space migration by ages decreasing from the Silurian–Devonian boundary (407 ± 8 Ma) in the Aïr province (North of Niger) through the Younger Granites of Nigeria (213–141 Ma), the BT (147–49 Ma) to the Paleocene-Present activity on the CL. This seems at first sight to result from a single north–south hotspot system. However, the magmatic period of the BT overlaps the period of plutonic magmatism on the CL and also, the ring complexes of Nigeria display roughly two SW-trending lines of decreasing ages. These observations suggest that magmatism in West-Central Africa may instead be the result of an interaction between a hotspot system and other important factors mainly of tectonic origin.

4. Relationships between tectonics and magmatism

4.1. The Pan-African structural inheritance

Three main structural units characterize the Pan-African basement in western and central Africa (Fig. 1): shear zones, fold zones and thrust zones. Shear zones are the most prominent and represent lithospheric faults (Ngako et al., 1991; Moreau et al., 1994; Poudjom Djomani et al., 1997). The structure of the Aïr basement, that was built during the Pan-African orogeny (Black et al., 1991; Liégeois et al., 1994), results from the assembly of three main terranes (Assodé, Barghot and Aouzegueur) separated by N–S trending shear-zones or mega-thrusts (Fig. 3C). These shear zones and thrusts control: (1) the variation in thickness and/or deformation of the sedimentary cover; (2) the location of basement topographic highs and; (3) the location of the magmatic activity (Moreau et al., 1994). The most important of those shear zones, the Raghane mega-shear zone (Fig. 3C) can be observed over a 400 km distance in Aïr and runs for more than 1000 km, as it corresponds to the southern extension of the 8°30′ E lineament of the Hoggar (Demaiffe and Moreau, 1996; Abdelsalam et al., 2002). In general, N–S mega-thrust faults were followed by NW–SE trending sinistral wrench faults and by complementary ENE–WSW and NE–SW trending dextral faults (Ball, 1980). In Nigeria, the major faults are NE–SW to NNE–SSW and ENE–WSW trending dextral wrench faults (Rahaman et al., 1984, and references therein; Ferré et al., 1998). Distribution of Triassic–Jurassic anorogenic ring complexes in the Jos Plateau defines a sigmoidal megagash geometry with a ENE–WSW mean direction that is probably linked to shear movement along pre-existing ENE–WSW trending wrench faults in the Pan-African basement (Rahaman et al., 1984; Black et al., 1985). This suggests that the Aïr and Younger Granites provinces were not emplaced under the same stress regime (Demaiffe and Moreau, 1996). The BT is a NE–SW trending extensional sedimentary basin (Benkhelil et al., 1988; Benkhelil, 1989) considered to be the failed arm of a Cretaceous triple junction, the two other rift arms of which subsequently developed into the South Atlantic Ocean and the Equatorial mega-shear zone (Burke and Dewey, 1974). Opening of the trough has also been attributed to reactivation during Cretaceous-Early Tertiary times of late Pan-African NE trending dextral shear zones (Guiraud and Maurin, 1992). In Cameroon, the basement is affected by a major translithospheric mega-shear that extends ENE from the Gulf of Guinea, through southern Chad and the Central African Republic into western Sudan. This Central African Shear Zone referred to as the Ngaoundéré or Foumban lineament (Browne and Fairhead, 1983; Cornachia and Dars, 1983) or the Central Cameroonian Shear Zone (Ngako et al., 1991), is a dextral shear that was formed during the Pan-African orogeny (Jorgensen and Bosworth, 1989) and is delineated by broad mylonite zones (Cornachia and Dars, 1983). The Patos and Pernambuco-Adamawa branches and their N–S relays control the geometry of the BT (Maurin et al., 1986; Guiraud and Maurin, 1992) and the CL, respectively (Fig. 1). Detailed structural studies of some syntectonic Pan-African granitoids in Cameroon (Kwékam, 1993; Nguiessi Tchankam et al., 1997; Tagne Kamga et al., 1999; Tagne

Kamga, 2003) show that they are broadly elongated and aligned NE–SW, consistent with their successive emplacement coeval with acting and oblique sinistral shear zones formed during an earlier deformation phase (Ngako, 1999). For example, in the Ngondo complex (1000 km^2), the geometry of the internal foliation trajectories and the joint orientation suggest that it was controlled by a N30° sinistral shear zone (Tagne Kamga et al., 1999), a conclusion early drawn for the Bandja complex (30×10 km) which outcrops in a N30° elliptic sheet (Nguiessi Tchankam et al., 1997). In the Biu Plateau, the distribution of volcanic necks appears to be controlled by a N–S alignment of Tertiary faults. The emplacement of Paleocene and Eocene alkali granite intrusions in Cameroon appears to be similarly fault controlled (Moreau et al., 1987). Indeed, it is partly superimposed on a pre-existing fracture zone (Déruelle et al., 1991), the Central African Shear Zone (Cornachia and Dars, 1983) (Fig. 4). Else, it has been suggested that volcanoes in the offshore part of the CL are located at places where the CL crosses fracture zones (see Meyers et al., 1998, and references therein) while inland volcanoes are located along structures related to Riedel-style shear zones (Déruelle et al., 1991). Fold zones are characterized by Pan-African domes or diapirs of granitoid (calc-alkaline) rocks (Grant, 1978; Ngako, 1999). They determine broad areas bounded by the Nigerian and Cameroonian shear zones and are dominantly characterized by the occurrence of Paleozoic to Cenozoic ring complexes. Thrust zones (Ball et al., 1984; Jégouzo, 1984; Nédélec et al., 1986, 1993; Nzenti et al., 1988; Pénaye et al., 1993) charac-

