Where are the Eburnian–Transamazonian collisional belts?[1]

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The reconstruction of Early Proterozoic crustal evolution and geodynamic environments, in Africa and South America, is incomplete if cratonic areas alone are studied. If the presence of high-grade gneisses is considered as a first clue to past collisional behaviour, 2 Ga high-grade gneisses are more abundant within the Pan-African–Brasiliano mobile belts than in the intervening pre-Late Proterozoic cratons. The West African craton and the Guiana–Amazonia craton consist of relatively small Archaean nuclei and widespread low- to medium-grade volcanic and volcanoclastic formations intruded by Early Proterozoic granites. By contrast, 2 Ga granulitic assemblages and (or) nappes and syntectonic granites are known in several areas within the Pan-African–Brasiliano belts of Hoggar–Iforas–Air, Nigeria, Cameroon, and northeast Brazil. Nappe tectonics have been also described in the Congo–Chaillu craton, and Early Proterozoic reworking of older granulites may have occurred in the São Francisco craton. The location of the Pan-African–Brasiliano orogenic belts is probably controlled by preexisting major structures inherited from the Early Proterozoic. High-grade, lower crustal assemblages 2 Ga old have been uplifted or overthrust and now form polycyclic domains in these younger orogenic belts, though rarely in the cratons themselves. The Congo–Chaillu and perhaps the São Francisco craton are exceptional in showing controversial evidence of collisional Eburnian–Transamazonian assemblages undisturbed during Late Proterozoic time.

La reconstitution de l'évolution crustale et des environnements géodynamiques au Protérozoïque précoce dans l'Afrique et l'Amérique du sud est incomplète lorsque seuls les cratons sont pris en compte. Si on considère la présence de gneiss de haut degré de métamorphisme comme un premier indice d'une collision passée, on connaît plus de roches de ce type âgées de 2 Ga dans les zones mobiles d'âge pan african–brésilien que dans les cratons. Par exemple, le craton ouest-africain et le craton guyanais–amazonien sont constitués par des noyaux archéens relativement petits et par d'immenses étendues constituées de formations volcaniques et volcano-clastiques peu à moyennement métamorphiques recoupées par des granites d'âge protérozoïque précoce. Au contraire, dans les chaînes d'âge pan africain–brésilien du Hoggar, des Iforas, de l'Air, du Nigeria, du Cameroun et du nord-est Brésil, on connaît de nombreux cas de granulites datées aux environs de 2 Ga. La trace de tectonique tangentielle de cet âge est attestée par la présence de granites syntectoniques. Des charriages de cet âge ont aussi été décrits dans le craton du Congo–Chaillu, et il est possible que certaines granulites plus anciennes du craton de São Francisco aient été réactivées au cours du Protérozoïque précoce. La localisation des ceintures orogéniques d'âge pan africain–brésilien est probablement contrôlée par des cicatrices pre-éxistantes, datant du Protérozoïque précoce. Les assemblages métamorphiques de haut degré, représentant la croûte inférieure datant de 2 Ga, ont été surélevés ou charriés; ils forment maintenant les domaines polycycliques des ceintures orogéniques plus récentes mais on n'en trouve que rarement des équivalents dans les cratons eux-mêmes. Les cratons du Congo–Chaillu et de São Francisco sont différents car ils montrent des traces (controversées pour le second) d'une collision d'âge eburnéen–transamazonien non perturbée ultérieurement.

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Introduction

In Africa and South America, three cratons are separated by a complex network of Pan-African–Brasiliano orogenic belts (ca. 600 Ma): the Guiana–Amazonia craton (GAC); the West African craton (WAC), with its possible South American São Luis extension; and the São Francisco and Congo–Chaillu cratons (SFC and CCC). Proterozoic links and common structures on both sides of the Atlantic Ocean have often been discussed (Hurley *et al.* 1975; Onstott and Hargraves 1981; Torquato and Cordani 1981; Lesquer *et al.* 1984; Onstott *et al.* 1984; Bozhko 1986; Cohen and Gibbs 1989; Porada 1989; Caby 1989). Although different possibilities have been proposed, depending on the Atlantic fit used, good agreement exists for correlation between the Late Proterozoic Pan-African and Brasiliano belts; correlations between internal structures of the cratons, however, are more ambiguous, whatever the fit. Our starting point was the map produced by the International Atomic Energy Agency (1986), using Bullard's fit (Bullard *et al.* 1965), where some structural interpretations are disputable. Although the type of fit used is critical when dealing with Late Proterozoic belts, we think that for earlier structures it does not matter much, especially if processes and (or) chronologies are the main considerations. When widespread kinematic data are available in pre-Late Proterozoic terranes, the quality of the fit will become critical.

The Late Proterozoic cratons either consist mostly of juvenile Early Proterozoic crust with restricted Archaean nuclei or, if dominantly Archaean, have been partly reworked during the Early Proterozoic Eburnian or Trans-Amazonian event. Each craton shows a particular pattern. Correlations, especially structural ones, are very difficult to assess. The orientation of the structural grain is obviously different from craton to craton, implying large crustal displacements and (or) rotations before or during the Late Proterozoic (Fig. 1) (Onstott and Hargraves 1981; Cohen and Gibbs 1989). An interesting feature that has not received adequate attention is that Archaean and Early Proterozoic terranes also form large tracts within the intervening younger belts that form the Pan-African–Brasiliano orogenic network. These regions have never been seriously considered,

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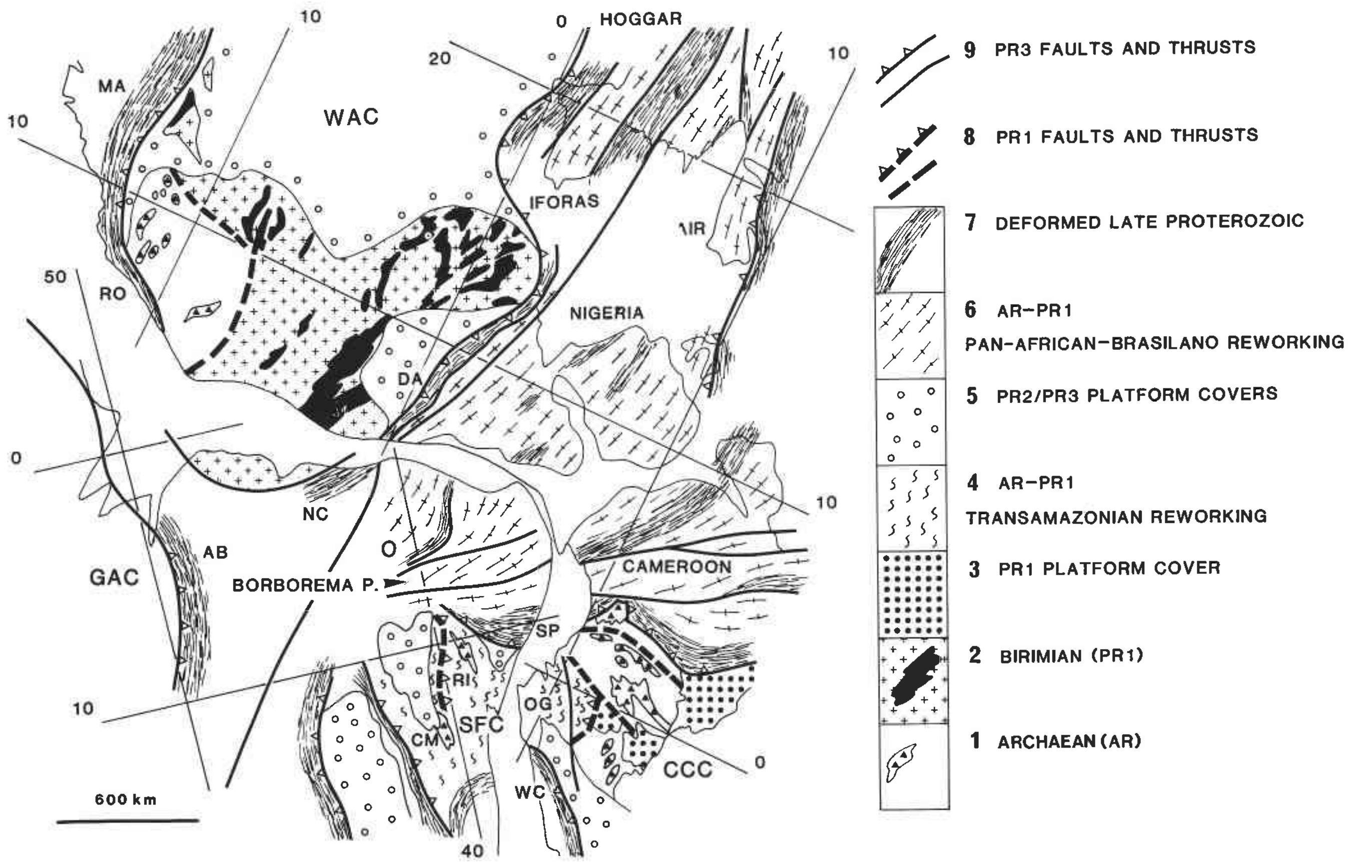

