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Brazil–Africa Geological Links

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ABSTRACT

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In this work, the main evidence and conclusions regarding geological links between Brazil and Africa are summarized, with emphasis on the geochronological aspects. Taking into account the geographical position, as well as the similarities in the geochronological pattern, the following main provinces of the two continents are correlated:

(1) The Imataca and Falawatra complexes in the Guayana Shield and the Liberian Province of West Africa.

(2) The Paraguay—Araguaia and the Rockelide Fold Belts.

(3) The São Luiz and the West African cratonic areas.

(4) The Caririan Fold Belt of northeastern Brazil and the Pan-Africa Belt of Nigeria and Cameroon.

(5) The Jequié Complex of Bahia, the Ntem Complex of Cameroon and similar rocks of Gabon and Angola.

(6) The Ribeira Fold Belt in Brazil and the West Congo and Damara Belts in West and South Africa.

In addition, other geological links are considered, such as some of the major linear fault zones which can be traced across the margins of South America and Africa, in the pre-drift reconstructions. Correlations are also made of the tectonic and stratigraphic evolution of the Paraná and Karroo syneclises, and the Brazilian and African marginal basins around the South Atlantic, during their initial stages.

Finally, several similarities in the tectonic evolution of South America and Africa, during and after the onset of drifting, are shown to be compatible with a recent origin for the South Atlantic floor, as required by sea-floor spreading and continental drift between South America and Africa.

INTRODUCTION

The great controversy related to the continental drift hypothesis essentially began with the publication of Wegener's (1912) work *Die Enstehung der Kontinente*. The discussions lasted for several decades, until recently in the 1950's and 1960's, when important scientific developments brought about a strong revitalization of the theory, within the major framework of plate tectonics.

In recent years, several lines of evidence, originating in such differing fields as paleomagnetism, oceanography, marine geophysics, geochronology and others, have demonstrated conclusively, in the authors' opinion, that the separation of continental masses with concomitant formation of ocean basins can no longer be considered simply as a hypothesis. Articles like Hurley's (1968) *The confirmation of Continental Drift* were published in the specialized literature, reporting the new interpretations for large-scale tectonic processes based on the following principal scientific results:

(1) Interpretation of linear magnetic anomalies in the ocean basins in terms of geomagnetic reversals and sea-floor spreading from mid-ocean ridges.

(2) The establishment of a precise stratigraphy for young marine sediments collected through deep-sea drilling in the ocean basins.

(3) Interpretation of seismological data within active belts such as island arcs, mid-ocean ridges, and large transcurrent and transform faults.

(4) The geometric juxtaposition of continental masses on opposite sides of ocean basins (Atlantic and Indian) accurately determined by means of computers.

(5) The correlation of geological features of continental regions which would have been adjacent according to pre-drift reconstructions.

Many papers have been published along the line of research mentioned in item 5, most of which relate to geological comparisons of features belonging to South America and Africa. These continents have attracted attention since the beginning of the continental drift hypothesis, because of the striking similarities in their coastlines in the South Atlantic Ocean. The main references are Mantovani (1909), Taylor (1910), Du Toit (1921, 1927, 1928, 1938), Keidel (1922), Leme (1929), Maack (1934, 1967, 1968), Choubert (1935), Longwell (1944a, b), Beurlen (1961), Martin (1961, 1968), Pflug (1963), Bullard et al. (1965), Compston et al. (1968), Loczy (1968), Allard (1969), Allard and Hurst (1969), Strangway and Vogt (1970), Creer (1972), Horowitz (1972), Bigarella (1973a, b), Colbert (1973), Keast (1973).

With the development of geochronology, mainly within the last ten years or so, many comparative tests of a quantitative character have been made, their fundamental concerns being the position of age-province boundaries and the comparison between geochronological patterns within correlative regions. Some of the main published works that include geochronological data are: Hurley et al. (1967), Tugarinov (1967), Almeida (1968), Almeida and Black (1968), Hurley (1968), Hurley and Rand (1969), Siedner and Miller (1968), Melcher et al. (1972), Almeida et al. (1973), Cordani (1973, 1975), Torquato and Amaral (1973), Torquato (1974, 1975).

Finally, several papers have been published in the last few years dealing with the mechanism of separation of South America and Africa, already within the context of plate tectonics. In these papers, geological phenomena related to the origin of the South Atlantic were described on the basis of evidence collected along the continental margins of both continents, and/or the ocean floor. Some noteworthy papers are Cordani (1970, 1975a), Loczy (1970), Asmus and Porto (1972), Northfleet et al. (1972), Asmus and Ponte (1973), Burek (1973), Douglas et al. (1973), Ridge (1974), Asmus (1975), Gorini and Bryan (1975), Mascle and Renard (1975), Ponte and Asmus (1975), Reyment et al. (1975), Rona (1975), Sial (1975), Burke and Wilson (1976), Sial et al. (1976).

In this work, we will attempt to summarize the main evidence and conclusions regarding geological links between Brazil and Africa, emphasizing those items considered most important in the above-mentioned papers. We will also add some pertinent comments in the light of recent advances on the subject. Special attention will be given to the geochronological aspects, since they are particularly adequate for accurate comparisons.

First, we will set forth the correlations between the existing geochronological provinces, from north to south, along the Atlantic margins of both South America and Africa. Next, certain geological features that could be considered as "links" will be briefly discussed. Finally, similarities in the tectonic evolution of South America and Africa, during and after the onset of drifting, as well as some pertinent tectonic events within the South Atlantic basin, will be compared.

THE MATCHING OF PRECAMBRIAN AGE PROVINCES, IN A PRE-DRIFT RECONSTRUCTION OF SOUTH AMERICA AND AFRICA

In this section, we will indicate the pertinent correlations between Brazil and Africa, and two main aspects will be outlined: (1) the geographical position of adjacent age provinces and their continuity in a pre-drift reconstruction; and (2) similarities in the geochronological patterns observed in regions considered analogous, on both sides of the South Atlantic.

In the opinion of the present authors, the geochronological control, although not uniform, seems to be acceptable in every case in which a correlation can be attempted. All the major geochronological provinces are already well defined, on both continents, and their boundaries are known with acceptable accuracy.

The Imataca and Fallawatra complexes of the Guayana Shield, and the Liberian age-province in West Africa

Hurley et al. (1967) emphasized the great similarities between the geochronological evolution of the basement rocks of Sierra Leone and Liberia in West Africa and that of analogous rocks in Venezuela, Guayana, and Surinam in South America. In both regions, very ancient nuclei composed of igneous and metamorphic rocks of amphibolite and granulite facies yielded Rb—Sr reference isochrons of about 2700—2800 m.y., as well as isolated age values within the 3000—3600 m.y. interval. These high-grade gneissic and granitic rocks on both sides of the Atlantic contain some metasedimentary remains, including iron formations, a fact that increases the validity of the lithological correlation.