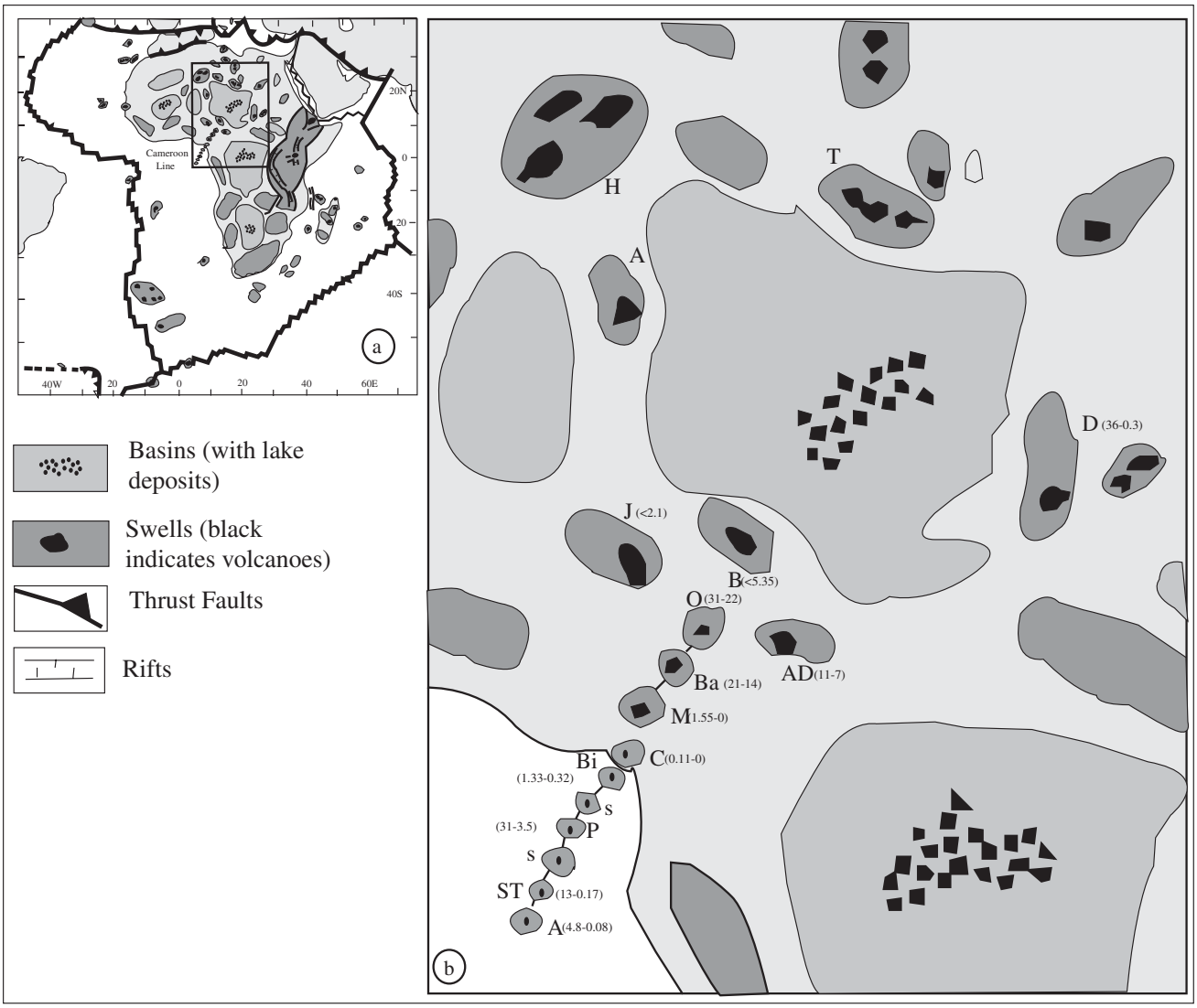

Fig. 5. (a) Basins and swells of the African plate (after Burke, 2001) showing among others, in the rectangle the Cameroon Line of 10 volcano-capped swells and the three swells at the landward end of the Cameroon Line (the Jos, Biu and Ngaoundéré swells). (b) Detail of the rectangle showing ages' distribution (in million years) of volcano-capped swells. H: Hoggar; A: Aïr; T: Tibesti; D: Darfur; J: Jos Plateau; Bi: Biu Plateau; AD: Adamawa Plateau; O: Mount Oku; Ba: Mount Bambouto; M: Mount Manengouba; C: Mount Cameroon; Bi: Bioko island, P: Principé island; ST: São Tomé island, A: Annobon island, s: seamount. Age data sources are: Grant et al. (1972), Fitton and Dunlop (1985), Halliday et al. (1988), Lee et al. (1994), Frank et al. (1999), Marzoli et al. (1999), Kagou Dongmo et al. (2001) and Aka et al. (2004).

terize the main structures of the Pan-African belt and overlay the archaean and eburnean boundary. These zones reveal no post-Pan-African magmatic activity, neither intrusive, nor effusive.

4.2. Swell-and-basin structures and magmatic provinces

Topographically, the general structures in western and central Africa suggest a long-lived continental extension activity, ongoing at least since Ordovician from one magmatic province to the other. These structures are represented either by large African lithospheric domes or swells such as the Hoggar, Aïr, Adamawa, Tibesti, Darfur (Poudjom Djomani et al., 1997; Burke, 2001) and the Great Lakes of East Africa (Ebinger et al., 1989), or by grabens, such as the BT (Benkhelil et al., 1988) (Fig. 5).

Domes correspond to high plateaus and mark the early stages of rift evolution. In Aïr, Jallouli (1989) estimated the thickness of the elastic lithosphere to be 20–30 km which is thin for a continental environment, but comparable to what is commonly observed in rift zones (Poudjom Djomani, 1993). Hartley et al. (1996) estimated a particularly thin elastic thickness for the lithosphere in the general region of the CL and Poudjom Djomani et al. (1997), in a more local study, with similar data sets but using somewhat different analytical procedures, found both crustal thickness and elastic thickness of lithosphere to be unusually thin in the continental part of the CL. For example, their map of crustal thickness (their Fig. 6) has a minimum value of 18 km at ca. lat. 7°N, long. 11.5°E recently referred to by Burke (2001) as the location of a mantle plume (the '711 plume'). The location of these swells coincides with magmatic provinces of different ages as in Aïr and in the CL. In Cameroon, the four islands of Bioko, Principé, São Tomé and Annobon and the four central volcanoes of Mount Cameroon, Manengouba, Bambouto and Oku occupy swells of the CL (Fig. 5). Also included are two large seamounts, one between Bioko and Principé and the other between Principé and São Tomé (Burke, 2001). They define a 1000-km long SW–NE straight line and display a "swell and basin" geometry which recalls the horst and graben structure of the whole CL (Déruelle et al., 1991).

In West and Central Africa, Guiraud and Maurin (1992) recognize two main phases of rifting separated by

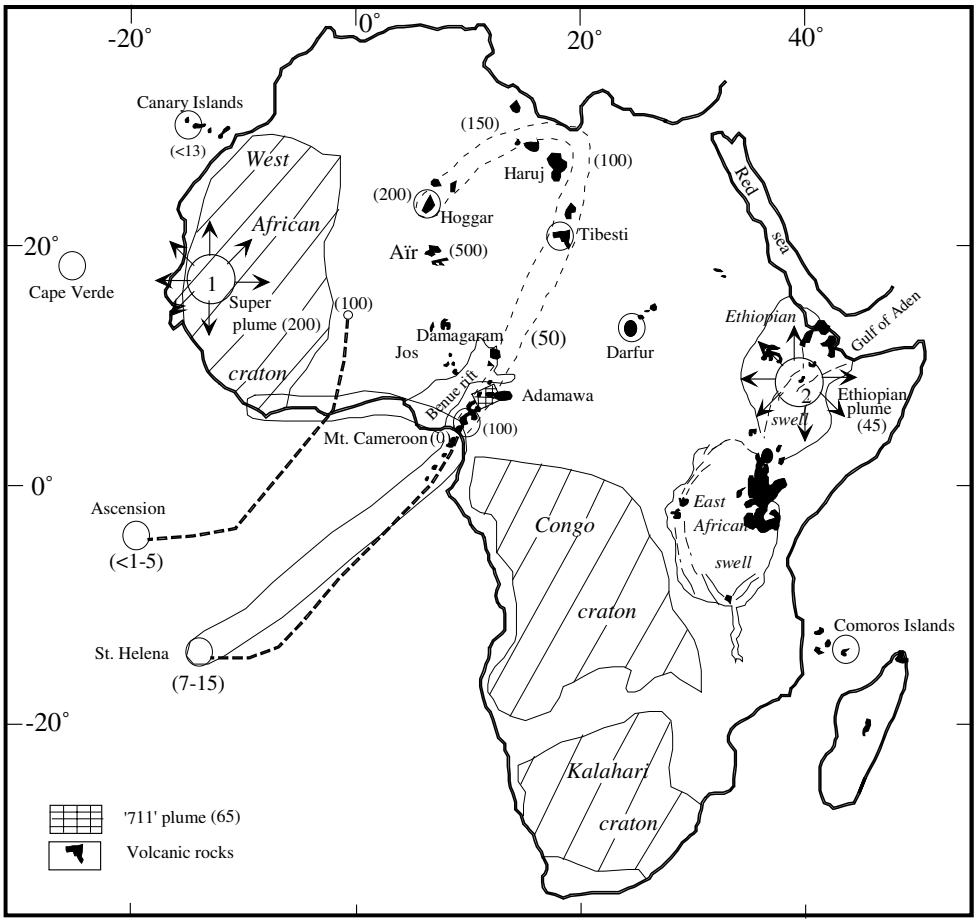

Fig. 6. Map showing some hotspots and hotspot tracks in Africa. Thick dotted line: Hotspot tracks since 100 Ma B.P. to their presently active locations (Duncan, 1981). Thin dotted line: 'Cameroon' hotspot tracks since 200 Ma B.P. from Hoggar to Mount Cameroon (Van Houten, 1983); Continuous thin line: Hotspot track from Sierra Leone to St. Helena (Morgan, 1983); 1: Mesozoic supper plume axis (Wilson, 1997); 2: Ethiopian plume axis (Ebinger and Sleep, 1998). The '711' plume is after Burke (2001). Numbers in parentheses represent ages in Ma. See text for more details.

