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Test of Continental Drift by Comparison of Radiometric Ages

A pre-drift reconstruction shows matching geologic age provinces in West Africa and Northern Brazil.

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A collaborative program of radiometric age determination has been started between geochronology laboratories at the University of São Paulo and the Massachusetts Institute of Technology. This article is a progress report on two investigations which were presented separately at the meetings of the Geological Society of America in November 1966 (*1*). Many individuals and institutions in several countries (*2*) are assisting in the collection of samples and geological field work. Detailed reports covering the different regions will be published separately.

West Africa is divided dominantly into two major age provinces, with potassium-argon and rubidium-strontium age determinations generally in the range 2000 million years in Ghana, the Ivory Coast, and regions to the west and in the range 550 million years in the eastern part of Dahomey, Nigeria, and regions to the east. The sharp boundary between these provinces appears to head southwestward from a point near Accra (Fig. 1) and, had Africa and South America been together at the time the boundary was formed, would have entered Brazil just east of São Luis on the north coast. The first objective of our investigation was, therefore, to look for this age boundary near São Luis and, if it were found, to see whether the age provinces on either side of it matched those in West Africa. About 150 age analyses made to date show that these three correlations exist, giving evidence in support of the hypothesis that the continents were at one time joined together.

Analytical Results and Discussion of Precambrian Geochronology

It was planned that both potassium-argon and whole-rock rubidium-strontium age measurements should be made on the same samples, where possible, in order to provide added information on the history of the basement rocks. The potassium-argon analyses were carried out in the São Paulo laboratory (*3*) recently established under the guidance of J. H. Reynolds, and were restricted to Brazilian samples. The whole-rock rubidium-strontium analyses were carried out in the M.I.T. laboratory on samples from Africa and from Brazil and other South American countries (*4*). In metamorphic terrains it is generally not feasible to use the isochron method of determining an initial Sr^{87}/Sr^{86} ratio, except in a rough way (*5*). The error in the age equation due to the uncertainty in this ratio is minimized by selecting the few samples with highest rubidium-strontium ratios from a much larger collection of samples taken in the field. In some instances—for example, in the case of basement drill-core samples—this is not possible, and we have resorted to presentation of the data as plots rather than as actual age values. Only by plotting numerous samples in the manner suggested by Nicolaysen (*6*) can an age estimate be made and evaluated in such cases. In general, the rubidium-strontium age determinations on whole rock are somewhat greater than the potassium-argon determinations on mica, a difference representing roughly the spread between the time of closure of the rock system as a whole to migrations of components and the time of closure of the mineral systems within the rock. Both values may be used in geological correlations of the kind attempted here, with the understanding that the age values obtained by the two methods will not be the same, and that the difference is an important added source of information.

Geological and geochronological studies in Brazil and West Africa are widely reported in the literature (see *7–12*). Age data are presented in Figs. 1 and 2, wherein the continents are shown fitted together according to the reconstruction of Bullard *et al.* (*13*).

The West African (Guinean) shield is dominated by two periods of orogenic activity which have resulted in pervasive new or overprinted age values in the two major groupings: 2000(±) and 550(±) million years. The first of these periods was discovered by Bonhomme (*9*), who gave the name Eburnean to the orogeny, which was based on age measurements made in Ghana and the Ivory Coast Republic.

The Massachusetts Institute of Technology, Cambridge, and the University of São Paulo, São Paulo, Brazil, collaborated in the study described in this article. Drs. Hurley, Rand, Pinson, and Fairbairn are affiliated with the Massachusetts Institute of Technology; Drs. de Almeida, Melcher, Cordani, Kawashita, and Vandoros, with the University of São Paulo.

Most of Bonhomme's measurements were made on separated micas, but a few whole-rock rubidium-strontium measurements, together with subsequent analyses by Vachette (*11*), substantiated the primary nature of the orogenic activity. Locally, ages in the 2900-million-year range are sometimes found, particularly in Liberia and regions to the west, and these may represent an earlier orogeny.

The second age group, 550(±) million years, was developed in Nigeria and neighboring territories, in part through the investigations of N. J. Snelling and others of the British Overseas Surveys and in part by various other geochronologists. It has been found that this period of metamorphism and orogenesis has affected a large part of the entire continent of Africa, and it is now known as the Pan-African Orogenic Cycle (*12*). The rather sharp boundary between these age provinces coincides with the overthrust zone extending from southeast Ghana northeastward through Togo, Dahomey, and Upper Volta (Fig. 1, heavy dashed line).