In addition, both regions were affected by a strong orogenic episode in the Middle Precambrian. This major event is called Eburnean in Africa and Transamazonian in South America, and is associated with large mobile belts in which sedimentary—volcanic complexes were affected by strong regional metamorphism and repeated granitic injections about 1800—2100 m.y. ago.

In a recent paper, Gaudette et al. (1978) reported a better controlled isochron age of 2800 m.y. for the Fallawatra granulitic Complex, thereby strengthening the age correlation with the ancient nuclei of Imataca and Liberia.

In summary, the geochronological pattern, as evidenced mainly by Rb—Sr whole-rock isochron work, indicates a similar geologic evolution of Venezuela, Surinam, Sierra Leone and Liberia, with at least three major cycles in the Early to Middle Precambrian, about 3000—3600 m.y., 2700—2800 m.y. and 1800—2100 m.y. ago. Moreover, although the two regions in Africa and South America are physically separated by a relatively narrow Late Precambrian belt (the Rockelides and their counterpart, the Paraguay—Araguaia Belt), their structural trends merge together, defining a single and very large ancient segment of continental crust. A schematic representation of the continuity of the age provinces across the Atlantic rift can be found in Hurley and Rand (1973).

The Rockelide Fold Belt in West Africa and the Paraguay—Araguaia Belt in Brazil

A narrow metasedimentary belt of Pan-African age (Late Precambrian to Early Paleozoic), the Rockelide Fold Belt, was described as surrounding the western side of the West African craton (Allen, 1969). It includes the Rockel River Series, comprising phyllites, quartzites, itabirites and metavolcanic rocks, that overlies a basement in which Liberian and/or Eburnean rocks were rejuvenated by the Pan-African orogenic cycle.

The Paraguay—Araguaia Belt, whose northern part exhibits N—S structural trends, is in direct continuation with the Rockelide Belt in the pre-drift reconstruction. This unit passes below the Mesozoic and Cenozoic sediments of the Lower Amazon Basin, at the mouth of the Amazon River, and has yielded ages in the 400—700 m.y. range. Within the Paraguay—Araguaia Belt, the northernmost lithostratigraphic unit is the Tocantins Group, made up of low-grade metamorphic rocks, comparable with those of the Rockel River Series, and exhibiting a similar geochronological pattern (Hasui et al., 1975a).

The West African and the São Luiz cratonic areas

The West African craton is a geotectonic unit of great dimensions, which includes the above-described Liberian Province. It was extensively affected by the Eburnean orogeny, about 2000 m.y. ago. The São Luiz cratonic area in South America seems to be a small piece of the same large unit that separated during the Mesozoic drifting episode. The boundaries with the Late Precambrian orogenic belts on both sides of the cratonic areas fit perfectly in the pre-drift reconstruction. In addition, the geochronological pattern, with its predominance of Eburnean/Transamazonian ages, is completely comparable, as demonstrated by Hurley et al. (1967) and confirmed by Tugarinov (1967). In Fig. 1, based on Hurley et al. (1967) the geochronological results available at that time are plotted, showing the indicated correlations.

The Caririan Fold Belt (Borborema Province) of northeast Brazil and the Pan-African Belt of Nigeria and Cameroon

The great geological similarities pointed out by Almeida (1968), and Almeida and Black (1968), as well as the geochronological comparison attempted by Hurley et al. (1967), support the obvious correlation between

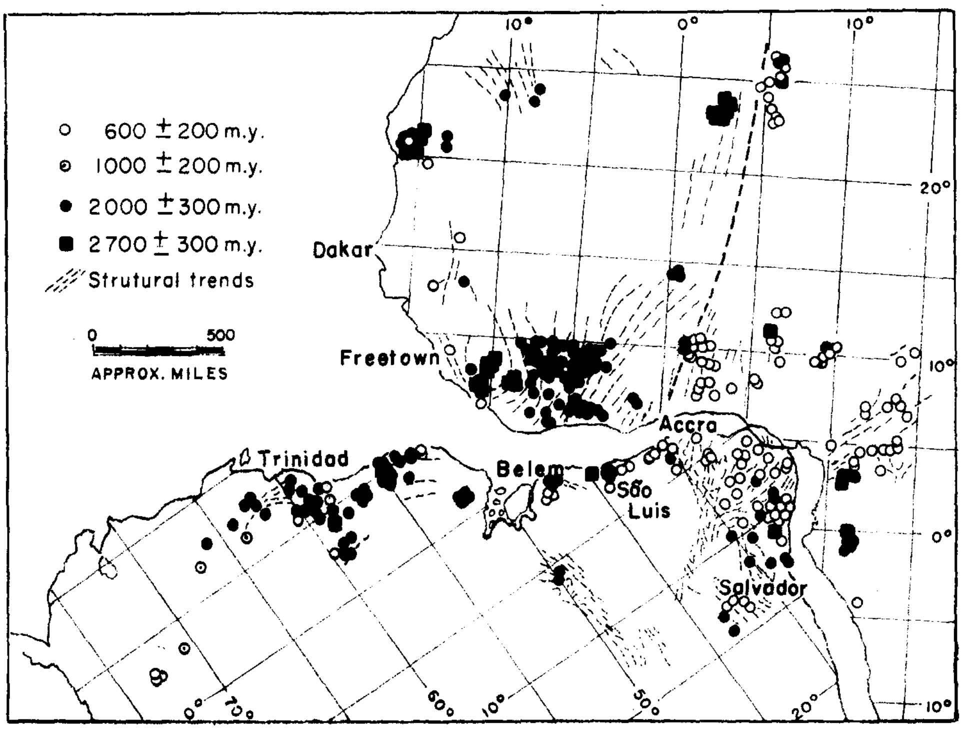


Fig. 1. Geochronological correlation attempted by Hurley et al. (1967). The São Luiz and the West African cratonic areas and the Caririan and Pan-African Late Precambrian regions.

northeast Brazil, and Dahomey, Nigeria and Cameroon. In both regions, a strong orogenic episode during the Late Precambrian produced metasedimentary rocks, induced granitization and the formation of granitic rocks of different types, and rejuvenated crustal rocks of pre-Brazilian and pre-Pan-African age (Almeida, 1967; Kennedy, 1964; Grant, 1973). Almeida (1968) has previously emphasized the great geological similarities between these regions (Fig. 2). Besides the structural trends which merge together in the pre-drift reconstruction, other geological features can be compared, such as the well-defined pegmatitic provinces, or the Sn mineralization in both continents.