a major Aptian (ca. 117 Ma) unconformity. (1) The Neocomian-Early Aptian (ca. 144–117 Ma) phase that began in the basins of East and Northeast Brazil, Gulf of Guinea, South Chad, Sudan, Kenya, North and East Niger, North Egypt and Libya. Late Jurassic magmatic activity appears to precede this rifting phase in Northeast Brazil, South Sudan and the BT of Nigeria. (2) The Middle-Late Aptian-Albian (ca. 117–98 Ma) phase marked among others by the development of pull apart basins in an oblique extensional regime from Benue to southern Chad, related to strike-slip movement along the Central African Shear Zone (Bosworth, 1992). Magmatic activity in the BT was particularly important during the Cretaceous-Early Tertiary and took place during several phases, contemporaneous with the opening and infilling of the trough (Wilson and Guiraud, 1992). The first phase (Early Cretaceous: 141–106 Ma; Baudin, 1991) is related to the main extensional tectonic regime which affected the trough. During the Tertiary, basaltic magmas were emplaced throughout the entire trough with the greatest concentration in the NE (Wilson and Guiraud, 1992). This Post-Cretaceous extension and volcanism in the Upper Benue corresponds to a period of general stress release after the Santonian or Cretaceous compressional events (Benkhelil, 1989). In general, magmatic activity is predominantly basaltic (basalts are transitional from alkaline to tholeiitic types) in the Upper Benue, although rhyolites occur locally. In the Garoua basin, which represents the eastern continuation of the Yola branch of the Upper Benue, the strata are cut by lineaments which may have acted as strike-slip or normal faults. Tertiary–Quaternary magmatism associated with these lineaments occurs as dolerite sills, Paleocene (65–60 Ma) alkaline complexes and Neogene trachy-phonolite necks and dykes (Guiraud et al., 1987). An entirely younger undersaturated anorogenic complex (Kokoumi) belonging to the basin and including a gabbro-nepheline syenite series (39 Ma) and lamprophyre dykes (20.5 Ma) has been recently studied (Ngounouno et al., 2001).

5. Discussion and conclusions

From the synthesis above, it appears that (1) there is a time–space link among the magmatic alkaline provinces in West-Central Africa, from 407 ± 8 Ma in Aïr (North Niger) and 330–260 Ma in Damagaram-Mounio (South Niger) to 66-Present in Cameroon through 213–141 Ma in Jos Plateau (northern Nigeria) and 147–49 Ma in the BT (southern Nigeria). The migration follows a North–South trajectory in the Aïr-Damagaram-Jos provinces, and a NW–SE trajectory in the BT-CL provinces; (2) only the Aïr province displays a N–S trend of magmatic complexes, the Jos Plateau, BT and CL complexes show three parallel lines rather trending NE–SW; (3) Each trend is parallel to a shear or fracture zone: N–S Raghane shear zone for the Aïr, NE trending wrench fault for Jos Plateau, NE-trending dextral shear zone for the BT, NE-trending sinistral fault oblique to the Central African Shear Zone or fracture zones directed N70°E for the CL (Fig. 4); (4) Only the ages of the Younger Granites of Nigeria become steadily younger from Dutse (213 Ma) in the NE to Afu (141 Ma) in the SW over a distance of 420 km; (5) There is a great overlap between the third magmatic period in the BT (68–49 Ma) and the ages of anorogenic complexes (66–30 Ma) of the CL, while the beginning of the first magmatic period (147 Ma) coincide, within analytical error range, with the end of the emplacement of granite complexes of Nigeria (141 Ma). All these geometrical, structural, geochemical and geochronologic data would suggest a complex interaction of mantle plumes with a northward moving continental lithosphere intensely deformed during Pan-African and including deep seated faults controlling the Phanerozoic extension and creation of successive magmatic provinces or magmatic lines.

The origin of intra-plate magmatism on the African continent (and elsewhere in the world, e.g., Smith and Lewis, 1999) is still a topic of great contention. Some workers such as Halliday et al. (1990), Wilson and Guiraud (1992), Lee et al. (1994) and Ebinger and Sleep (1998) link it to the role of mantle plumes. Mantle plumes are objects largely independent of plates and large-scale mantle circulation. They carry heat and isotopes from their source (any internal boundary layer) to the surface (Loper and Stacey, 1983). Isolated plumes coming from a localized source of buoyancy (either thermal or compositional) have been shown to explain quantitatively a number of hotspot features such as the dynamic swells (Sleep, 1990; Olson, 1990). For low buoyancy ratio (i.e. weak density anomaly of chemical origin), large domes or "superswells" are generated whereas for higher buoyancy ratio, long-lived thermochemical plumes are produced (Davaille, 1999; Davaille et al., 2002). On the basis of (i) fluid mechanics arguments; (ii) the observations of the huge volumes that must be melted to produce flood basalts and (iii) the long durations of their conduits which must produce island chains, Courtillot et al. (2003) suggested a core-mantle boundary origin for primary plumes. Such plumes are thought to be more voluminous, are over 500 km in diameter, have ascended a much greater distance (Griffiths et al., 1989). But for Anderson (2000), all non-plate boundary volcanism can be explained by shallow plate-related stresses that fracture the lithosphere and cause volcanism along these cracks, promoted for instance by a secondary eye-driven convection in the upper mantle.

5.1. A St. Helena type of hotspots for the Aïr-Damagaram-Jos Plateau–BT–CL magmatic trend

Most of the African hotspots have been active since the Cretaceous (Duncan, 1981). To explain the extensive Triassic-Early Jurassic magmatism along the West African and North American margins, Wilson (1997) suggested the location of a pre-Pangea continental break-up 'super plume' axis beneath West Africa (Fig. 6). Studies of uplift

history, topography and seismic tomography of the African plate and underlying mantle (Lithgow-Bertelloni and Silver, 1998) indicate that southern Africa is underlain by a large-scale buoyant, low seismic velocity structure extending from just above the core-mantle boundary to near the base of the African lithosphere and that the ascend of this material could be feeding many hotspots in Africa (Gurnis et al., 1999). The question arises as to which of the African hotspots was responsible for the magmatism of the Aïr–Damagaram-Jos-BT–CL. Given (1) the tectonic and the geochemical links between the BT and the CL, (2) the geologic evidence (Wilson, 1992; Wilson and Guiraud, 1992; O'Connor and Le Roex, 1992) that the St. Helena hotspot was located in the Gulf of Guinea in the Cretaceous and played an important role in the opening of the BT and break up of Equatorial Atlantic and (3) the geochronologic and structural relations between the Aïr–Damagaram-Jos-BT–CL magmatic provinces, it may be suggested that the genesis of these magmatic provinces lies in the interaction between the St. Helena hotspot and deep lithospheric fractures. Courtillot et al. (2003) suggest that surface hotspots (plume manifestations) on Earth may have three distinct origins corresponding to the three boundary layers between the core-mantle boundary and the surface of the Earth: (i) deepest part of the lower mantle referred to as "Morganian"; (ii) bottom of the transition zone at the top of the largest transient domes that correspond to the superswells; (iii) upper mantle features referred to as "Andersonian"; these may be linked to the asthenosphere and be a passive response to forms of lithospheric breakup. The authors term the first type Primary hotspots and the others, Secondary hotspots, the latter being characterized by the short length and duration of the tracks and the lack of flood basalts at the onset. Their $^{3}He/^{4}He$ ratios are low compared to that of the primary hotspots. On this basis, Courtillot et al. (2003) showed that St. Helena, Hoggar, Cameroon and Tibesti are secondary hotspots sharing almost similar criteria. The plume source for the CL suggested by Lee et al. (1994) to be at the 670 km transition zone is in agreement with the resulting secondary hotspots; but the Andersonian hotspot seems to us more likely, based on Halliday et al. (1990) who considered the HIMU Pb isotope signature of the CL to be inherited from relatively recent U/Pb fractionation at 125 Ma during impregnation of the uppermost mantle by the St. Helena hotspot when the Equatorial Atlantic opened.