The results of age determinations for West Africa are summarized schematically in Fig. 1. The compilation includes all of the rubidium-strontium and potassium-argon measurements we have been able to find in the literature, plus about 30 new whole-rock rubidium-strontium measurements from the M.I.T. laboratory.

The Guayana Shield of northern South America has been partially mapped and dated in Venezuela and parts of the Guianas. Its possible extension into Brazil is suggested by the new age measurements. The north-central part of the Guayana Shield in Venezuela is generally underlain by an east-northeast-striking belt of gneisses (*14*) known as the Imataca Complex. Younger and lower-grade meta-

Fig. 2. (right). Age measurements for Africa made by Bonhomme (*9*), Vachette (*11*), and others (*7*) and including new age values reported in this article; the rubidium-strontium determinations were recalculated on the basis of $Rb^{87}\lambda = 1.39 \times 10^{-11}$/yr. The values for Brazil are ages determined in the study discussed. The dashed lines are structural trends; the solid lines (except for continental margins) are geologic boundaries either taken from the literature (*7–10*) or unpublished (see *2*). Dating techniques: (●) rubidium-strontium, whole rock; (○) rubidium-strontium, mineral; (×) potassium-argon; (+) other. Minerals: (*W*) whole rock; (*b*) biotite; (*m*) muscovite; (*l*) lepidolite; (*f*) potassium-feldspar; (*h*) hornblende; (*na*) sodium amphibole.