FIG. 1. Classical Bullard fit of Africa and South America, showing assumed links for the Late Proterozoic between opposite sides of the Atlantic Ocean. 1, Archaean granite–gneisses and greenstone belts; 2, Early Proterozoic formations in WAC (Birmian) (volcanic formations are in black); 3, Early Proterozoic undeformed cover in CCC (Francevilian); 4, Transamazonian (Eburnian) reworking of Archaean to Early Proterozoic formations; 5, Middle to Late Proterozoic platform covers; 6, Pan-African–Brasiliano reworking of Archaean to Early Proterozoic formations; 7, deformed Late Proterozoic formations. WAC, West African craton; MA, Mauritanides belt; RO, Rockel belt; DA, Dahomeyan belt; GAC, Guiana–Amazonia craton; Borborema P., Borborema Province; SP, Sergipe belt; AB, Araguaia belt; NC, northwest Ceara belt; O, Oros belt; SFC, São Francisco craton; RI, Rio Itapicuru greenstobe belt; CM, Contendas Mirante formation; CCC, Congo–Chaillu craton; OG, Ogooue schist belt.

together with the cratons, when assessing the Early Proterozoic geodynamic evolution of this part of Gondwana.

The Guiana–Amazonia craton is not discussed here (see reviews and recent geochronological data in Gibbs and Barron 1983, Hasui and Almeida 1985, Teixeira *et al.* 1989, Machado *et al.*, in press). After a brief review of some recent data and interpretations concerning the other cratons, we show that very large domains forming the Pan-African and Brasiliano belts comprise older, pre-Late Proterozoic terranes and that there is evidence for Early Proterozoic collisional behaviour in these regions. We outline evidence for ca. 2 Ga collisional features using criteria such as high-grade deformed rocks, crust-derived granitoids, and tangential tectonics, with an emphasis on the two regions that are best known to the authors: northeast Brazil and the Hoggar Shield. This interpretation is at variance with that given in some recent papers that deny any post-Archaean, pre-Late Proterozoic event in the Pan-African–Brasiliano mobile belt (Caby and Arthaud 1986; Ajibade *et al.* 1987; Caby 1989).

A comment concerning the validity of our age correlations is appropriate here. The poor accuracy of most available ages only allows us to define broad age ranges and to only partly establish the chronology of both the Eburnian and the Transamazonian orogenies. Even U–Pb ages, which are still very rare, have been obtained in most cases from large fractions of zircon and, in instances of multi-episodic lead loss and (or) polycyclic evolution, are often difficult to interpret unambiguously. However, existing data document the occurrence of ca. 2 Ga terranes within the Pan-African and Brasiliano belts. These terranes correspond mostly to high-grade metasedimentary formations, probably derived from the erosion of nearby Archaean crust, and contrast sharply with the large regions of the craton that are underlain by Early Proterozoic juvenile continental crust.

Eburnian and Transamazonian events in the cratons

West African craton (WAC)

The ca. 2 Ga old Eburnian event was first defined by Bonhomme (1962) in the West African craton on the basis of Rb–Sr model ages. Two major Archaean nuclei form the western part of the craton: the Kenema–Man domain (or Liberian domain) in Liberia, Sierra Leone, and western Ivory Coast and the Amsaga domain in Mauretania (Fig. 2; reviews in Bessoles 1977; Williams 1978; Black 1980; Rollinson and Cliff 1982; Cahen *et al.* 1984; Camil and Tempier 1985). However, there is not obvious structural continuity, between a northern shield (Reguibat) and southern one (Man), which are separated by a wide Late Proterozic basin, and there is little evidence for collisional features except along the margin of the Kenema–Man Archaean nucleus (Feybesse *et al.* 1989, 1990) and in the Fetreko region (Lemoine 1985).

A linear paired gravity anomaly that underlies the northern-

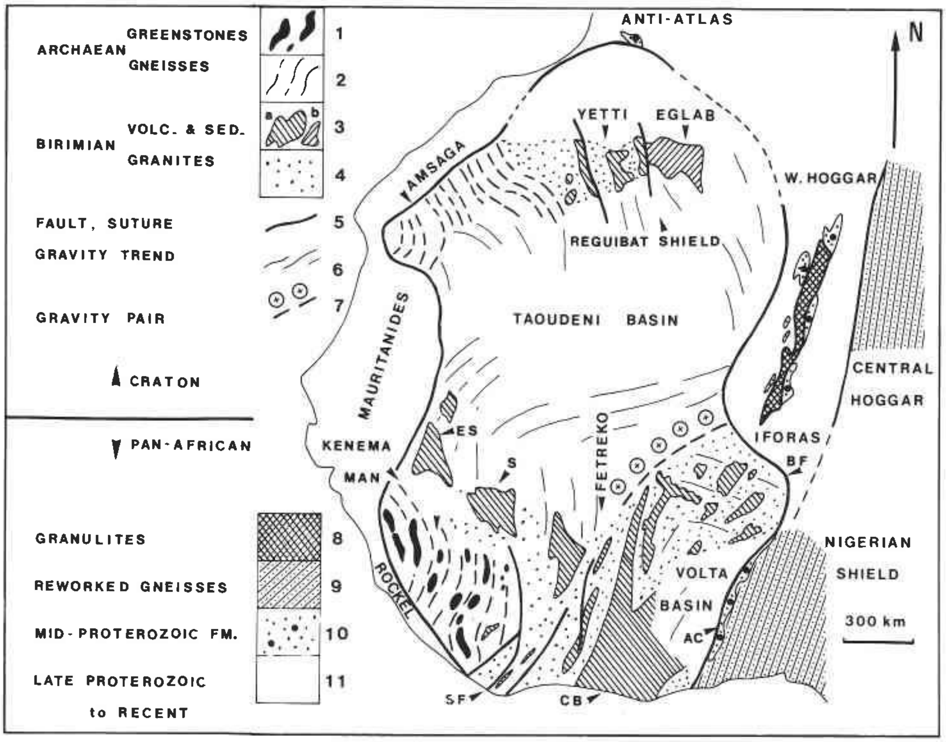

FIG. 2. Sketch map of the West African craton and its surroundings. 1, Kenema and Man Archaean greenstone belts; 2, archaean granite–gneisses; 2, Early Proterozoic low-grade sediments and volcanics (Birimian) (a) and rhyolite–granite terrane (b); 4, Early Proterozoic granite–gneisses; 5, major faults, lineaments, and possible sutures around the craton; 6, gravity trends (from Lesquer *et al.* 1984); 7, paired gravity anomaly (Lesquer *et al.* 1984); 8, In Ouzzal and Iforas Eburnian granulites; 9, central Hoggar and Nigeria high-grade gneisses (partly Early Proterozoic in age); 10, Middle Proterozoic "Quartzite formation" (Atacora quartzites also may be Late Proterozoic); 11, Late Proterozoic to Recent formations; ES, eastern Senegal; S, Siguri basin; SF, Sassandra fault; CB, Comoe basin; AC, Altacora quartzites; BF, Burkina Faso greenstone belts.