5.2. At least two plumes beneath West and Central Africa

The overall N–S trend changing to NW–SE one recalls that of the renowned Hawaiian-Emperor seamount chain described by Stock and Molnar (1987). This inter-province time–space migration within a ca 410 Ma period and over a distance of ~1650 km would correspond to an average migration speed of the African plate of ca 0.4 cm/yr in a northward direction over a deep (relatively fixed) heat source. But, based on the fact that all plumes born (as traps) in the last 100 Ma (i.e. Ethiopia-Yemen/Afar) are still quite active, whereas those born between 100 and 140 Ma may be failing and those older than 150 Ma do not in general have an active trace (Duncan and Richards, 1991; Courtillot et al., 1999), it is very difficult to explain the whole trend, by a simple motion of plate above one stationary hotspot as in the Hawaiian system. The 1650 km distance stretched by the magmatic provinces is more than three times the postulated diameter of the of the St. Helena plume tail (O'Connor and Le Roex, 1992; Wilson, 1992). Richards and Lithgow-Bertelloni (1996) demonstrated the difficulty of explaining abrupt plate motion changes in terms of mantle buoyancy forces that evolve continuously. This is in agreement with Demaiffe and Moreau (1996) who concluded from the alignment of the Aïr complexes and the Nigerian Younger Granites along the Raghane shear zone (N–S trending) and a ENE megashear respectively, that they were not emplaced under the same stress regime. It is also corroborated by the age data (Rahaman et al., 1984) which show a faster rate of migration within the Nigerian province (Shira to Afu) of 0.9 cm/yr than the migration between the southern Niger (Matsena) and the Nigerian (Shira) provinces which can be calculated at 0.3 cm/yr. Burke (2001) demonstrated that a single plume, dubbed the "711" plume, formed the Nigerian granites, generated a topographic dome at ca. 140 Ma on which the triple-rift system among which the BT developed and was also involved in forming the Cameroon granitic complexes: (i) Between 213 and 141 Ma, the 711 plume generated a 400 km-long line of intrusions as the continent moved over it. (ii) From 140 Ma to 66 Ma, the plume moved ca. 300 km with respect to the overlying continental lithosphere, having been caught up in the evolution of the Benue rift system (Maluski et al., 1995) rather than forming a line of intrusions. (iii) Since 66 Ma, the 711 plume has stayed in the same place, close to lat. 7°N and long 11.5°E, but has been associated with the development of the CL. This is geochemically supported by the similar major and trace element chemistry between the Biu Plateau known as the landward end of the CL and the Jos Plateau lavas and the fact that the Jos Plateau lavas also span a similar range in isotopic composition, overlapping the data of the CL as a whole (Rankenburg et al., 2004).

5.3. Controls by lithospheric fractures

Paleomagnetic measurements (e.g. Burke, 1996) show a rotation of the African plate through ca. 45° counter-clockwise about a poorly defined internal pole in the general area of lat 7°N, long 11.5°E, between ca.140 and 30 Ma. Even if the N–S trend of the Niger complexes could be linked to the NE–SW trend of the CL complexes via this 45° counter-clockwise rotation, the parallelism between the BT and the Nigerian Younger Granites to the North and the CL to the South, seems consistent with a structural link between them, in addition to the role of the 711 plume.

According to Wilson and Guiraud (1992), the Tertiary in the northern part of the CL was characterized by an E–W extension (Guiraud et al., 1987), resulting from a general stress release following the Santonian compressional event. The extensional tectonic regime controlled the location of the Neogene to Quaternary volcanic rocks of the CL and those of the Jos Plateau, the northern Benue and of the Biu Plateau. Remote sensing and autocorrelation analyses in the CL (Moreau et al., 1987) and in the Aïr massif (Moreau et al., 1994) suggest a control by lithospheric structures for the emplacement of the ring complexes as well as a relationship between a transtensional regime and intraplate alkaline magmatism. According to their model, only a sinistral shear along the N70°E (Adamawa) direction is consistent with a tension gash having the CL trend. In this Riedel model (Fig. 7a), $T = \text{N25°E}$, $R = \text{N55°E}$, $R' = \text{N175°E}$, $P = \text{N85°E}$ with σ_1 oriented N40°E and $\sigma_3 = \text{N130°E}$. In the model proposed for the Aïr massif (Fig. 7b), the N20°E direction represents the Riedel direction (R) of a N5°E dextral shear zone assimilated to the Raghane shear zone (Liégeois et al., 1994); the N50°E, N90°E and N170°E could correspond to the T (compressional axis), *R'* sinistral and *P* dextral directions, respectively. More recently, Burke (2001) distinguished an ancestral CL marked by the plutonic complexes emplaced between 66 and 30 Ma, during the 45° rotation of the African plate and a CL of volcano-capped swells which formed on top of the granitic complexes after the rotation ceased at ca. 30 Ma. He suggests that the granitic complexes recorded a zone of extension and may indicate the presence of a short wavelength shallow-mantle convection system and that the convection pattern set up at 30 Ma appears to have occupied the existing zone of extension and perhaps to have assimilated an existing convection pattern. According to him, that extensional stress developed as part of the local stress field at the right-angled bend (Emery and Uchupi, 1984) in the Cameroon continental margin. Indeed, the location and azimuth of the two lines overprint Pan-African paleo-sutures marked by the alignment of synkinematic granites onshore and by the fact that the opening of the South Atlantic followed the Pan-African suture of the Adamastor Ocean, West of the Mid-Atlantic Ridge (Smith and Lewis, 1999); therefore indicating the role of rejuvenation of Precambrian faults during Cretaceous time (Moreau et al., 1987) in the emplacement of the CL. For Lee et al. (1994), the CL originates from a sublithospheric enriched "hot zone" periodically fed and melted deep mantle plumes, and this zone of hotter mantle represents reactivated mantle previously enriched during the breakup of the South Atlantic in the Mesozoic. Of relevance here is the fact that isotopic systematics of some lavas from the oceanic sector of the CL imply the involvement of a continental crustal component (Rankenburg et al., 2005) and the "LOMU" component in Mid-Atlantic Ridge basalts described by Douglass et al. (1999) and Douglass and Schilling (2000) is isotopically similar to Pan-African continental crust. Assuming that the line as a whole shares a common source, Rankenburg et al. (2005) propose that the continental signature seen in the oceanic sector of the CVL is caused by shallow contamination, either by continent-derived sediments or by rafted crustal blocks that became trapped in the oceanic lithosphere during continental breakup in the Mesozoic. The focus of magmatism is therefore partly controlled by preferential flow paths through the lithosphere (Lee et al., 1994). As suggested by Smith (1993), the parallelism between the BT and the CL can better be explained in terms of controls of lithospheric structures; these are readily illustrated by intraplate volcanism in the Atlantic Ocean basin, which can be considered the simplest example of

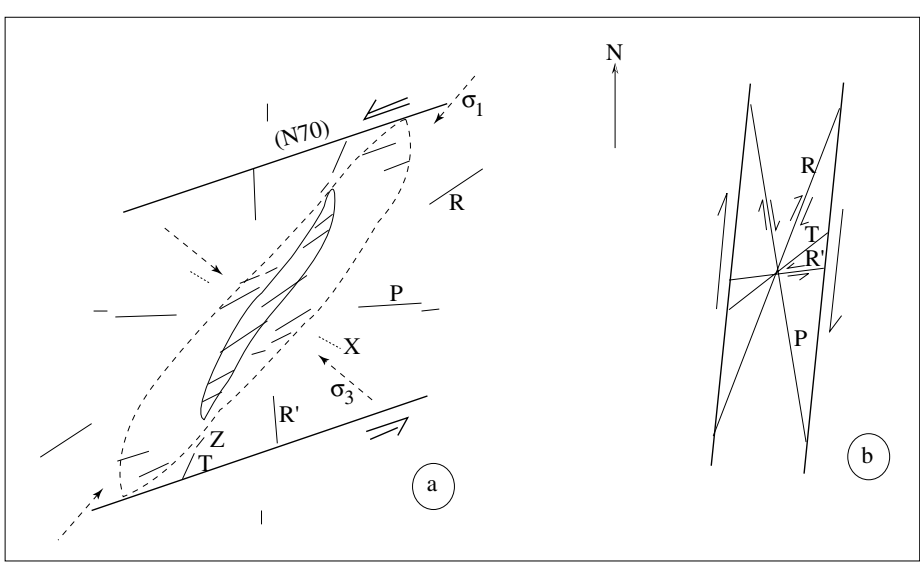

Fig. 7. Riedel models proposed to explain the main structures controlling the emplacement of the Cameroon (a) and Aïr (b) ring complexes, found on satellite imagery and the autocorrelation graphs (Moreau et al., 1987, 1994).

rifting as the ridge system still parallels the continental margins (Smith and Lewis, 1999).