The recent work by Neves (1975) on the geotectonic regionalization of northeast Brazil permits a more detailed comparison of the areas in terms of geology and geochronology. He described the region as being characterized by alternating folded belts and median massives (or tectonic highs), a structural pattern which seems to be also applicable to the Pan-African region of West Africa. For instance, the Rio Piranhas tectonic high of Neves appears to be correlatable with the Idadan region of Nigeria. In the Rio Piranhas area, granitic rocks, gneisses and migmatites of the São Vicente Complex, with NNE—SSW structural trends, exhibited Rb—Sr whole-rock isochron ages of about 2700 m.y. and 2200 m.y. (Pessoa, 1976). Furthermore, the K—Ar mineral ages in the 450—600 m.y. range bear witness to the widespread rejuvenation during the Brasiliano Cycle. In the Ibadan region, Grant (1970) and Burke et al. (1976) described the existence of a granite—gneissic rock of about 2200 m.y. associated with a basement of banded gneisses. In addition, the entire region was affected by the Late Precambrian Pan-African orogeny.

Some difficulties exist in the detailed correlations along the southeastern border of the Late Precambrian geotectonic units, and in the relations of these units with the cratonic regions of São Francisco, in Brazil, and the Congo, in Africa.

At first, based on remarkable lithological similarities, Allard and Hurst (1969) and Allard (1969) correlated the metasediments of the Vasa Barris Group in Brazil with the metasediments of the Ndjole Series of Gabon (Fig. 3). However, this unit belongs to the Congo Craton, a stable area during the Pan-African orogeny, and their rocks, therefore, must be older (Cahen and Snelling, 1966; Cordani, 1973). Correlation with the Vasa Barris Group, of Brasiliano age, is untenable. Cordani (1973) and Torquato (1974), correlated the Vasa Barris Group with the Mbalmayo—Bengbis, Dja and Semba—Ouesso Series, which borders the Congo Craton along its northwestern part (Cahen and Snelling, 1966) and is of supposed Pan-African age.

Torquato (1974) suggests a connection of these Late Precambrian belts, Vasa Barris, Mbalmayo—Bengbis, Dja and Semba—Ouessa, with the N—S trending West Congo Belt, in a "knot" with three arms, one of which is presently hidden in the continental shelves of South America and Africa. In this reconstruction, the Pernambuco—Alagoas Massif (Neves, 1975), in which pre-Brasiliano ages have been detected, could be correlatable with the Chaillu

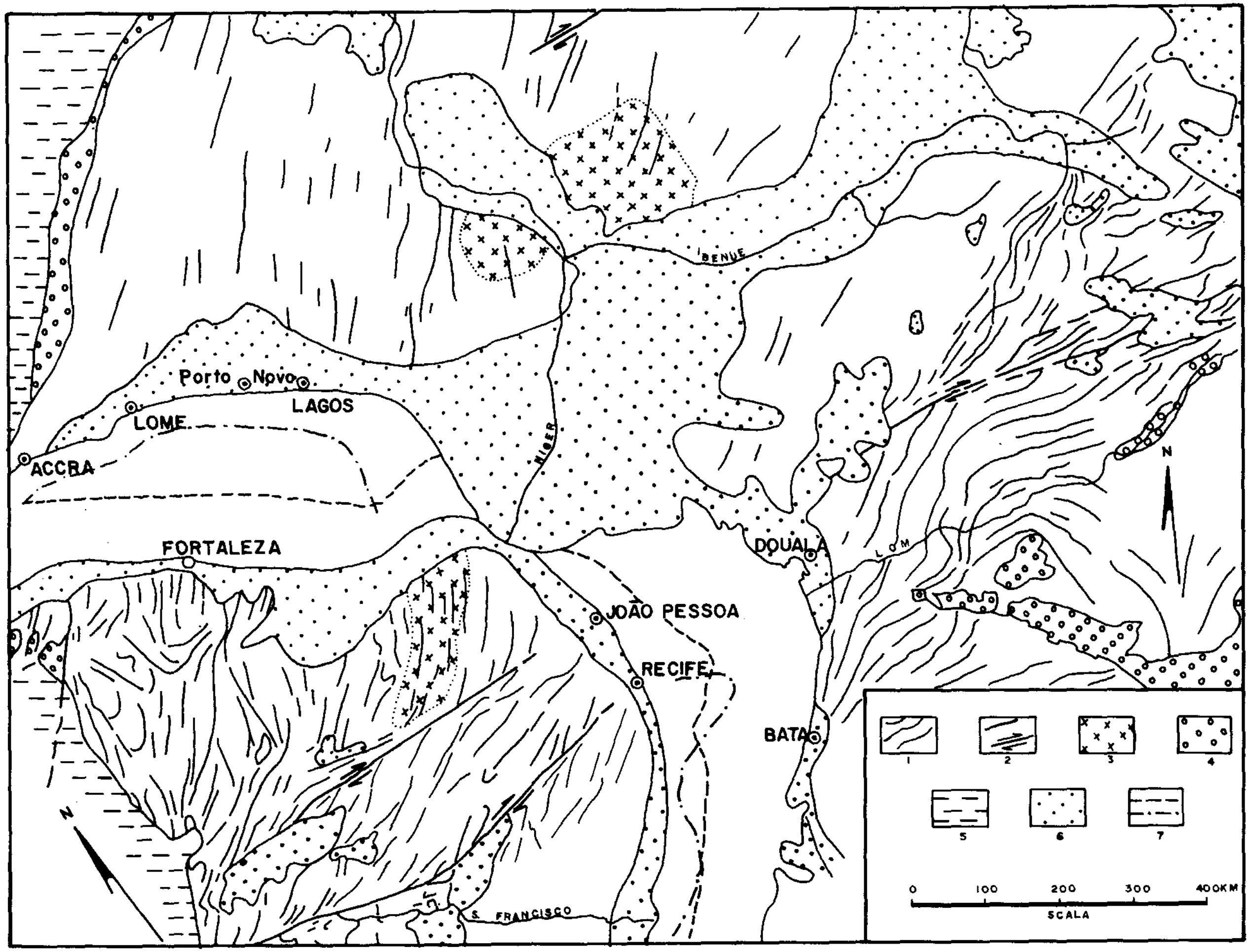


Fig. 2. Comparison of some geological features of western Africa and northeastern Brazil. Legend: *1* = trends of bedding and schistose or gneissic structures; *2* = wrench faults; *3* = pegmatite metallogenetic provinces; *4* = Cambrian (?) series, little folded; *5* = Lower Palaeozoic sediments; *6* = Mesozoic and Cenozoic sedimentary and volcanic cover; *7* = 2000-m isobaths (Almeida, 1968).