most part of the Fetreko belt could suggest a collisional origin (Lesquer *et al.* 1984; A. Lesquer, personal communication, 1988). This belt is outlined by a leucogranitic complex (Lemoine 1985) and is parallel to the collisional contact with the Liberian nucleus, described recently (Feybesse *et al.* 1989, 1990). In the rest of the craton, there is no clear evidence for continental collision in the form of large-scale nappe tectonics or linear high-grade domains.

Most of the Early Proterozoic rocks belong to low-grade metasedimentary and metavolcanic formations (Birimian series) and form linear to sinuous belts separated by granite and granite–gneiss batholiths. Such a pattern strongly resembles that of Archaean-type greenstone belts. Recent isotopic data preclude any component older than 2.2 Ga, suggesting that most of the WAC is formed of juvenile Early Proterozoic crust (Abouchami *et al.* 1989; Boher *et al.* 1989; Leube *et al.* 1990).

Congo–Chaillu craton (CCC)

In Gabon (Bassot 1988; Caen-Vachette *et al.* 1988), high-grade greenstone belts, which include extensive banded ironstone formations, are associated with granulite-facies granite–gneisses (2.7–3.2 Ga). The regional trend is east–west in the northern part of the craton and north–south in the Chaillu region to the south. A collisional Eburnian orogenic belt is now well documented in the Ogooue regions in the central part of the craton (Prian *et al.* 1988; Ledru *et al.* 1989). A thrust-and-fold belt with an eastward vergence overlies the well-dated Early Proterozoic "Francevillian" foreland basin. Metamorphic internal nappes, the so-called Ogooue schists, include reactivated basement and, locally, prograde granulite-facies rocks.

São Francisco craton (SFC)

The widespread occurrence of Archean rocks has been proved radiometrically in several parts of the infrastructure of the São Francisco craton (see review by Mascarenhas and Sá 1982, for instance). However, the tectonic significance of younger "Transamazonian" ages (2.2–1.9 Ga) is still poorly understood. Critical points may be summarized as follows:

(1) The existence of a north–south-trending Transamazonian belt (ca. 2.0 Ga) has been proposed in the central part of the craton, in the Jacobina region (Cordani and Brito Neves 1982; McReath and Sabaté 1987). A collisional origin was recently suggested for this belt, based on the occurrence of leucogranites (Gaal *et al.* 1987; Rudowski *et al.* 1987; Cuney and Sabaté 1989; Cuney *et al.* 1990; Vidal *et al.* 1989). On the other hand, from petrological and geochemical evidence, the easternmost part of the craton (Itabuna complex) has recently been interpreted as a metamorphosed Early Proterozoic magmatic arc (Barbosa and Fonteilles 1989; Figueiredo 1989), which may be matched to the Ogooue belt in Gabon.

(2) Field evidence in the northern part of the craton, as well as available radiometric data, contradicts the regional framework described above. Here, the north–south-trending structures of the craton are older than overlying 2.0–1.9 Ga Transamazonian nappes and parautochtonous metasediments that belong to the northern Borborema Province (see below). The north–south tectonic grain of the craton was acquired after a period of major ductile strike-slip–transpressional deformation, mostly under amphibolite-facies conditions. The westward-verging thrust affecting the Early Proterozoic Jacobina quartzites is probably an associated feature. The strike-slip event was accompanied by

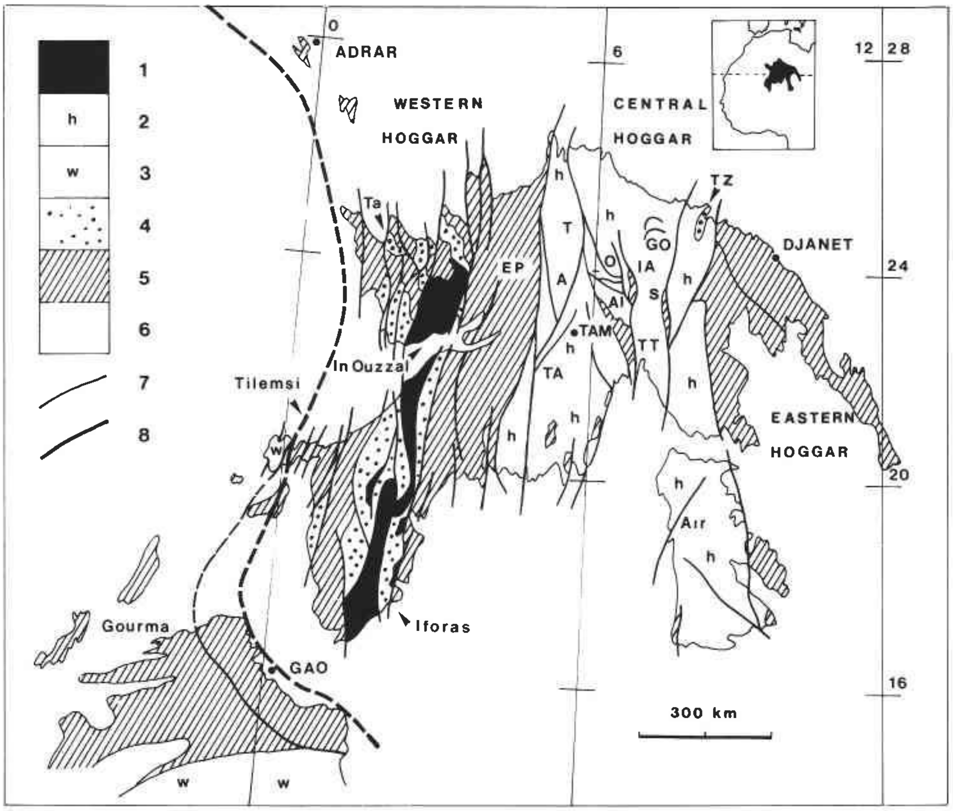

FIG. 3. Sketch map of the Hoggar shield (Hoggar, Iforas, and Air). 1, Archean and 2 Ga In Ouzzal and Iforas granulites; 2, dominantly 2 Ga central Hoggar high-grade gneisses; 3, West African craton basement; 4, western Hoggar high-grade gneisses and Middle Proterozoic "Quartzite formation"; 5, Late Proterozoic Pharusian series: low-grade volcanics and sediments; 6, Paleozoic to Recent formations; 7, major faults and thrusts; 8, Pan-African suture zone; Ta, Tassendjanet; EP, eastern Pharusian belt; T, Tefedest; A, Arechchoum and Amsinassene gneisses and metasediments; TAM, Tamanrasset; TA, Tin Amzi area; Al, Aleksod; O, Ouadenki; GO, gour Oumelalen; IA, In Assakane; S, Serouenout; TT, Tin Tarabine; TZ, Tazat.