5.4. An alternative for the SW–NE Nigeria, Benue Trough and CL parallel trendings

An alternative model, susceptible to take into account the whole geometry and structure of the intraplate magmatism in West and Central-Africa could be that of Hieronymus and Bercovici (2000). This model explains the distribution of non-hotspot island and seamount chains in terms of the vulnerability of the lithosphere to magma penetration due to lithospheric stresses and the effects of melting of the conduit walls. Their theory is based on the assumption that (1) transport of magma through the brittle part of the lithosphere occurs via fractures and (2) melt is distributed uniformly at the base of the lithosphere. It turns out that an initial perturbation is required in all cases to localize the volcanic activity. This initial perturbation may be provided by a change in the tectonic stress field due to a plate motion reorganization (which is amplified locally by an inhomogeneity in the lithosphere), the formation of a small sublithospheric melting anomaly or a change in convection. Hieronymus and Bercovici (2000) have finally shown that multiple lines of volcanoes can result from interaction of flexural, membrane and tectonic stresses. Indeed: (i) due to the tensile membrane stresses, several volcanoes typically form in the space between any two volcanoes of the initial chain; (ii) membrane stresses perpendicular to the axis of the volcanic line (or ridge) also interact with the flexural stresses to generate volcanism away from the axis. This off-axis volcanism eventually forms additional lines of volcanoes parallel to the first one.

Following the above model, the fact that geometric techniques (Wessel and Kroenke, 1997) do not clearly locate any fixed hotspot in the Aïr province indicate that the N–S trending complexes are likely to be self-propagating disturbances of magmatic loads and associated flexure with a more or less uniform sublithospheric melt distribution as illustrated in the Fig. 4 of Hieronymus and Bercovici (2000). The NE–SW trending Younger Granites of Nigeria initiated at time of plate motion change, marked by a change in the tectonic stress field as already mentioned by Demaiffe and Moreau (1996) and were emplaced following some local perturbation, the formation of a small sublithospheric melting anomaly. Here, melt migration may be aided by tectonic and flexural stresses, such that the complexes are limited in extent to the melting region of the plume. Membrane stresses perpendicular to the axis of the Younger Granite trend, interacted with the flexural stresses to generate the NE–SW BT and CL trends. Noteworthy is the volumetrically restricted Mesozoic to Cenozoic magmatism of the BT (Maluski et al., 1995) which is similar to the small size of the CL granitic complexes and their volcano-capped swells (Burke, 2001). Shen et al. (1995) demonstrated that the individual lines of volcanoes compete with each other for melt. It is thus possible that the region between the volcanic lines has largely been drained of magma, thus allowing only the formation of small magmatic bodies (Scheirer et al., 1996).

Acknowledgements

This work is dedicated to late Professor A.B. Kampunzu in remembrance of his great interest for evolution of Phanerozoic Magmatism in Africa. We are gratefull to the anonymous reviewers for their constructive comments and to Prof. A. Nédélec for her precious advices on the former manuscript.

References

Abdelsalam, M.G., Liégeois, J.P., Stern, R.J., 2002. The Saharan metacraton. Journal of African Earth Sciences 34, 119–136.

Aka, F.T., Nagao, K., Kusakabe, M., Sumino, H., Tanyileke, G., Ateba, B., Hell, J., 2004. Symmetrical helium isotope distribution on the Cameroon volcanic line, West Africa. Chemical Geology 203, 205–223.

Anderson, D.L., 2000. The thermal state of the upper mantle: no role for mantle plumes. Geophysical Research Letters 27, 3623–3626.

Badejoko, T.A., 1986. Triclinicity of K-feldspars and trace element content of Mesozoic granites of Central Nigeria. Chemical Geology 54, 43–51.

Ball, E., 1980. An example of very consistent brittle deformation over a wide intracontinental area: the late Pan-African fracture system of Tuareg and Nigerian shield. Tectonophysics 6, 363–379.

Ball, E., Bard, J.P., Soba, D., 1984. Tectonique tangentielle dans la catazone panafricaine du Cameroun: les gneiss de Yaoundé. Journal of African Earth Sciences 2, 91–95.

Baudin, P., 1991. Le magmatisme mésozoïque à cénozoïque du fossé de la Benoué (Nigéria). Géochronologie, pétrogenèse, cadre géodynamique. Ph.D Thesis, Université Aix-Marseille III, unpublished.

Benkhelil, J., 1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). Journal of African Earth Sciences 8, 251–282.

Benkhelil, J., Danielli, P., Ponsard, J.F., Popoff, M., Saugy, L., 1988. The Benue Trough: Wrench fault related basins on the border of the Equatorial Atlantic. In: Manspeizer, M. (Ed.), Triassic-Jurassic Rifting – Continental Break-up and the Origin of the Atlantic Ocean and Passive Margins. Development in Geotectonics, vol. 22. Elsevier, Amsterdam, pp. 789–819.

Black, R., Lameyre, J., Bonin, B., 1985. The structural setting of alkaline complexes. Journal of African Earth Sciences 3, 5–16.

Black, R., Liégeois, J.P., Navez, J., Vialette, Y., 1991. Terrains exotiques dans les zones externes de la chaîne Trans-saharienne: les clefs fournies par l'Aïr Sud-oriental (République du Niger). Comptes Rendus de l'Académie des Sciences Paris 312, 889–895.

Bosworth, W., 1992. Mesozoic and Early Tertiary rift tectonics in East Africa. In: Ebinger, C.J., Gupta, H.K., Nyambok, I.O. (Eds.), Seismology and Related Sciences in Africa. Tectonophysics, vol. 209, pp. 115–137.

Bowden, P., Karche, J.P., 1984. Mid-plate A-type magmatism in the Niger–Nigeria province: age variations and implications. In: Klerkx, J., Michot, J. (Eds.), Géologie Africaine. Musée Royale d'Afrique Centrale, Tervuren, pp. 167–177.

Bowden, P., Kinnaird, J.A., 1984. Geology and mineralization of the Nigerian anorogenic ring complexes. Beith Geologisches Jahrbuch B 56, 197–299.

Bowden, P., van Breemen, O., Hutchinson, J., Turner, D.C., 1976. Palaeozoic and Mesozoic age trends for some ring complexes in Niger and Nigeria. Nature 259, 297–299.

Brown, W.L., Moreau, C., Demaiffe, D., 1989. An anorthosite suite in a ring-complex: crystallization and emplacement of an anorogenic type from Abontorok, Aïr, Niger. Journal of Petrology 30, 1501–1540.

Browne, S., Fairhead, J.D., 1983. Gravity study of the Central African Rift system: a model of continental disruption 1. The Ngaoundere and Abu Gabra rifts. Tectonophysics 94, 187–203.

Brunet, M., Dejax, J., Brillançeau, 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 Benoué en Afrique occidentale (Bassin du Mayo Oulo Léré, Cameroun), en relation avec l'ouverture de l'Atlantique sud. Comptes Rendus de l'Académie des Sciences Paris 305, 1125–1130.

Burke, K., 1996. The African plate. S.A. Journal of Geology 99, 341–409.

Burke, K., 2001. Origin of the Cameroon Line of volcano-capped swells. Journal of Geology 109, 349–362.

Burke, K.C., Dewey, J.F., 1974. Two plates in Africa during the Cretaceous? Nature 249, 313–316.

Caen-Vachette, M., Tempier, P., Kamgang, P., 1987. Le massif tertiaire du Nkogam (Ouest Cameroun): caractéristiques principales et géochronologiques Rb/Sr sur roches totales. Journal of African Earth Sciences 6, 521–524.

Cahen, L., Snelling, N.J., Delhal, J., Vail, J.R., Bonhomme, M., 1984. The Geochronology and Evolution of Africa. Clarendon, Oxford, p. 512.

Caldeira, R., Munhá, J.M., 2002. Petrology of ultramafic nodules from São Tomé Island, Cameroon Volcanic Line (oceanic sector). Journal of African Earth Sciences 34, 231–246.

Cornachia, M., Dars, R., 1983. Un trait structural majeur du continent africain: les linéaments centrafricains du Cameroun au golfe d'Aden. Bulletin de la Société Géologique de France 25, 101–109.