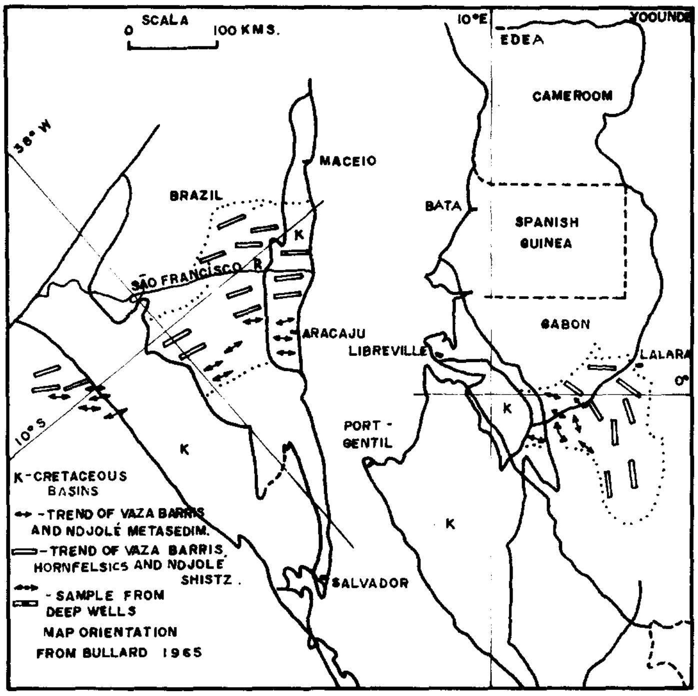


Fig. 3. Correlation conceived by Allard and Hurst (1969), regarding the metasediments of Vasa Barris, in Brazil, and Ndjole in Gabon.

Massif of Cameroon, from which granulitic rocks have yielded ages of up to 2800 m.y. A different hypothesis was presented by Cordani (1973), comparing the granulites of the Chaillu Massif with similar rocks of the Jequié Complex in Bahia. According to this author the geochronological pattern in both units indicates the presence of Archean rocks, and the lack of extensive Pan-African/Brazilian rejuvenation. The main reconstruction suggested by Cordani (1973) is shown in Fig. 4.

Allard and Hurst (1969) suggested a complete correlation between the post-orogenic deposits of the Estancia Formation in Brazil with the Noya Series of Gabon and the upper part of the West Congo Belt (Schisto-calcaire and Schisto-greseuse Series). In these units, ages of about 450—500 m.y. were obtained, the best controlled value being the 460 m.y. age for the Estancia Formation, dated by Rb—Sr whole-rock isochron work. The Estancia/Noya correlation seems to be very probable indeed. However, the upper part of the West Congo Belt is located much more to the south and can probably be correlated more correctly with the epimetamorphic rocks of the Rio Pardo Group in southern Bahia. The above-mentioned hypothetical link suggested by Torquato (1974) could bring all of these units within the same belt of Pan-African/Brasiliano age.

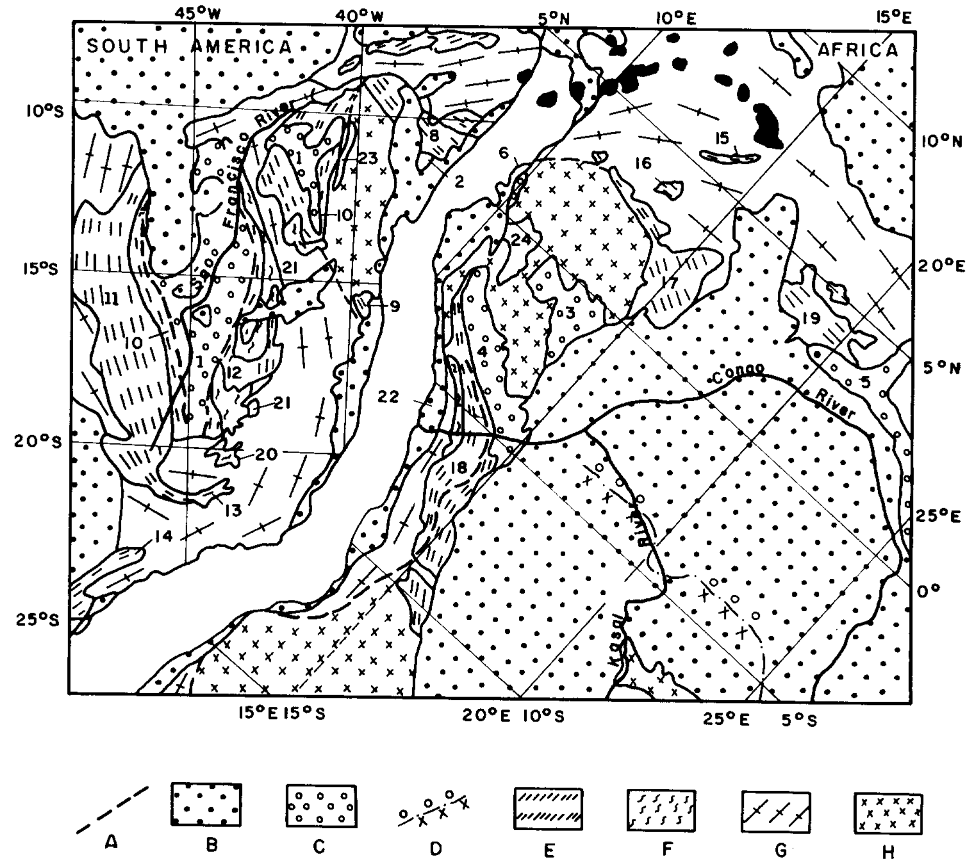


Fig. 4. Correlation among the geotectonic units of eastern South America and western Africa, according to Cordani (1973). Legend: *A* = boundaries for the regions affected by the Brasiliano/Pan-African Cycle; *B* = Phanerozoic sedimentary covers; *C* = unfolded and unmetamorphosed Precambrian sedimentary covers; *D* = boundary for the cratonic sedimentary cover, after subsurface data; *E* = paraplatformal areas, and/or folded belts of Brasiliano/Pan-African age; *F* = older folded belts, rejuvenated at about 450—700 m.y.; *G* = infra-structure of the Brasiliano/Pan-African belts; *H* = stable cratonic areas in Late Precambrian times.