the emplacement of north–south-elongated syn- to late-tectonic granites and syenites, including the leucogranites referred to in point 1 (Jardim de Sá *et al.* 1982), which are generally regarded as Transamazonian, mostly on the basis of 2.2–1.8 Ga Rb–Sr and K–Ar mineral ages. Recent Rb–Sr isochron ages confirm this attribution: a syntectonic granite at 2.15 Ga (Itaberaba; I. McReath, personal communication, 1989) and a posttectonic granite at 1.97 Ga (Campo Formoso; Sabate *et al.* 1990). Closer to the São Francisco River, granitoids intruding low-grade greenstone and metasediments have been dated at 2.7–2.6 Ga (Sobradinho and Rio Salitre areas, see Fig. 5 for location; M. H. F. Macedo, personal communication, 1990); these rocks overlie, in turn, 2.9–3.1 Ga old high-grade gneisses and migmatites dated by an Rb–Sr isochron. To the east the Rio Capim greenstones are intruded by a 3.1 Ga old tonalite (Rb–Sr isochron; Mascarenhas and Sá 1982; Jardim de Sá *et al.* 1984). A 2.1 Ga U–Pb zircon age has been obtained on a posttectonic granite bordering the Rio Itapecuru greenstone belt (Gaal *et al.* 1987, personal communication, 1987; McReath and Sabate 1987). From these data we conclude that the north–south strike-slip event in the craton cannot be younger than 2.2–2.1 Ga. Protolith ages and recumbent structures are probably at least 2.5–2.3 Ga old (M. G. Silva, personal communication, 1989; Gaal *et al.* 1987), both in greenstones (Itapecuru) and in granulite-facies gneisses.

These points show that age tectonic relations in the SFC are far from being resolved. The strike-slip event predates the Transamazonian tangential structures identified farther north in the Borborema Province (see below) and reworks high-grade rocks and corresponding older structures that are in part Archean and in part Early Proterozoic in age.

Eburnian–Transamazonian assemblages within the mobile belts

Hoggar–Iforas–Air (Fig. 3)

Tassendjanet nappe (Caby 1970)

High-grade metasediments including quartzites and marbles are crosscut by 2 Ga granites and are unconformably overlain by the very low grade Late Proterozoic Stromatolite series (Caby 1970). These granites have yielded 2.15 Ga Rb–Sr isochrons and U–Pb ages on zircons; biotite model ages are close to 1.7 Ga (Picciotto *et al.* 1965; Allegre and Caby 1972). Pre-unconformity high-grade metamorphic assemblages are very good evidence of an Eburnian (or, at least, pre-Late Proterozoic) tectonometamorphic event. Similar gneissic units are known within and north of the Iforas batholith in Mali.

Iforas and In Ouzzal granulitic units (Boullier 1982; Kienast and Ouzegane 1988)

These units comprise granitic gneisses, charnockitic intrusives, ultramafic and mafic bodies, and metasediments (aluminous and Al–Mg-rich gneisses, magnetite-bearing quartzites, and marbles). The Archaean age of most of the material has been demonstrated by Rb–Sr and Sm–Nd systematics (Ferrara and Gravelle 1966; Allegre and Caby 1972; Ben Othman *et al.* 1984) and U–Pb dates on zircons (Lancelot *et al.* 1976). U–Pb zircon systematics indicates that 2.1 Ga old granulite-facies metamorphism overprinted Archean rocks of unknown metamorphic grade (Lancelot *et al.* 1976). Data are from newly crystallized and inherited zircons, often single grains, from charnockites and metaquartzites. Eburnian tectonics in the In Ouzzal unit are represented by a N60°E-trending structural grain that is clearly oblique to Pan-African structures. Granulites were already at the surface when Middle to Late Proterozoic formations were deposited. During the Pan-African orogeny, the Iforas granulitic unit was thrust upon a high-grade tectonic "melange," and the Iforas and In Ouzzal units were partly reworked, with a southward increase in both deformation and metamorphic grade. In the Iforas region, the Pan-African metamorphic grade locally reaches granulite-facies conditions (Boullier and Barbey 1988).

Central Hoggar

Narrow linear belts of low-grade metavolcanics and associated clastic sediments, the "Pharusian" series are generally considered to be Late Proterozoic in age, although there is no good chronological control. They are possibly equivalent to the so-called Pharusian II in western Hoggar (Dupont *et al.* 1987). These low-grade formations are separated from ubiquitous banded grey gneisses and high-grade metasediments by major tectonic contacts (M. Briedj, J. Leterrier, and J. M. Bertrand, unpublished observations). The banded gneisses, of tonalitic to granodioritic composition, have yielded 2.4 Ga ages and are commonly associated with ca. 2 Ga K-rich orthogneisses and with metasediments (Rb–Sr isochrons; Bertrand and Lasserre 1976). The latter age more likely represents an emplacement age, as both Pan-African metamorphism and deformation, recorded in mineral ages and a U–Pb zircon lower intercept (Barbey *et al.* 1989), are very strong in central Hoggar. A 3.5 Ga old Pb–Pb age has been obtained in the northeastern part of central Hoggar (Latouche 1978).

A widespread metasedimentary formation underlies a large part of central Hoggar and comprises thick units of marbles and quartzites (locally magnetite-bearing quartzites) associated with Al-rich metapelites and intermediate to mafic metagreywackes. Metamorphic grade varies from upper amphibolite to granulite facies. The foliation dips gently over large areas and, in places, is affected by recumbent folds; foliation is steeper near the Pharusian belts and late Pan-African shear zones.

Evidence for an Early Proterozoic age of this metasedimentary formation and for an Eburnian metamorphic assemblage is seen in several areas. The assemblages are preserved in "mega-boudins" within the Pan-African nappes, dated by the emplacement of syn- to late-tectonic granitoids between 630 and 580 Ma (Bertrand *et al.* 1986; Lapique *et al.* 1987). Critical ages and structural observations are as follows:

(1) In the Tin Amzi area, a 2.1 Ga U–Pb zircon age has been obtained from a slightly deformed S-type granite and corresponding restite, intruded into metasedimentary granulites (Bertrand *et al.* 1986).

(2) In the Aleksod area, an early tectonic banding (crosscutting tholeiitic dykes older than 1.4 Ga; Bertrand and Lasserre 1976) is locally preserved in the older banded gneisses. In most cases, this early banding has been almost completely transposed by a regional, gently dipping, post-dyke foliation. Metasediments and associated migmatites previously attributed to the Middle Proterozoic (Bertrand and Lasserre 1976) have recently yielded a 2.15 Ga U–Pb zircon age (Barbey *et al.* 1989). The complete recrystallization of the accessory minerals in the melanosome of the migmatite and the development of complex metamorphic overgrowths on magmatic cores of zircons suggest that the ca. 600 Ma U–Pb discordia lower intercept dates the nappe-forming event that caused near-melting conditions. Therefore, the 2.15 Ga upper intercept age is believed to represent the age of a granodioritic protolith (Barbey *et al.* 1989).

(3) In the Amsinassene and Tefedest areas, similar metasediments have been described (Vitel 1979). A Rb–Sr isochron on banded gneisses with some granulite-facies remnants indicates an Eburnian age (Vialette and Vitel 1981).

(4) In the Gour Oumelalen area, Eburnian granulites have been described by Latouche (1978). Charnockitic bodies were emplaced 2 Ga ago (Rb–Sr isochron) in a metasedimentary pile comprising a thick, banded ironstone formation associated with marbles (Latouche and Vidal 1974).