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. Journal of Petrology 37, 1341–1358.

Courtillot, V., Jaupart, C., Manighetti, I., Tapponnier, P., Besse, J., 1999. On causal links between flood basalts and continental breakup. Earth and Planetary Science Letters 166, 177–195.

Courtillot, V., Davaille, A., Besse, J., Stock, J., 2003. Three distinct types of hotspots in the Earth's mantle. Earth and Planetary Science Letters 205, 295–308.

Davaille, A., 1999. Simultaneous generation of hotspots and superswells by convection in a heterogeneous planetary mantle. Nature 402, 756–760.

Davaille, A., Girard, F., Le Bars, M., 2002. How to anchor hotspots in a convecting mantle? Earth and Planetary Science Letters 203, 621–634.

Demaiffe, D., Moreau, C., 1996. Crustal growth in Aïr (Niger, West Africa): significance of the Palaeozoic anorthosite-bearing anorogenic province. In: Demaiffe, D. (Ed.), Petrology and Geochemistry of Magmatic Suites of Rocks in the Continental and Oceanic Crusts. Université Libre Bruxelles, Belgium, pp. 35–49.

Demaiffe, D., Moreau, C., Brown, W.L., 1991. Ring-complexes of Ofoud-type in Aïr, Niger, a new anorogenic-type anorthosite association. In: Kampunzu, A.B., Lubala, R.T. (Eds.), Magmatism in Extensional Structural Settings, The Phanerozoic African Plate. Springer-Verlag, Berlin, pp. 359–382.

Déruelle, B., Moreau, C., Nkoumbou, C., Kambou, R., Lissom, J., Njonfang, E., Ghogomu, T.R., Nono, A., 1991. The Cameroon Line: a review. In: Kampunzu, A.B., Lubala, R.T. (Eds.), Magmatism in Extensional Structural Settings, The Phanerozoic African Plate. Springer-Verlag, Berlin, pp. 274–327.

Douglass, J., Schilling, J.G., 2000. Systematics of three-component, pseudo-binary mixing lines in 2D isotope ratio space representations and implications for mantle plume – ridge interaction. Chemical Geology 163, 1–23.

Douglass, J., Schilling, J.G., Fontignie, D., 1999. Plume – ridge interactions of the Discovery and Shona mantle plumes with the southern mid-Atlantic ridge (40°–55°S). Journal of Geophysical Research – Solid Earth 104, 2941–2962.

Duncan, R.A., 1981. Hotspots in the southern oceans – an absolute frame of reference for motion of the Gondwana continents. Tectonophysics 74, 29–42.

Duncan, R.A., Richards, M.A., 1991. Hotspots, mantle plumes, flood basalts, and true polar wander. Review of Geophysics 29, 31–50.

Ebinger, C.J., Sleep, N.H., 1998. Cenozoic magmatism throughout east Africa resulting from impact of a single plume. Nature 395, 788–791.

Ebinger, C.J., Bechtel, T.D., Forsyth, D.W., Bowin, C.O., 1989. Effective elastic plate thickness beneath the East African and Afar plateaus and dynamic compensation of the uplifts. Journal of Geophysical Research 94, 2883–2901.

Emery, K.O., Uchupi, E., 1984. Geology of the Atlantic Ocean Chart XI. Springer, New York, p. 1050.

Ferré, E.C., Caby, R., Peucat, J.J., Capdevilla, R., Monié, P., 1998. Pan-African, post-collisional, ferro-potassic granite and quartz-monzonite plutons of Eastern Nigeria. Lithos 45, 255–279.

Fitton, J.D., 1980. The Benue Trough and the Cameroon Line – a migrating rift system in West Africa. Earth and Planetary Science Letters 51, 132–138.

Fitton, J.D., 1983. Active versus Passive continental Rifting: evidence from the West African Rift system. Tectonophysics 94, 473–481.

Fitton, J.D., Dunlop, H.M., 1985. The Cameroon Line, West Africa and its bearing on the origin of oceanic and continental alkali basalts. Earth and Planetary Science Letters 72, 23–38.

Fosso, J., Ménard, J.-J., Bardintzeff, J.-M., Wandji, P., Tchoua, F.M., Bellon, H., 2005. Les laves du mont Bangou: une première manifestation volcanique éocène, à affinité transitionnelle, de la Ligne du Cameroun. Comptes Rendus Geoscience 337, 315–325.

Frank, G., Steiner, G., Volker, F., Pudlo, D., Hammerschmidt, K., 1999. Plume related alkaline magmatism in central Africa – the Meidob Hills (W Sudan). Chemical Geology 157, 27–47.

Ghogomu, R.T., Moreau, C., Brown, W.L., Rocci, G., 1989. The Ntumbaw complex, NW Cameroon: an atypical anorogenic ring complex of intermediate composition. Journal of African Earth Sciences 8, 1–9.

Grant, N.K., 1978. Structural distinction between a sedimentary cover and an underlying basement in the 600 m.y. old Pan-African domain of northwestern Nigeria, West Africa. Geological Society of America Bulletin 89, 50–58.

Grant, N.K., Rex, D., Freeth, S.J., 1972. Potassium-radium age and strontium isotope ratio measurements from volcanic rocks in north-eastern Nigeria. Contributions to Mineralogy and Petrology 35, 277–292.

Griffiths, R.W., Gurnis, M., Eitelberg, G., 1989. Holographic measurements of surface topography in laboratory models of mantle hotspots. Geophysical Journal 96, 477–495.

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

Guiraud, R., Bellion, Y., Benkhelil, J., Moreau, C., 1987. Post-Hercynian tectonics in Northern and Western Africa. Geological Journal 22, 433–466.

Guiraud, R., Binks, R.M., Fairhead, J.D., Wilson, M., 1992. Early Cretaceous rifts of West and Central Africa. In: Ziegler, P.A. (Ed.), Geodynamics of Rifting, vol. II Case history studies on rifts: North and South America and Africa. Tectonophysics, vol. 213, pp. 227–234.

Gurnis, M., Mitrovica, J.X., Ritsema, J., Van Heijst, H.J., 1999. Constraining mantle density structure using geological evidence of uplift rates: the case of the African superplume. Geochemistry, Geophysics, Geosystems 1, paper 1999GC000035.

Halliday, A.N., Dicken, A.P., Fallick, A.E., Fitton, J.D., 1988. Mantle Dynamics: A Nd, Sr, Pb and O isotope study of the Cameroon Line volcanic chain. Journal of Petrology 29, 181–211.

Halliday, A.N., Davidson, J.P., Holden, P., DeWolf, C.P., Lee, D.-C., Fitton, J.G., 1990. Trace element fractionation in plume and the origin of HIMU mantle beneath the Cameroon Line. Nature 347, 523–528.

Hartley, R., Watts, A.B., Fairhead, J.D., 1996. Isostasy of Africa. Earth and Planetary Science Letters 137, 1–18.

Hieronymus, C.F., Bercovici, D., 2000. Non-hotspot formation of volcanic chains: control of tectonic and flexural stresses on magma transport. Earth and Planetary Science Letters 181, 539–554.

Jacquemin, H., Gouhier, J., Brown, W.L., Parsons, I., 1981. Les associations minérales du complexe anorogénique de Mboutou (Nord Cameroun). Comptes Rendus de l'Académie des Sciences Paris 292, 203–206.

Jallouli, 1989. Caractérisation du comportement mécanique de la lithosphère continentale à partir des données gravimétriques. Implications géodynamiques pour la chaîne panafricaine du Sahara Central de l'Afrique (Aïr). Ph.D thesis, University Paris-sud, unpublished.

Jégouzo, P., 1984. Evolution structurale du Sud-Ouest Cameroun durant l'orogène panafricain. Association de tectoniques cisaillante et chevauchante. Colloque CNRS, chevauchement et déformation, Toulouse, p. 23.

Jorgensen, G.J., Bosworth, W., 1989. Gravity modelling in the Central African Rift System, Sudan: rift geometry and tectonic significance. In: Rosendahl, B.R., Rogers, J.J.W., Rach, N.M. (Eds.), African Rifting. Journal African Earth Sciences, vol. 8, pp. 283–306.