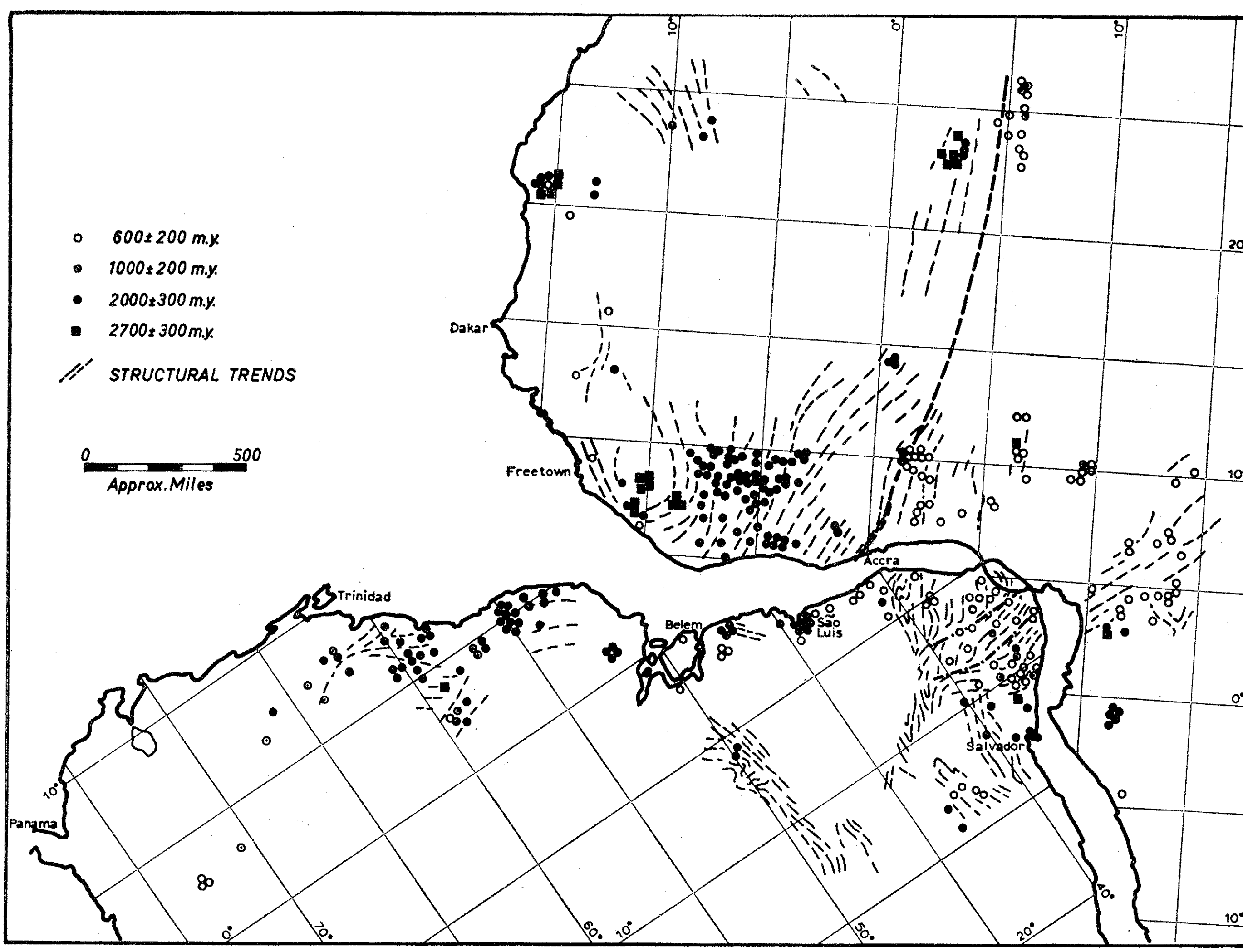
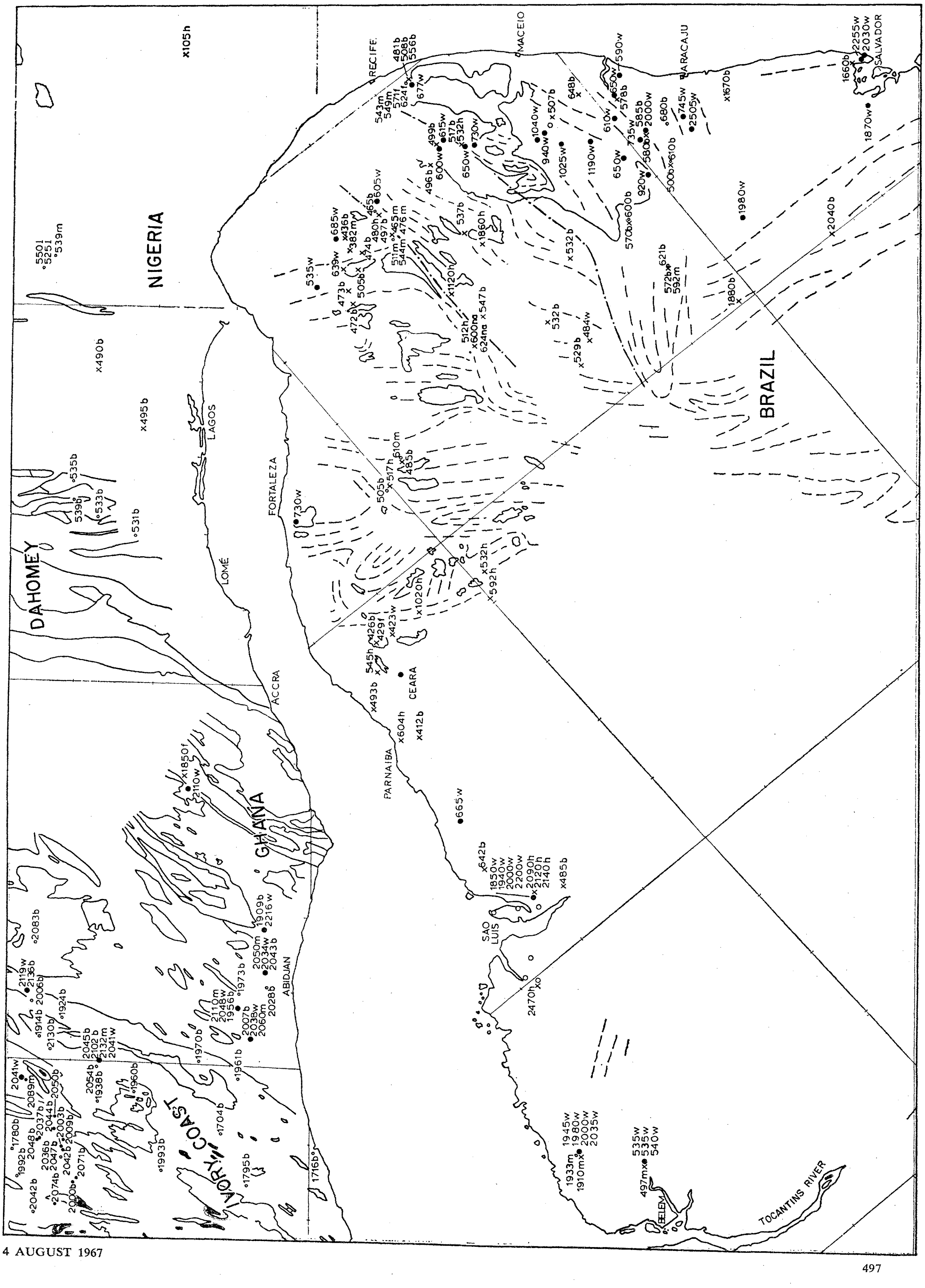


Fig. 1. West Africa and South America shown fitted together according to the reconstruction of Bullard *et al.* (*13*). In West Africa the 2000-million-year Eburnean age province (solid circles) adjoins the 550-million-year Pan-African age province (open circles); the boundary between them is shown by the heavy dashed line. If Africa and South America were once joined together, this line would have entered Brazil near São Luis. The age measurements for Brazil appear to show the same age provinces as those in West Africa, with the boundary at the predicted location. There may be a similar correlation between West Africa and the east coast of Brazil north of Salvador.