Late Eburnian extensional basins in Hoggar and neighbouring areas

A widespread clastic formation occurring on both sides of the In Ouzzal and Iforas units (Davison 1980) consists mostly of thick orthoquartzites and impure Al-rich quartzites interlayered and intruded by numerous sills of alkaline to peralkaline rhyolites and granites (Dostal *et al.* 1979). The alkaline intrusives have been dated at ca. 1.8 Ga (U–Pb on zircons) in western Hoggar and Iforas (Caby and Andreopoulos-Renaud 1983). Similar undated thick quartzitic formations in Morocco, central Hoggar (Tazat area), Benin, and Togo possibly have the same age. In northeast Brazil, the Oros belt, the lowest part of which is similar in lithology to the alkaline intrusives, also has yielded ages in the 1.8–1.7 Ga range (Sá *et al.* 1988). Geochemical signatures of the igneous rocks from Oros change from orogenic calc-alkaline to postorogenic alkaline, with younging in the sequence (Sá and Leterrier, personal communication, 1990). Such formations are continuous for several thousand kilometres (Fig. 2) and show only Pan-African–Brasiliano deformation and metamorphism. Taken together, all these features are best explained within a framework of late Eburnian–Transamazonian extensional basins that were probably developed at the rear of a large orogenic belt and were later disrupted and tectonized during the Pan-African–Brasiliano orogeny.

Summary of the Eburnian features identified in the Hoggar–Iforas–Air shield

In central Hoggar, pre-Pan-African granulite-facies assemblages have been described in many places. The overall lithostratigraphy comprises the following: banded granodioritic to tonalitic gneisses, presumably Archaean but not precisely dated; K-rich orthogneisses, dated ca. 2 Ga and showing an unusual peraluminous and calc-alkaline geochemical signature; and large units of metasediments, including banded ironstones. All ages determined on orthogneisses associated with both metasediments and banded gneisses are close to 2 Ga. Metasediments have been scraped off the banded-gneiss domains and domes and now form large-scale Pan-African nappe structures.

In western Hoggar, metasediments occurring in the In Ouzzal – Iforas are more restricted in volume, and most Eburnian intrusives are charnockitic (Boullier 1982; Lancelot *et al.* 1983).

Mafic and ultramafic units, which are probably Early Proterozoic in age, have been reported from several places in both western and central Hoggar (Iforas granulitic unit and Kidal assemblage: J. Leterrier, C. Alibert, and A. M. Boullier, personal communication, 1988; Ouadenki formation: Bertrand and Lasserre 1976).

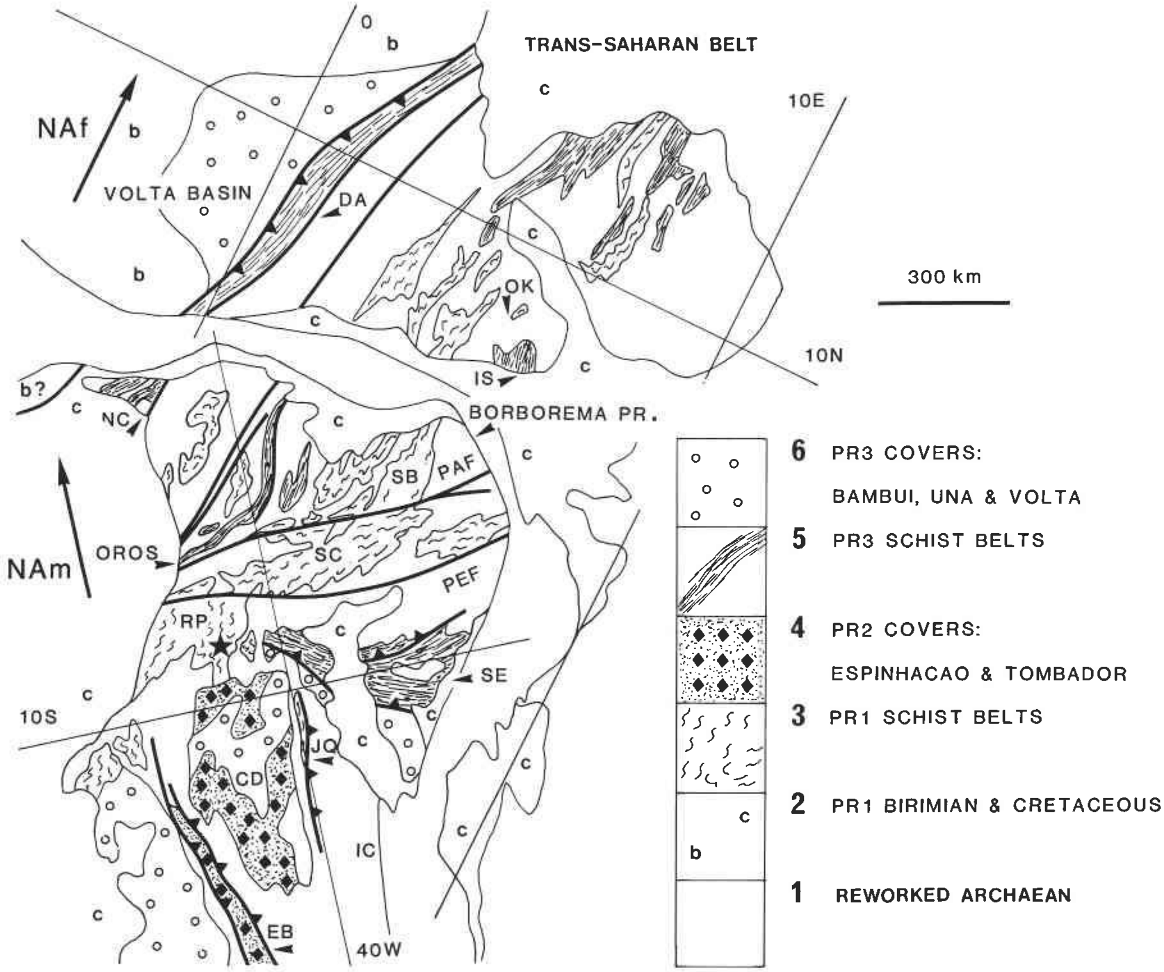

FIG. 4. Early and Middle to Late Proterozoic schist belts in Nigeria and northeast Brazil. 1, Granite–gneisses, mostly variably reworked Archaean; 2, West African craton, Birimian domain (b) and Cretaceous basins (c); 3, assumed Early Proterozoic schists and metasediments; 4, undeformed Middle Proterozoic cover, Esphinhacao and Tombador formations; 5, Middle to Late Proterozoic schist belts; 6, undeformed Late Proterozoic cover, Bambui, Una, and Volta formations; DA, Dahomeyan belt with Atacora quartzites; OK, Okene schist belts; IS, Iguarra sequence; NC, northwest Ceara; SB, Serido belt; SC, Salgueiro–Cachoerinha belt; RP, Riacho do Pontal belt; PAF, Patos fault; PEF, Pernambuco fault; SE, Sergipe belt; CD, Chapada Diamantina basin; JQ, Jacobina quartzites; EB, Espinhaçao belt; IC, Itabuna complex. American north (NAm) and African north (NAf) are indicated.

The Eburnian tectonics of the Hoggar shield cannot be deciphered because of the high-grade reworking that occurred during the Pan-African orogeny. However, aside from some areas where an Eburnian foliation is actually preserved (e.g., Tassendjanet and In Ouzzal; more disputable within tectonic "fishes" in central Hogga), our contention is that such high-grade metamorphic conditions developed on thick metasedimentary formations of platform or passive continental margin type and may be realized only in a collisional tectonic environment.

Nigeria shield

Three main rock assemblages are commonly recognized in the Precambrian of Nigeria: basement gneisses, schist belts, and "older" granites. The emplacement of the granites (dated between 680 and 520 Ma) was accompanied by a major strike-slip ductile event, with the formation of fold and shear zones, and is the best and only proven effect of the Pan-African orogeny. Basement grey gneisses, which locally intrude older metasediments, have yielded U–Pb ages between 3.0 and 2.5 Ga (Rahaman 1988; Dada 1989).