Kagou Dongmo, A., Wandji, P., Pouclet, A., Vicat, J.-P., Cheilletz, A., Nkouathio, D.B., Alexandrov, P., Tchoua, M.F., 2001. Evolution volcanologique du mont Manengouba 'Ligne du Cameroun': nouvelles données pétrographiques, géochimiques et géochronologiques. Comptes Rendus de l'Académie des Sciences Paris 333, 155–162.

Kambou, R., Nzenti, J.P., Soba, D., 1989. Apport à la connaissance des complexes anorogéniques d'âge tertaire de la Ligne du Cameroun: le complexe pluto-volcanique de Tchégui (Nord-Cameroun). Comptes Rendus de l'Académie des Sciences Paris 308, 1257–1260.

Kamdem, J.B., Kraml, M., Keller, J., Henjes-Kunst, F., 2002. Cameroon Line magmatism: conventional K/Ar and single-crystal laser $^{40}Ar/^{39}Ar$ ages of rocks and minerals from the Hossere Nigo anorogenic complex, Cameroon. Journal of African Earth Sciences 35, 99–105.

Karche, J.P., Vachette, M., 1978. Age et migration de l'activité magmatique dans les complexes paléozoïques du Niger, conséquences. Bulletin de la Société Géologique de France 20, 941–953.

Kinnaird, J.A., 1985. Hydrothermal alteration and mineralization of the alkaline anorogenic ring-complexes of northern Nigeria. Journal of African Earth Sciences 3, 185–222.

Kwékam, M., 1993. Le massif plutonique calco-alcalin pan-africain de Fomopéa (Ouest Cameroun), cadre structural, pétrologie, géochimie, interprétation géodynamique. Doctorat 3ème cycle thesis, University of Yaoundé I, unpublished.

Lasserre, M., 1978. Mise au point sur les granitoïdes dits "ultimes" du Cameroun: Gisements, pétrographie et géochronologie. Bulletin du B.R.G.M. 2, 143–159.

Lee, D.C., Halliday, A.N., Fitton, J.G., Poli, G., 1994. Isotopic variation with distance and time in the volcanic islands of the Cameroon Line: evidence for a mantle plume origin. Earth and Planetary Science Letters 123, 119–138.

Lee, D.C., Halliday, A.N., Davies, G.R., Essene, E.J., Fitton, J.G., Temdjin, R., 1996. Melt enrichment of shallow depleted mantle: a detailed petrological, trace element and isotopic study of mantle derived xenoliths and megacrysts from the Cameroon Line. Journal of Petrology 17, 415–441.

Liégeois, J.P., Black, R., Navez, J., Latouche, L., 1994. Early and late Pan-African orogenies in the Aïr assembly of terranes (Tuareg shield, Niger). Precambrian Research 67, 59–88.

Lithgow-Bertelloni, C., Silver, P., 1998. Dynamic tomography, plate driving forces and the African superswell. Nature 395, 269–272.

Loper, D.E., Stacey, F.D., 1983. The dynamical and thermal structure of deep mantle plumes. Physics of Earth and Planetary Interior 33, 304–317.

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

Marzoli, A., Renne, P.R., Piccirillo, E.M., Castorina, F., Bellieni, G., Melfi, A.J., Nyobe, J.B., N'ni, J., 1999. Silicic magmas from the continental Cameroon volcanic line (Oku, Bambouto and Ngaoundere): $^{40}Ar/^{39}Ar$ dates, petrology, Sr-Nd-O isotopes and their petrogenetic significance. Contributions to Mineralogy and Petrology 135, 133–150.

Marzoli, A., Piccirillo, E.M., Renne, P.R., Bellieni, G., Lacumin, M., Nyobe, J.B., Aka, F.T., 2000. The Cameroon Volcanic Line revisited: petrogenesis of continental basaltic magmas from lithospheric and asthenospheric mantle sources. Journal of Petrology 41, 87–109.

Meyers, J.B., Rosendahl, B.R., Harrison, C.G.A., Ding, Z.-D., 1998. Deep-imaging seismic and gravity results from offshore Cameroon Volcanic Line and speculation of African hot-lines. Tectonophysics 284, 31–63.

Maurin, J.C., Benkhelil, J., Robineau, B., 1986. Fault rocks of the Kaltungo lineament, NE Nigeria, and their relationship with Benue Trough tectonics. Journal of Geological Society of London 143, 587–599.

Montigny, R., Ngounouno, I., Déruelle, B., 2004. Âges K-Ar des roches magmatiques du fossé de Garoua (Cameroun): leur place dans le cadre de la " Ligne du Cameroun". Comptes Rendus Géoscience 336, 1463–1471.

Moreau, C., 1982. Les complexes annulaires anorogéniques à suites anorthositiques de l'Aïr Central et Septentrional (Niger). Thèse de Doctorat d'Etat, University of Nancy I, unpublished.

Moreau, C., Brown, W.L., Demaiffe, D., Dupont, P.L., Rocci, G., 1986. Un des plus grands ring-dykes du monde: le Meugueur-Meugueur, massif de l'Aïr, Niger. Comptes Rendus de l'Académie des Sciences Paris 303, 223–226.

Moreau, C., Brown, W.L., Demaiffe, D., Rocci, G., Perez, J.B., 1991. Palaeozoic magmatism in the Aïr massif (Niger). In: Kampunzu, A.B., Lubala, R.T. (Eds.), Magmatism in extensional structural settings, The Phanerozoic African plate. Springer-Verlag, Berlin, pp. 345–358.

Moreau, C., Regnoult, J.M., Déruelle, B., Robineau, B., 1987. A new tectonic model for the Cameroon Line, Central Africa. Tectonophysics 139, 317–334.

Moreau, C., Demaiffe, D., Bellion, Y., Boullier, A.-M., 1994. A tectonic model for the location of Palaeozoic ring complexes in Aïr (Niger, West Africa). Tectonophysics 234, 129–146.

Morgan, W.J., 1983. Hotspot tracks and the early rifting of the Atlantic. Tectonophysics 94, 123–139.

Moundi, A., Ménard, J.-J., Reusser, E., Tchoua, F.M., Dietrich, V.J., 1996. Découverte des basaltes transitionnels dans le secteur continental de la Ligne du Cameroun, massif du Mbam (Ouest-Cameroun). Comptes Rendus de l'Académie des Sciences Paris 322, 831–837.

Nana, R., Dietrich, V.J., Tchoua, F.M., Reusser, E., 2001. Pétrologie des péridotites en enclaves dans les basaltes récents de la région de Nyos (Ligne du Cameroun). Journal of GeoScience Society of Cameroon, Special Publication, Abstract Issue (GSAF12), vol. 1, pp. 83–84.

Nédélec, A., Myniem, D., Barbey, P., 1993. High-P – high-T anatexis of Archaean tonalitic grey gneisses: the Eseka migmatites, Cameroon. Precambrian Research 62, 191–205.

Nédélec, A., Macaudière, J., Nzenti, J.-P., Barbey, P., 1986. Evolution structurale et métamorphique des schistes de Mbalmayo (Cameroun). Implications pour la structure de la zone mobile pan-africaine d'Afrique Centrale, au contact du craton du Congo. Comptes Rendus de l'Académie des Sciences Paris 303, 75–80.

Ngako, V., 1999. Les déformations continentales panafricaines en Afrique centrale: résultat d'un poinçonnement de type himalayen. Doctorat d'Etat thesis, University of Yaoundé I, unpublished.

Ngako, V., Jégouzo, P., Nzenti, J.P., 1991. Le cisaillement centre camerounais. Rôle structural et géodynamique dans l'orogenèse panafricaine. Comptes Rendus de l'Académie des Sciences Paris 313, 457–463.

Ngounouno, I., Déruelle, B., Demaiffe, D., 2000. Petrology of the bimodal Cainozoic volcanism of the Kapsiki plateau (northernmost Cameroon, Central Africa). Journal of Volcanology and Geothermal Research 102, 21–44.

Ngounouno, I., Moreau, C., Déruelle, B., Demaiffe, D., Montigny, R., 2001. Pétrologie du complexe alcalin sous-saturé de Kokoumi (Cameroun). Bulletin de la Société Géologique de France 172, 675–686.