NIGERIA
DAHOMEY
GHANA
IVORY COAST
BRAZIL
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MACEIO
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ABIDJAN
FORTALEZA
CEARA
PARNAIBA
SAO LUIS
BELEM
TOCANTINS RIVER

volcanic and metasedimentary rock assemblages are believed to be stratigraphically between the overlying Roraima formation and the Imataca basement. The Roraima has been dated by McDougall *et al.* (*15*) by the potassium-argon method, with results in the range 1.6 to 2.1 billion years. An intrusive granite in the Imataca has been dated in the M.I.T. laboratory by V. G. Posadas; a good isochron plot of rubidium-strontium whole-rock measurements gave an age of 2150 million years. These ages are matched by a similar range reported for the Guianas by McConnell *et al.* (*16*), Choubert (*17*), and Priem *et al.* (*18*). Thus it would appear that the pervasive orogenic activity in the Guayana Shield near the northeast coast of South America is within the general age range of the Eburnean orogenic period in West Africa. The greater ages in western Liberia are matched by the greater age of the Imataca Complex (3000 million years) (*19*) in the northwestern Guayana Shield.

Figure 2 shows age measurements made to date from northern Brazil, except for a few measurements made for regions just off the lower left corner of the map. The locations of these are shown in Fig. 1. Samples from northwest of the mouth of the Amazon River gave an average age of 2200 million years (rubidium-strontium whole-rock analysis) and 1750 (potassium-argon analysis). Southward from Belém the ages are found to be close to 2000 million years by both methods. These first few determinations on rocks from this large basement area show that this part at least was not affected by the events of 450 to 650 million years ago which occurred so broadly in the northeastern part of Brazil.

Near the coast, between Belém and São Luis, the rocks have yielded ages of around 2000 million years by both methods. The potassium-argon value of 2470 million years is subject to a large experimental error. Whole-rock rubidium-strontium data for rocks in this older range are shown in Fig. 3.

To the south of this old area, at a locality east of Belém, both potassium-argon analysis on mica and rubidium-strontium whole-rock analysis give ages of about 500 million years. The locality may be in the younger age province to the east, or it may be affected by some intrusive activity connected with that province.

Of particular interest is the area near the town of São Luis. A sampling program in this region was initiated solely because the region was on what would be the direct extension of the age boundary between the 2000-million-year and the 550-million-year age provinces of West Africa if the two continents were fitted together. It was interesting to find that the same age boundary appears at almost exactly the predicted location. The age data from the basement exposure just south of São Luis are shown in Figs. 2 and 3. The effect of the boundary is clear: potassium-argon age determinations are in the range 410 to 640 million years, and whole-rock rubidium-strontium determinations are still in the 2000-million-year range. Slightly further to the east, the whole-rock age also has dropped to 665 million years.