A major debate concerns the significance of the so-called "schist belts" (Fig. 4), regarded as either entirely Late Proterozoic – Pan-African in age or possibly older (see discussions in Ajibade *et al.* 1987 and Rahaman 1988). Like the gneissic basement, some of the schist belts show flat-lying structures that predate the emplacement of Pan-African "older granite." There are no reliable combined field and age constraints relating to these structures. However, the following points must be taken into consideration:

(1) Syntectonic sheets of pink orthogneisses (Okene area), emplaced in the axial plane of recumbent folds, crosscut the grey gneisses and high-grade metasediments, including banded iron formations, and are affected by a flat-lying foliation (Annor and Freeth 1985). Rb–Sr model ages and errorchrons suggest an Eburnian age for these intrusions (Caen-Vachette and Umeji 1987).

(2) In southwestern Nigeria, several augen-gneiss bodies postdate the grey gneisses and are also affected by tangential deformation. Burke *et al.* (1976) described field relations consistent with syntectonic ca 1.9–1.85 Ga emplacement (U–Pb zircon ages and Rb–Sr isochrons; Rahaman *et al.* 1983; Rahaman 1988). There is little support for the proposed correla-

tion of these bodies with the Middle Proterozoic alkaline rhyolite–granite association of the Hoggar–Iforas region (Ajibade *et al.* 1987; Caby 1989). In some areas at least, the augen gneisses appear to intrude schist-belt lithologies.

(3) Field relationships and comparative structural evolution suggest a distinction between "older" and "younger" schist belts as previously described in northwestern Nigeria (Grant 1978; Fitches *et al.* 1985). A Pan-African age has been recently proposed for most of the schist belts (Ajibade *et al.* 1987). These two proposals are not completely opposed; for example, the Iguarra sequence (Odeyemi 1988) in southwestern Nigeria shows a relatively simple structural evolution and seems to postdate the tangential deformation described above. This sequence, like others in northwestern Nigeria, obviously shows a monocyclic Pan-African evolution (Holt *et al.* 1978).

In conclusion, there is, in Nigeria, a strong possibility that a major Eburnian event involved not only reworking of Archean grey gneisses of tonalite–trondjemite–granodiorite type but also supracrustal deposition, intrusion of augen-gneiss protoliths, important tangential tectonics, and high-grade metamorphism, as in central Hoggar and northeast Brazil. The possibility that the Pan-African belt as a whole may correspond to a Late Proterozoic oblique "collage" of exotic terranes (Ajibade and Wright 1989; Caby 1989) implies that structural correlations between separated schist belts must be carefully handled.

Northeast Brazil, Borborema Province

The concept of several Late Proterozoic Brasiliano fold belts with intervening older nuclei (Almeida *et al.* 1981; Cordani and Brito Neves 1982) is here retained only for the northwestern Ceará region, considered to be the continuation of the Trans-Saharan belt, and for the Sergipe belt, which is an extension of the Cameroon belt, along the northeastern edge of the São Francisco craton. Another Brasiliano belt formed only of post-Eburnian formations, the Oros belt, has been described in southeastern Ceará (Jardim de Sá 1984; Jardim de Sá *et al.* 1984, 1988; Sá *et al.* 1988) (Fig. 4).

Widespread granitoid plutonism and synchronous strike-slip shear zones are again the best-known results of the Brasiliano orogeny across the whole Borborema Province (Brito Neves *et al.* 1982; Jardim de Sá 1984; Jardim de Sá *et al.* 1987). By contrast, there is growing evidence for pre-Brasiliano supracrustal deposition, granite intrusion, and tangential deformation along a belt running from the northern coast of Brazil (in the Seridó region), facing Nigeria, to the northern edge of the São Francisco craton (Jardim de Sá 1988; Jardim de Sá *et al.* 1988). We believe that these older features can be ascribed to the Transamazonian orogeny.

This belt includes, from north to south, several units separated by the large Patos and Pernambuco shear zones: the Seridó Group, the Salgueiro–Cachoeirinha Group, and the Casa Nova complex at Riacho do Pontal. Actually, there is very little lithological difference between these groups, and they share a noteworthy structural continuity. They thus have been traditionally regarded as coeval units, and we share this view. Differences in the overall metamorphic grade and structural trends along this belt are hardly surprising, taking into account a combined horizontal slip along the two major shear zones of 500 km, as implied by the map pattern. Within the belt, supracrustals include basal shelf-type formations and thick turbidite–flysch deposits, the latter now forming extensive micaschist units. No regional, major unconformity has been found within the rock pile, as recently proposed by Caby (1989); rather there are numerous normal contacts and lateral facies changes and minor erosional breaks, as are usually found in orogenic basins. In Seridó the lower part of the pile and its gneissic basement (2.7–2.3 Ga old) are intruded by augen gneisses and other granitoids, with ages of ca. 2.0–1.9 Ga (Rb–Sr isochrons and zircon U–Pb; Jardim de Sá *et al.* 1988). Sheet like intrusions in the axial planes of recumbent folds attest to syntectonic emplacement during tangential deformation under greenschist- to amphibolite-facies, low- to intermediate-pressure conditions. Southward transport directions are indicated by kinematic indicators. The basement gneisses have also been extensively reworked and isotopically reset, especially for Rb–Sr (Macedo *et al.* 1984). Field observations are in opposition to Caby's (1989) concept of anorogenic intrusions in platform-type formations, which were proposed to explain the ca. 2.0 Ga ages. In the Salgueiro–Cachoeirinha Group, similar metaplutonics intrude low-grade flysch formations, consistently displaying high-temperature deformation features and metamorphic gradients associated with flat-lying foliations, features only explained by their syntectonic intrusion. Rb–Sr dates of ca. 1.0 Ga obtained in these rocks are regarded as meaningless ages (Jardim de Sá *et al.* 1988).

Further decisive evidence for the presence of the Transamazonian orogeny along the belt comes from the northern border of the São Francisco craton in the Riacho do Pontal region (Jardim de Sá *et al.* 1988) (Fig. 5). South of the Sobradinho dam, south-verging micaschist nappes rest on high-grade basement and parautochtonous quartzites, indicating a cratonic margin towards the south. The nappes are cut and refolded by north–south strike-slip shear zones that controlled the emplacement of ca. 1.85 Ga syntectonic granites (Rb–Sr isochrons; Jardim de Sá *et al.* 1988). Micaschists, quartzites, and basement are, in turn, unconformably overlain by undeformed subhorizontal cratonic sequences, the Middle Proterozoic Espinhaço Supergroup, and the Late Proterozoic Una Group. Thus, besides forming a cratonic margin during Brasiliano times, with apparently gradational and increasing deformation and plutonic emplacement towards the north, this region acted as the foreland for the micaschist nappes (Casa Nova Formation) during the 2.0–1.8 Ga old Transamazonian orogeny.

All these field relations and geochronological data support the proposed Early Proterozoic age for the central belt of the Borborema Province (Fig. 4). Furthermore, as already pointed out in the section on the São Francisco craton, the relationships observed near Sobradinho imply an older age for the north–south-trending structures occurring in the craton (2.3–2.2 Ga or older). Thus the so-called Transamazonian event in the craton cannot be easily linked with the one described here for the Borborema Province.