Nguiessi Tchankam, C., Nzenti, J.P., Nkonguin Nsifa, E., Tempier, P., Tchoua, F.M., 1997. Les granitoïdes calco-alcalins syn-cisaillement de Bandja dans la chaîne panafricaine nord-équatoriale au Cameroun. Comptes Rendus de l'Académie des Sciences Paris 325, 95–101.

Njonfang, E., Moreau, C., 2000. The mafic mineralogy of the Pandé massif, Tikar plain, Cameroon: Implications for a peralkaline affinity and emplacement from highly evolved alkaline magma. Mineralogical Magazine 64, 525–537.

Njonfang, E., Kamgang, P., Ghogomu, T.R., Tchoua, F.M., 1992. The geochemical characteristics of some plutonic-volcanic complexes along the southern part of the Cameroon Line. Journal of African Earth Sciences 14, 255–266.

Nkouathio, D.G., Ménard, J.-J., Wandji, P., Bardintzeff, J.M., 2002. The Tombel graben (West Cameroon): a recent monogenetic volcanic field of the Cameroon Line. Journal of African Earth Sciences 35, 285–300.

Nkoumbou, C., Déruelle, B., Velde, D., 1995. Petrology of Mt Etinde nephelinites series. Journal of Petrology 36, 373–395.

Nono, A., Déruelle, B., Demaiffe, D., Kambou, R., 1994. Tchabal Nganha volcano in Adamawa (Cameroon): petrology of a continental alkaline lava series. Journal of Volcanology and Geothermal Research 60, 147–178.

Nzenti, J.P., Barbey, P., Macaudière, J., Soba, D., 1988. Origin and evolution of the Late Precambrian high-grade yaoundé gneisses (Cameroon). Precambrian Research 38, 91–109.

Orajaka, J.P., 1986. Geochemistry of Kaffo Valley albite-riebeckite-granite, Liruei granite ring-complex, Northern Nigeria. Chemical Geology 56, 85–92.

O'Connor, J.M., Le Roex, A.P., 1992. South Atlantic hot spot-plume systems: 1. Distribution of volcanism in time and space. Earth and Planetary Science Letters 113, 343–364.

Olson, P., 1990. Hotspots, swells and mantle plumes. In: Ryan, M.P. (Ed.), Magma transport and storage. Wiley, New York, pp. 33–51.

Parsons, I., Brown, W.L., Jacquemin, H., 1986. Mineral chemistry and crystallization conditions of the Mboutou layered gabbro-syenite-granite complex, North Cameroon. Journal of Petrology 27, 1305–1329.

Pénaye, J., Toteu, S.F., Van Schmus, W.R., Nzenti, J.-P., 1993. U-Pb and Sm-Nd preliminary geochronologic data on the Yaoundé series, Cameroon: signification of the granulitic rocks in the 'Centrafrican' belt. Comptes Rendus de l'Académie des Sciences Paris 317, 782–794.

Poudjom Djomani, Y.H., 1993. Apport de la gravimétrie à l'étude de la lithosphère continentale et implications géodynamiques. Etude d'un bombement intraplaque: le massif de l'Adamaoua (Cameroun). Editions ORSTOM, Paris, France no. 109.

Poudjom Djomani, Y.H., Nnange, J.M., Diament, M., Ebinger, C.J., Fairhead, J.D., 1995. Effective elastic thickness and crustal thickness variations in west central Africa inferred from gravity data. Journal of Geophysical Research 100, 22047–22070.

Poudjom Djomani, Y.H., Diament, M., Wilson, M., 1997. Lithospheric structure across the Adamawa plateau (Cameroon) from gravity studies. Tectonophysics 273, 317–327.

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. Journal of African Earth Sciences 7, 409–431.

Rahaman, M.A., Van Breemen, O., Bowden, P., Bennett, J.N., 1984. Age migration of anorogenic ring-complexes in northern Nigeria. Journal of Geology 92, 173–184.

Rankenburg, K., Lassister, J.C., Brey, G., 2004. Origin of megacrysts in volcanic rocks of the Cameroon volcanic chain – constraints on magma genesis and crustal contamination. Contributions to Mineralogy and Petrology 147, 129–144.

Rankenburg, K., Lassister, J.C., Brey, G., 2005. The role of continental crust and lithospheric mantle in the genesis of Cameroon Volcanic Line lavas: constraints from isotopic variations in lavas and megacrysts from the Biu and Jos Plateau. Journal of Petrology 46, 169–190.

Richards, M.A., Lithgow-Bertelloni, C., 1996. Plate motion changes, the Hawaiian-Emperor bend, and the apparent success and failure of geodynamic models. Earth and Planetary Science Letters 137, 19–27.

Scheirer, D.S., Macdonald, K.C., Forsyth, D.W., Shen, Y., 1996. Abundant seamounts of the Rano Rahi seamount field near the East Pacific Rise, 15°S to 19°S. Marine Geophysical Research 18, 13–52.

Shen, Y., Scheirer, D.S., Forsyth, D.W., Macdonald, K.C., 1995. Trade-off in production between adjacent seamount chains near the East Pacific Rise. Nature 373, 140–143.

Sleep, N.H., 1990. Hotspots and mantle plumes: some phenomenology. Journal of Geophysical Research 95, 6715–6736.

Smith, A.D., 1993. The continental mantle as a source for hotspot volcanism. Terra Nova 5, 452–460.

Smith, A.D., Lewis, C., 1999. The planet beyond the plume hypothesis. Earth Science Review 48, 135–182.

Stock, J.M., Molnar, P., 1987. Revised history of early Tertiary plate motion in the southwest Pacific. Nature 325, 495–499.

Tagne Kamga, G., 2003. Petrogenesis of the Neoproterozoic Ngondo plutonic complex (Cameroon, west central Africa): a case of late-collisional ferro-potassic magmatism. Journal of African Earth Sciences 36, 149–171.

Tagne Kamga, G., Mercier, E., Rossy, M., Nsifa, E.N., 1999. Synkinematic emplacement of the Pan-African Ngondo igneous complex (West Cameroon, central Africa). Journal of African Earth Sciences 28, 675–691.

Temdjim, R., Boivin, P., Chazot, G., Robin, C., Rouleau, E., 2004. L'hétérogénéité du manteau supérieur à l'aplomb du volcan du Nyos (Cameroun) révélée par les enclaves ultrabasiques. Comptes Rendus Géoscience 336, 1239–1244.

Toteu, S.F., Bertrand, J.M., Pénaye, J., Macaudière, J., Angoua, S., Barbey, P., 1991. Cameroon: a tectonic keystone in the Pan-African network. In: Lewry, J.F., Stauffer, M.R. (Eds.), The Early Proterozoic Trans-Hudson Orogen of North America. In: Special paper 37. Geological Asoociation of Canada, pp. 483–496.

Toteu, S.F., Van Schmus, W.R., Penaye, J., Michard, A., 2001. New U-Pb and Sm-Nd data from north-central Cameroon and its bearing on the pre-Pan African history of central Africa. Precambrian Research 108, 45–73.

Van Houten, F.B., 1983. Sirte Basin, North-Central Libya: Cretaceous rifting above a fixed mantle hot spot? Geology 11, 115–118.

Wessel, P., Kroenke, L., 1997. A geometric technique for relocating hotspots and refining absolute plate motions. Nature 387, 365–369.

Wilson, M., 1992. Magmatism and continental rifting during the opening of the South Atlantic Ocean: a consequence of Lower Cretaceous super-plume activity? In: Storey, B.C., Alabaster, T., Pankhurst, R.J. (Eds.), Magmatism and the causes of continental Break-up. Geological Society Special Publication, vol. 68, pp. 241–255.

Wilson, M., 1997. Thermal evolution of the Central Atlantic passive margins: continental break-up above a Mesozoic super plume. Journal of Geological Society of London 154, 491–495.

Wilson, M., Guiraud, R., 1992. Magmatism and rifting in West and Central Africa, from Late Jurassic to Recent times. Tectonophysics 213, 203–225.

Wright, J.B., 1975. Anorthosite first occurrence in Nigeria and relevance to Younger Granite genesis. Mineralogical Magazine 40, 193–196.