Nomenclature for the geotectonic units: *1* = Bambui Group; *2* = Estancia Formation; *3* = Francevillian System; *4* = West Congo System; *5* = Lindian-Ubangian System; *6* = Noya Series; *7* = Ceará Series; *8* = Sergipe geosyncline; *9* = Rio Pardo Group; *10* = Lavras—Bambui Groups; *11* = Canastra Group; *12* = Macaubas Formation; *13* = São João del Rey Group; *14* = Açungui Group; *15* = Lom Series; *16* = Mbalmayo—Bengbis and Dja Series; *17* = Semba—Ouesso Series; *18* = West Congo System; *19* = Liki—Bembian System; *20* = Minas Group; *21* = Espinhaço Group; *22* = Mayumbian System; *23* = Jacobina Group; *24* = Ndjole Series.

The Jequié Complex in Bahia, the Ntem Complex of Cameroon and similar in rocks in Gabon and Angola

The main geological feature of the Lower Precambrian which can be compared in South America and Africa is the existence of large areas of granulite terrain from which ages in the 2600—2900 m.y. range have been obtained. In Brazil, these rocks make up the Jequié Complex of eastern Bahia (Cordani, 1973), whereas in Africa they can be found in a very large area, from the Kasai Shield to the Atlantic coast, most probably underlying the cratonic sedimentary cover of the Congo Basin (see Fig. 4). Along the Atlantic coast of Africa, granulitic rocks crop out such as in the Ntem Complex in Cameroon within the Chaillu Massif, in the Cuanza Horst in Angola, where ages of about 2850 m.y. were obtained (Delhal et al., 1976), and in Gabon, for which radiometric dates are not yet available.

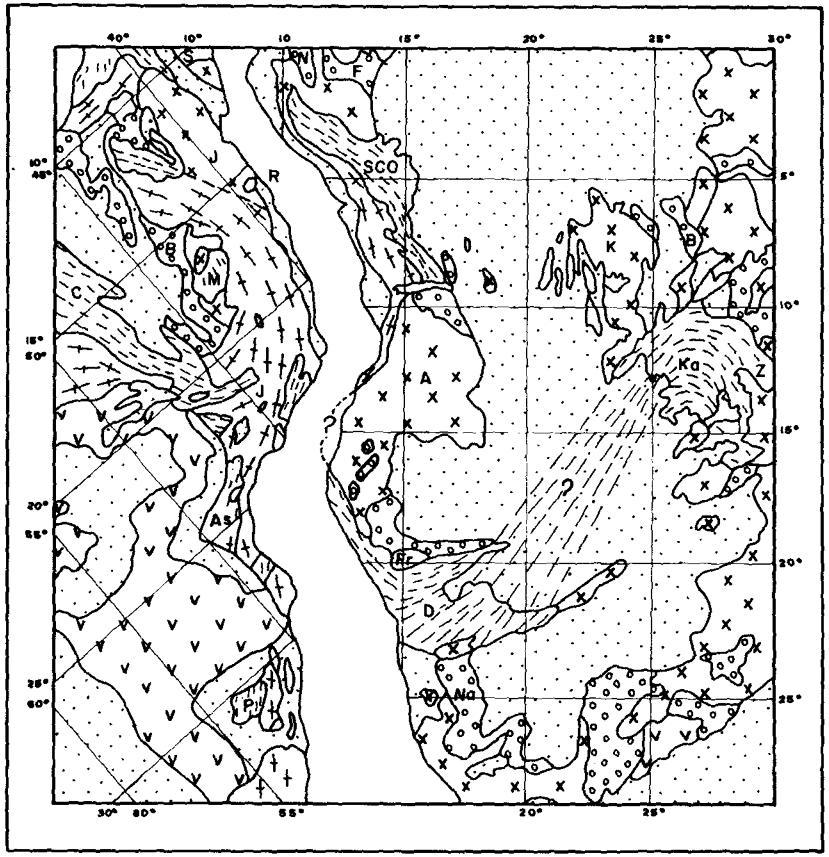
The existence of a very large granulitic/charnockitic region in Africa, at least from Kasai to Cameroon, was employed by Kröner (1976, 1977) to suggest that an old and extensive sialic crust existed since Archean times. In the pre-drift reconstruction this area became still larger, including the eastern part of the São Francisco Craton of Brazil.

The northern part of the Ribeira Belt (Mantiqueira Province) in Brazil and the West Congo Belt in West Africa

Along the southern Atlantic coasts of Brazil and Africa, a terrane with ancient rocks predominates, although this area was rejuvenated during the Brasiliano/Pan-African orogenic cycle. In Africa, these rocks, mainly gneisses and granites, occur along the coast from Gabon down to about 13°S latitude. In Brazil, the belt is much wider (about 300 km) and covers large parts of the states of Bahia, Minas Gerais, Espirito Santo and Rio de Janeiro. Also in Brazil, gneisses, migmatites and granites predominate, although in several nuclei granulitic rocks have been described.

In several places, pre-Brasiliano or pre-Pan-African ages have been obtained. However, extensive metamorphism and granitization took place in those regions in Late Precambrian times (Cordani et al., 1973; Cordani, 1973; Torquato, 1975, 1977; Torquato and Amaral, 1974). Many granites and migmatites were formed in close association with regional metamorphism, almost everywhere at the amphibolite facies level. On both continents, in these regions, the last regional cooling, as revealed by K—Ar and/or Rb—Sr ages on micas, occurred at about 450 m.y. ago. Fig. 5 matches the geologic and geochronologic provinces for the South Atlantic as interpreted by Torquato (1975).

To the south of the West Congo Belt in Angola, a large pre-Pan-African province occurs which extends along the coast down to 16°S of latitude. It is called the Angola Shield, and has yielded ages characteristic of the Eburnean orogeny, around 2000 m.y. (Torquato, 1974, 1977). In Brazil, a stable area



LEGEND

- Phanerozoic sedimentary cover
- Basaltic flows of Paraná.
- Precambrian Sedimentary cover slightly folded and metamorphosed
- Platform areas and/or belts of 450/700 my.
- Orogenic Belts of 450 / 700 my considered to be older but rejuvenated.
- Brázilian / Pan-African platforms.