Discussion and conclusions

The clearest conclusion of our review is that numerous ca. 2 Ga rock units exist within the Pan-African and Brasiliano mobile belts. Ages range from about 2.15 Ga (zircon ages from Hoggar) to 1.8 Ga (Rb–Sr isochrons from Nigeria and Brazil; recent reviews and references in Jardim de Sá *et al.* 1988; Rahaman 1988; Boullier, in press). In the Pan-African–Brasiliano belts, the terranes where ca. 2 Ga ages are found consist mostly of clastic sediments and orthoquartzite-carbonate, shelf-type sequences metamorphosed under medium- to high-grade conditions and closely associated with banded gneisses proved or presumed to be Archaean in age. Volcanics and mafic rocks are very restricted and poorly

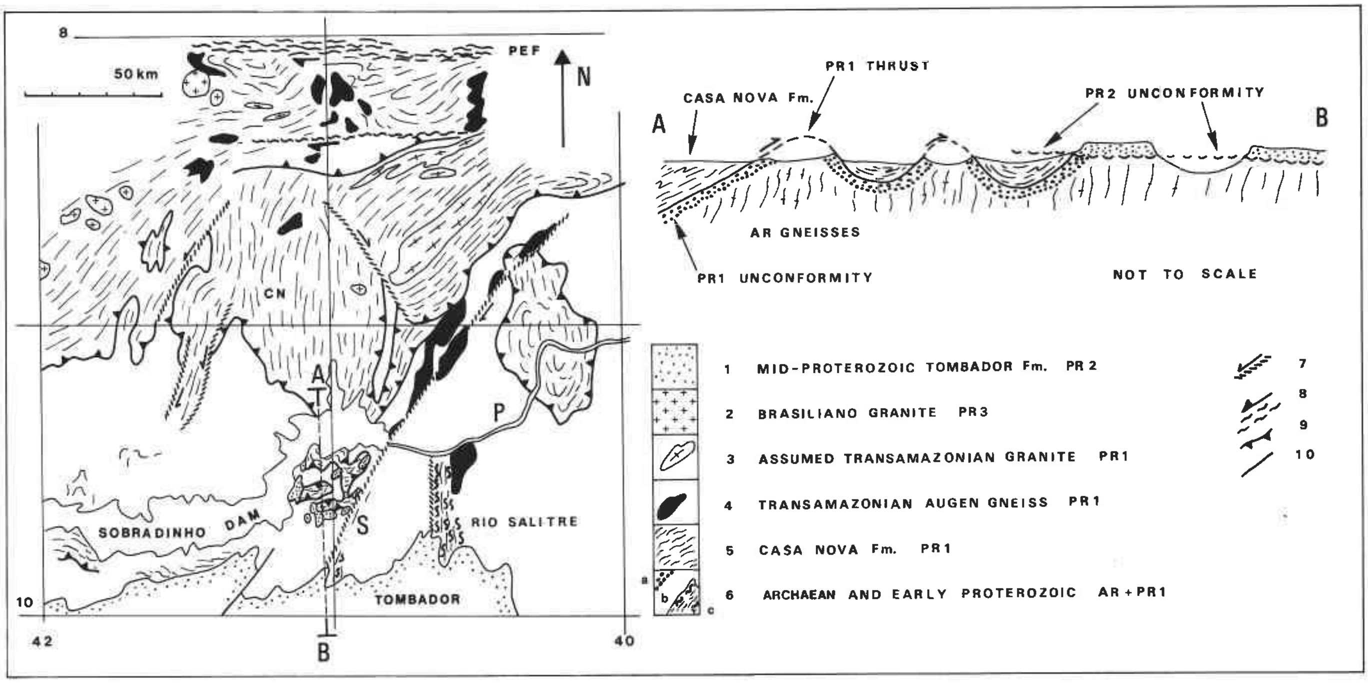

FIG. 5. Map and sketch cross section of the Riacho do Pontal region. 1, Archaean grey gneisses and granite–gneisses (Caraiba gneisses), including pre-Casa Nova supracrustals; 2, Casa Nova micaschists; 3, 2 Ga old porphyritic granites and augen gneisses; 4, assumed Transamazonian syntectonic granites; 5, Brasiliano alkaline intrusives; 6, undeformed Middle Proterozic Tombador quartzite formations; 7, Transamazonian strike-slip fault; 8, Brasiliano strike-slip fault (Pernambuco fault); 9, Transamazonian thrust; 10, Late fault; PEF, Pernambuco fault zone; CN, Casa Nova; P, Petrolina; S, Sobradinho.

known. The average metamorphic grade is often higher than that for Early Proterozoic formations occurring in the cratons. Eburnian granulite-facies assemblages are known in many localities in Hoggar–Iforas and Cameroon (Lancelot *et al.* 1976; Bertrand *et al.* 1986; Penaye *et al.* 1989). Our contention in that before being more or less strongly affected by the Pan-African or Brasiliano deformation and metamorphism, these terranes were strongly deformed, metamorphosed and intruded by granitoids during the Eburnian or Transamazonian orogeny.

We have stressed the strong contrast in Early Proterozoic characteristics between the cratons and the domains that are now reworked within the Pan-African–Brasiliano belts. Archean crust, including recognizable greenstone belts, is dominant in the CCC and SFC, with a varying Eburnian–Transamazonian reworking. WAC and GAC are formed dominantly of huge domains of juvenile Early Proterozoic crust with restricted Archean nuclei. On the other hand, the oldest terranes identified within the Pan-African–Brasiliano belts, when recognizable through the often very strong Late Proterozoic overprint, are either Archaean grey gneisses or Early Proterozoic metasediments, suggesting platform-type environments.

Archaean crust and Early Proterozoic metasediments in the Pan-African–Brasiliano belts

A sketch map of presumed crustal ages is shown in Fig. 6. Domains of proven juvenile Late Proterozoic crust have been identified in the Tilemsi "accretion domain" in Mali (Liegeois 1987) and suspected in several restricted areas in Algeria, Niger, and Brazil (Toteu *et al.* 1987; Jardim de Sá 1988; Davison *et al.* 1989; Boullier, in press). However, for most of the mobile belt, the "primary" age of the crust is Archaean, as shown by the abundance of Early Proterozoic metasediments, including a large proportion of clastic rocks, and by the widespread remnants of Archaean grey gneisses. There is, to date, no clear geochemical or lithological evidence to support the existence of Early Proterozoic crust; additions from the mantle at that time should have been very restricted (minor volcanics, a small amount of subalkaline intrusives?). Large areas such as In Ouzzal – Iforas, central Hoggar, Borborema Province, and most of Nigeria, situated within the Late Proterozoic mobile belt, represent twice-reworked Archaean crust. Thus, according to "crustal age," the crust forming most of the Pan-African–Brasiliano mobile belts appears older than most of the crust forming the West African craton, where accretion of a large volume of Early Proterozoic juvenile crust is now suspected (Abouchami *et al.* 1989).

A different interpretation has recently been defended (Caby and Arthaud 1986; Ajibade *et al.* 1987; Caby 1989), which implies the complete absence of Eburnian–Transamazonian orogenic features in the whole Pan-African–Brasiliano mobile belt. According to this interpretation, the ca. 2 Ga old granitic intrusives could represent an "anorogenic" (extensional?) event and the emplacement of predominantly alkaline magmas in a platform-type post-Archaean cover.