AFRICA

N - Ndjole serie.
F - Francevilian system.
SCO - Western Congo group.
K - Kasai and Northeast Angola shield.
B - Bushimay system.
Ka - Katanga orogenic belt.
A - Angola shield.
Z - Zambezi orogenic belt.
Fr - Franzfontein granite.
D - Damara group.
Na - Nama group

BRAZIL

B - Bambui group.
Je - Granulitic compex of Jequie.
C - Canastra group.
L - Lavras group.
As - Açungui - São Roque group.
J - São João del Rei group.
M - Macaúbas Formacion.
S - Sergipe geosyncline.
P - Porongos group.
R - Rio Pardo group.

DATA FROM
ÁFRICA: Tectonic Map 1/15.000.000 (modified)
BRAZIL: Tectonic Map 1/5.000.000 (modified)
Cordani - 1973.

Fig. 5. Geotectonic correlation between southeast Brazil and Southwest Africa (after Torquato, 1975).

during Brasiliano times in Rio de Janeiro region has not been detected. However, the basement for the Ribeira Belt in that region, the Paraiba Formation has yielded Transamazonian ages of the same order as those from the Angola Shield (Cordani et al., 1973).

The southern part of the Ribeira Belt (Mantiqueira Province), in southern Brazil and Uruguay, and the Damara Belt in Southwest Africa and vicinities

In South America, the Ribeira Belt continues to the south to Uruguay, with structural trends always parallel to the Atlantic coast. In Africa, the Damara Belt exhibits structural trends orthogonal to the coast line that turn abruptly to become parallel to the coast of Southwest Africa and Angola. The great lithological similarities, for instance between the metasedimentary units of the Damara and Açungui groups, allow an obvious correlation (Melcher et al., 1972; Torquato, 1974, 1975).

The geochronological patterns in both units are practically identical and typify the geological evolution in the Brasiliano Pan-African belts. The main period of regional metamorphism and syntectonic magmatism is placed at about 650—700 m.y.; late tectonic granites exhibit ages of around 600 m.y.; the main post-tectonic magmatism occurred about 520—540 m.y. ago; post-orogenic molassoid sequences, with associated volcanic rocks, were formed between 450 and 500 m.y. ago; and finally, the regional cooling of the belts, as evidenced by K—Ar ages of biotites, can be placed close to 450 m.y.

The South African coastal region, and the basement rocks of Uruguay and Buenos Aires Province of Argentina

These regions, perhaps, are the ones in which the correlations between the two continents are the least satisfactory.

Some comparatively small areas of Brasiliano/Pan-African age are known, for example the Malmesbury and Gariep belts of South Africa, and the basement rocks of the Sierra de La Ventana sediments (Cingolani and Deutsch, 1973).

Most probably, all these Late Precambrian areas were physically connected with the Ribeira and Damara belts through a hypothetical link comprising a large area which is now hidden in the continental shelves of South America and Africa. However, the African counterpart of the La Plata Craton of South America, in which Transamazonian rocks are predominant (Almeida et al., 1973), is not readily identifiable. According to Kröner (1977), along the southwestern coast of Africa, the basement is made up of Archean rocks of the Kalahari—Malagasy protoshield, rejuvenated during the Kibaran thermotectonic cycle (1100 ± 200 m.y.).

OTHER GEOLOGICAL LINKS

Besides the location and correlation among the main geochronological provinces, as described in the preceding section, other geological links should be mentioned.

Correlations among major tectonic lineaments

Several of the major linear fault zones can be traced across the margins of South America and Africa, in the pre-drift reconstruction.

Almeida (1968) has already pointed out that the fracture zone of Sobral—Pedro II in northern Brazil is the extension of the Alibory and Bifur lineaments in West Africa (Fig. 4). In the same work, the major tectonic lineaments of northeast Brazil, the Patos (Paraiba) and Pernambuco fault zones, are traced across the continents to the Foumbam and Ngaourandere fracture zones of Cameroon. The same correlations are made by Allard and Hurst (1969), and Allard (1969).

An extension of the system of transcurrent faults that occurs between Luanda/Salazar and Malange with E—W trends can be found in Brazil, as pointed out by Torquato (1975). Their counterpart is a complex system of faults, which includes the Ubatuba lineament, of Ridge (1974) and the Taxaquara and Cubatão fault zones. Hasui et al. (1975a) denominated this system the "São Paulo transcurrence zone".

Correlations of the tectonic and stratigraphic evolution of the large syneclises of Paraná and Karroo

The correlation between the sedimentary basins of Paraná in South America and Karroo in southern Africa has been made by several authors, dealing with many different aspects of geology, stratigraphy, paleontology and paleoecology. Because of their special importance, a few of them deserve to be quoted here, e.g., Du Toit (1921, 1927, 1938), Martin (1961, 1968), Maack (1967, 1968), Loczy (1968), Northfleet et al. (1972), Horowitz (1972), Keast (1973), Colbert (1973) and Bigarella (1973a, b).

We shall not repeat here the very many similarities found by these authors between the Paraná and the Karroo basins, and the sedimentary sequences of the Kaokoveldt, in Namibia and southern Angola. Briefly, the large syneclises started in Devonian times, when a marine transgression invaded an ortho-platform, producing similar sedimentation, the Ponta Grossa and Bokkeveld sequences. In Carboniferous and Permian times an extensive continental glaciation covered large parts of South America and Africa, the sedimentary sequences in the Paraná and Karroo basins being easily comparable and having very similar faunas and floras. Later on, in Early Mesozoic times, the large syneclises were completely filled up, and the Afro-Brazilian platform emerged, with large areas becoming covered by continental sediments. The absence of marine sediments of Jurassic—Triassic age, on both continents, led Kennedy (1965) to conclude that, at least until then, South America and Africa remained joined together.

A further link, this time a structural one, is the Late Paleozoic folding of the sedimentary strata at Sierra de La Ventana, in Argentina, which is completely matched, in South Africa, by similar structures within the Karroo Basin, near Cape Town (Martin, 1961). Such structures, together with the great sedimentary thicknesses, at least on the African side, led Du Toit (1938) to propose the term Samfrau geosyncline to a large unit with roughly E—W trends, connecting the southern parts of South America and Africa.

Comparison of the tectonic evolution of the Brazilian and African marginal basins around the South Atlantic during their initial stages

According to several recent works (Northfleet et al., 1972; Asmus and Ponte, 1973; Ponte and Asmus, 1975; Asmus, 1975; and others) based on paleontological data related to the marine invasions of the South Atlantic marginal basins, the separation of South America and Africa was gradual, and can be described by a three-phase history. Each phase is related to matching coastal regions in South America and Africa.

The first phase, in which the marginal basins exhibited a lower sequence of continental sediments followed by marine beds in Aptian/Albian times, took place upon a basement with structural trends roughly parallel to the present coast. In South America, the basement corresponds to the eastern Atlantic coast, south of the Pernambuco lineament. In Africa, it comprises the western South Atlantic coast, south of the Cameroon fracture zone. In that area, the so-called Afro-Brazilian depression of Northfleet et al. (1972), the marine environment in Albian times was favourable for the accumulation of thick sequences of evaporites in the marginal basins of Santos, Campos, Espirito Santo, Alagoas/Sergipe, Cuanza, Cabinda, Lower Congo and Gabon (Asmus and Ponte, 1973; Franks and Nairn, 1973). This situation indicated a restricted sea, a physical connection between Brazil and Africa to the north, and the existence of topographic elevations related to the Rio Grande and Walvis volcanic chains in the south.

In the second phase, the basement structures are oblique to the coastlines. In Brazil, these include the marginal basins along the northern and northeastern coast as far as the Paraiba lineament, while in Africa they include the marginal basins located between the Ivory Coast and Nigeria. In all these basins, except that of Barreirinhas (Asmus, 1975), marine sedimentation started in Cenomanian/Turonian times, although continental deposits are known to have been formed since Aptian/Albian times. Some compressional events are evidenced by folds and reverse faults affecting pre-Campanian sediments in the Ceará, Barreirinhas, Ghana and Ivory Coast marginal basins. This again points to their common geologic evolution.

The last region to be separated shows basement rocks with structural trends practically orthogonal to the coastline. This corresponds to the northeasternmost corner of Brazil, where the Pernambuco and Paraiba lineaments are located, and in Africa, it includes the Benue rift valley. The marginal basins in these areas exhibit a geologic evolution in which continental sedimentation started in Aptian/Albian times, but the first marine invasion occurred only in the Campanian. Intense magmatic activity, as evidenced by the Cabo igneous suite in Pernambuco and the volcanic massifs of Nigeria and Cameroon, has been described from along this segment of the continental margins. Almeida (1968) has called attention to the similarities of these magmatic rocks on both continents, although Burke and Wilson (1976) pointed out that the magmatic centers are aligned, but were not emplaced successively.

SIMILARITIES IN THE TECTONIC EVOLUTION OF SOUTH AMERICA AND AFRICA DURING AND AFTER THE ONSET OF DRIFTING

The final cratonization of the Brasiliano/Pan-African Cycle occurred about 450 m.y. ago, near the Ordovician—Silurian boundary, with the vanishing of the last post-orogenic tectonic and volcanic pulses. After this event, magmatic activity was practically absent in eastern South America and western Africa until the end of the Paleozoic.

The first intense episode of basaltic volcanism affecting the Afro-Brazilian territory occurred in the Permo-Triassic and was associated with the opening of the North Atlantic Ocean and the separation of North America from South America and Africa (which remained joined together: Thomaz et al., 1974). The Early Jurassic ages of basaltic rocks at the western border of the Parnaiba Basin of northern Brazil and the synchronous doleritic dykes of Liberia seem to confirm the observations of May (1971) regarding the formation of the North Atlantic. Some tectonomagmatic activities in the Early Triassic were also discovered in Angola (a basalt from Novo Redondo dated at 222 ± 16 m.y. by Torquato and Amaral, 1973) and in Uruguay (a basalt from Montevideo dated 211 ± 6 m.y. as reported by Minioli et al., 1971).

Preceding the formation of the South Atlantic rift, a linear uplift on both continents in a region parallel to the present coastline must have occurred, followed by the formation of graben and horst structures (Douglas et al., 1973). At that time, another major tectonic structure stretched from South America into Africa, the so-called "Moçamedes—Ponta Grossa Geotumor" of Torquato (1974), comprising the Ponta Grossa arch in Paraná, Brazil and the matching Moçamedes arch in Angola.

Although the oldest basaltic rocks are Triassic, it was only at the end of the Jurassic that the present coastlines began to be defined, with the formation of the already-mentioned Afro-Brazilian depression (Northfleet et al., 1972). At the same time, intense tectonic activity affected Africa and South America (the "Wealdian Reactivation" of Almeida, 1967).

The paroxysm of this tectonic episode occurred about 120—130 m.y. ago, when an immense volume of basaltic magma was extruded into the Paraná Basin to make up the Serra Geral Formation, (Cordani and Vandoros, 1967). At the same time, basaltic volcanism affected the eastern part of the Parnaiba Basin, and great dikes with E—W trends cut through the basement rocks of northeast Brazil (Cordani, 1970). The Early Cretaceous age of the Serra Geral basalts denies their supposed correlation with the Stormberg lavas of Triassic—Jurassic age of the Karroo Basin. A much more adequate correlation was made when Siedner and Miller (1968) dated the basaltic lavas and dolerites of the Kaokoveldt region, revealing ages of the same order as the Serra Geral basalts.

Later on, the intensity of the magmatic activity decreased with time in both South America and Africa, as continental drift proceeded and the magmatic foci were displaced towards the mid-Atlantic Ridge. In eastern South America, this phenomenon is clearly indicated (Cordani, 1970).

In the equatorial Atlantic, the fabric of the ocean floor allows further correlation among structural features, as shown in the work by Gorini and Bryan (1975) (Fig. 6). They studied the main fracture zones of the oceanic region and verified that these can be traced continuously from one continent to the other, dividing both coasts into sectors which are completely comparable. On both continents, these sectors contain marginal basins which developed independently of one another. The sedimentary basins representing the extensions of fracture zones are grabens (the Barreirinhas and offshore Ghana basins), while those located between fracture zones are half-graben structures (the Dahomey and Ceará basins).

Finally, the radiometric dates available for the volcanic islands of the South Atlantic are all younger than 18 m.y. (Cordani, 1970; Baker, 1973); this is completely compatible with a recent origin for the South Atlantic floor as required by the theory of sea-floor spreading and continental drift. As a model for the origin and development of the South Atlantic, we refer to the one proposed by Nairn and Stehli (1973), in which all geologic and geophysical evidence was taken into account.