Archaean crust and Early Proterozoic juvenile crust in the cratons

The main features displayed by the 2 Ga terranes in the cratons contrast sharply with their Pan-African–Brasiliano equivalents. Dominantly low-grade volcanic and volcanoclastic formations and associated granite-gneiss batholiths underlie most of the West African and Guiana cratons (Birimian series in West Africa, Guiana greenstones). The structural pattern and the occurrence of komatiites in these belts indicate a geodynamic setting strongly reminiscent of Archaean-type granite–greenstone belt associations. Recent geochemical investigations suggest that these regions may represent a huge volume of juvenile crust, initiated some 2.2 Ga ago (Gruau *et al.* 1983;

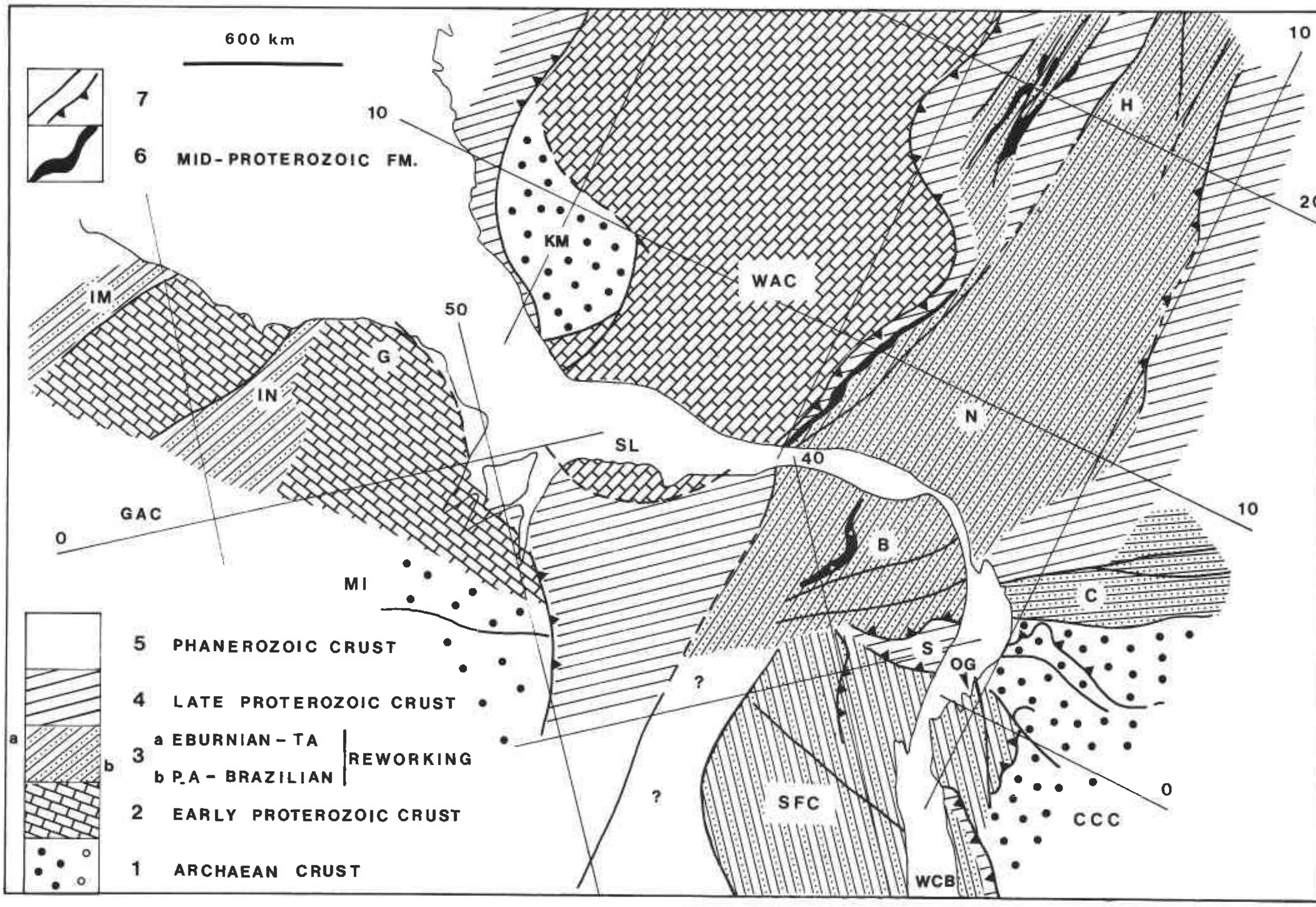

FIG. 6. Tentative sketch map of crustal age domains, showing the large north–south-trending array of high-grade terranes of Eburnian–Transamazonian age. The fit and scale are the same as in Fig. 1. 1, Proven or suspected Archaean nuclei; 2, domains of juvenile Early Proterozoic crust; 3, domains of Archaean crust with minor Early Proterozoic accretion, partly or completely reworked during the Eburnian–Transamazonian event only (a) or also during the Pan-African–Brasiliano event (b); 4, domains of assumed juvenile Late Proterozoic crust; 5, Atlantic domain of juvenile Mesozoic crust; 6, Middle Proterozoic "Quartzite formation" (uncertain attribution for the Atacora quartzites; undifferentiated in the São Francisco craton); 7, major lineaments and Pan-African or Brasiliano thrusts and sutures zones. Cratons: WAC, West African craton; KM, Kenema–Man Archaean nucleus; SL, São Luis craton; GAC, Guiana–Amazonia craton; IM, Imataca complex; IN, Inini complex; G, Guiana; MI, Maroni–Itacaunas belt; CCC, Congo–Chaillu craton. Northeast Brazil, Trans-Saharan, and central Africa belts: H, central Hoggar; N, Nigerian shield; B, Borborema Province of northeast Brazil; C, Cameroon belt; S, Sergipe belt; OG, Ogooue belt; SFC, São Francisco craton; WCB, West Congolian belt.

Gibbs and Barron 1983; Abouchami *et al* 1989; Boher *et al.* 1989).

A different situation exists in the São Francisco craton (despite conflicting interpretations), where Transamazonian (or more likely, early Transamazonian) deformation and metamorphism may overprint dominantly Archaean formations, with no (or restricted) imprint of the Brasiliano orogeny. In the eastern part of the São Francisco craton, there are major questions still to be answered regarding the Early Proterozoic evolution. Greenstone belts and high-grade gneisses are reworked by a strike-slip deformation older than 2.1 Ga, and it is not a simple matter to relate these events to the Eburnian collisional belt, as it is defined in the Congo-Chaillu carton (Ledru *et al.* 1989), or to the nappe tectonics in the Borborema Province. Although most lithologies involved in the SFC are truly Archean, some formations, for example, the Itapecuru greenstone belt and the Itabuna complex (see reviews by Davison *et al.* 1988; Figueiredo 1989), likely represent Early Proterozoic crustal additions. More U–Pb zircon ages are needed to define the age patterns of the SFC and the Borborema Province before the kinematics and the chronology of the Transamazonian belt can be fully understood.

It is not easy to actually prove a past collisional behaviour in such terranes, which are now included in complex, often high-grade, younger belts. However, the combination of the "minimum criteria" that we have chosen from the beginning, namely old high-grade metamorphism, nappe tectonics, and crustal melting, strongly suggests the existence of one or several orogenic belts ca. 2 Ga. A likely collisional origin for these belts is also supported indirectly by the crustal contrast existing between them and the cratons. Only in the cratons do we find an "accretive" geodynamic environment, with large-scale formation of juvenile crust; the mobile belts (2 Ga and 600 Ma combined) are formed of older continental crust and were probably the sites of intra- (or inter-) continental collision(s) at approximately the same time as young crust was forming in the cratons.

Could the Eburnian–Transamazonian and Archaean domains, which are present within the Pan-African–Brasiliano belt, have previously formed a unique collisional belt? Could the ill-fitting old crustal segments, which more often show high-grade, ca. 2 Ga metamorphic assemblages and local evidence for pre-Pan-African–Brasiliano nappe tectonics, represent the remnants of a transcontinental collisional superbelt like the Alpine–Himalayan superbelt? In such a belt, age differences and complex kinematic evolution are the rule. Obviously, more structural and geochronological data needed to test such a working hypothesis.

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