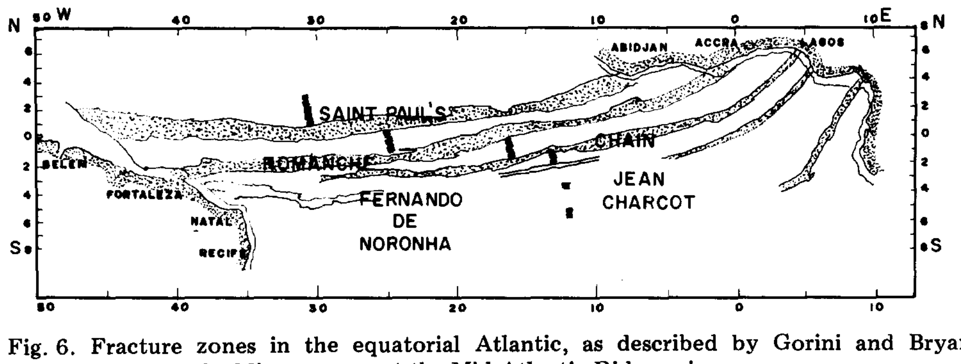


Fig. 6. Fracture zones in the equatorial Atlantic, as described by Gorini and Bryan (1975). Heavy dashed lines represent the Mid-Atlantic Ridge axis.

CONCLUSIONS

The Late Precambrian thermotectonic episodes related to the Brasiliano/ Pan-African cycles were very important in the formation and stabilization of the crust in the supercontinent of Gondwana (Dietz, 1972). However, all the

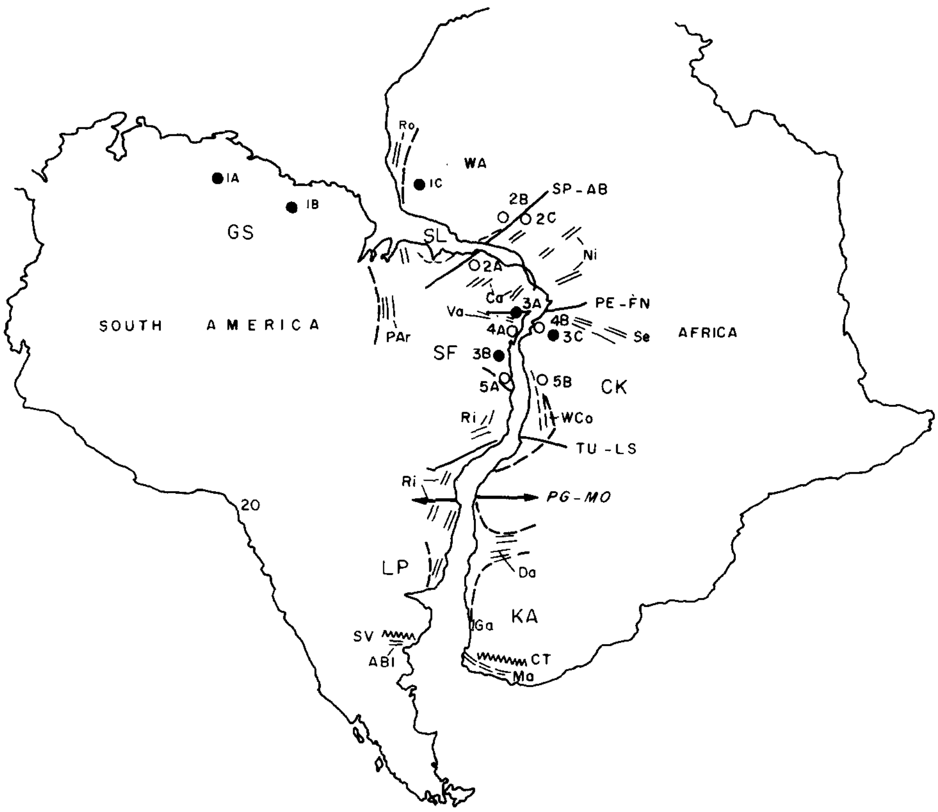


Fig. 7. Summary of the main Brazil—Africa geological links. Legend: *1A* = Imataca Complex; *1B* = Fallawatra Complex; *1C* = Liberian province; *2A* = Jaibaras Basin; *2B* = Voltaian Group; *2C* = Buem and Togo Formations; *3A* = Pernambuco—Alagos Massif; *3B* = Jequié Complex, *3C* = Chaillu massif; *4A* = Estancia Group; *4B* = Noya Series; *5A* = Rio Pardo Group; *5B* = Schisto-calcaire and Schisto-greseuse Series: *GS* = Guayana Shield; *SL* = São Luis cratonic area; *WA* = West African Craton; *SF* = São Francisco Craton; *CK* = Congo-Kasai Craton; *LP* = Rio de La Plata cratonic area; *KA* = Kalahari Craton; *PAr* = Paraguay—Araguaia Belt; *Ro* = Rockelide Belt; *Ca* = Caririan Fold Belt (Borborema Province); *Ni* = Pan African Province of Nigeria and Cameroon; *Va* = Vasa Barris Group; *Se* = Semba—Ouesso Series; *Ri* = Ribeira Belt; *WCo* = West Congo Belt; *Da* = Damara Belt; *ABl* = Aguas Blancas Formation; *Ma* = Malmesmury Group; *Ga* = Gariep Group; *SP—AB* = Sobral Pedro II and Alibory-Bifur lineaments; *PE—FN* = Pernambuco and Foumbam—Ngaurandere lineaments; *TU—LS* = Taxaquara—Ubatuba and Luanda—Salazar lineaments; *PG—MO* = Ponto Grossa—Moçamedes Geotumor; *SV—CT* = Sierra de La Ventana—Capetown Fold Belts.

Late Precambrian belts show clear evidence of their ensialic character. Almeida et al. (1973) stated that there are no indications for continental accretion encroaching on an old oceanic basin, which would have existed in the place now occupied by the South Atlantic Ocean. In addition, the paper by Piper et al. (1973), based on paleomagnetic data, suggests a relative stability for some of the major cratonic regions of Africa during a large part of the Precambrian (at least since 2000 m.y.). Unquestionable evidence for large-scale horizontal movements prior to the Mesozoic episode of continental drift is available at present.

The initial rifting in the South Atlantic, after which the separation of Brazil—Africa started, shows evident structural control since the present coastlines are roughly parallel to the basement structural trends. This is not the case for the equatorial Atlantic in which the coasts of South America and Africa are oblique to the basement structures.

Fig. 7 summarizes the main correlations discussed in this paper. It is evident that the geological links between Brazil and Africa are numerous, and strongly support the idea of a previous connection of these continental masses. When a working hypothesis withstands decades of debate and hundreds of tests especially conceived to prove or disprove it, and when, moreover, after progressively detailed studies these comparative tests turn out positively, then the convergence of evidence makes the theory highly acceptable, and probable. Eventually a limit is reached, beyond which the hypothesis should be virtually considered as fact. The links between Brazil and Africa are numerous, at all geological scales, from local to continental, and in general are very clear. This pattern can no longer be attributed to simple coincidence.

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