In Fig. 3 are also plotted a group of whole-rock measurements, made in

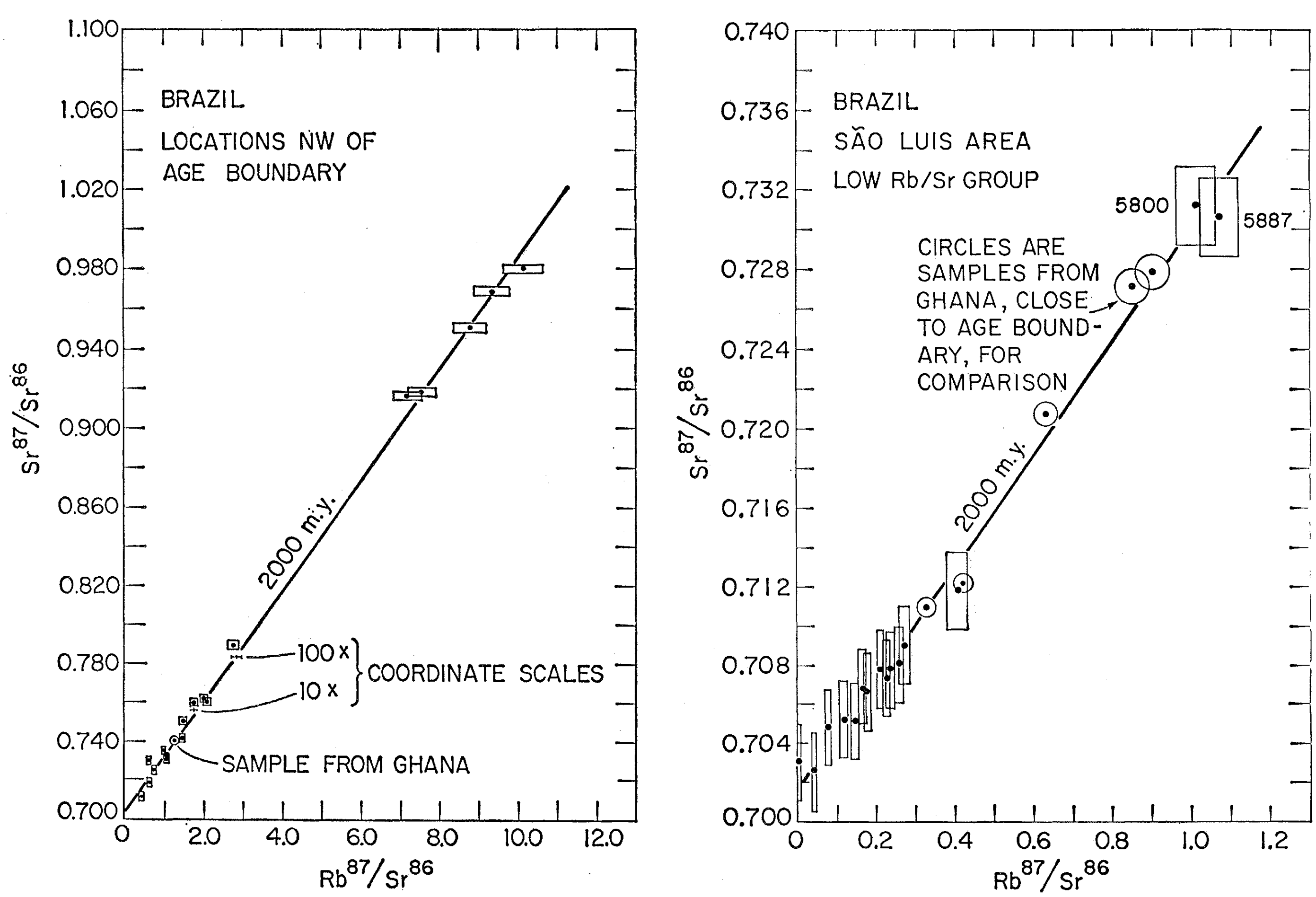

Fig. 3. Data from rubidium-strontium whole-rock analyses plotted relative to 2000-million-year isochrons in the São Luis area and to the west in Brazil. $Rb^{87}\lambda = 1.39 \times 10^{-11}$/yr. The points marked 10 × and 100 × were rubidium-rich samples for which values for the Rb^{87} and radiogenic Sr^{87} were divided by 10 and 100, respectively, to bring them onto the scale of the figure.

the M.I.T. laboratory by P. Kolbe (*20*), on South American metamorphic rocks from an area that would be almost exactly opposite the area next to the age boundary in Ghana if the two continents were fitted together. The correspondence in the whole-rock rubidium-strontium age determinations is evident.

The extensiveness of the orogenic event of 2000 million years ago in South America is noteworthy. Evidence of its effects are found in the Guayana Shield, in the coastal region northwest of São Luis and Belém, and to the southwest near the Tocantins River and, in addition, in the São Francisco Craton north of Salvador on the east coast and, as reported by Hart (*21*), in northeastern Argentina and southern Uruguay. This event thus appears to have affected much of the eastern half of the continent—an area extending as far south of the Amazon as it extends to the north. In view of the wide extension of this age province in South America, we propose, to the many geologists who have found the orogeny locally and given it local names, that a new name be adopted—the Trans-Amazonian Orogenic Cycle.

Eastward from São Luis to the east coast, the basement rocks show ages typical of the younger Caririan Orogeny, as seen in Fig. 2. The age distribution is similar to that found in the Pan-African Orogenic Cycle in Nigeria. In general the potassium-argon determinations on separated minerals range from 400 to 600 million years. The rubidium-strontium whole-rock determinations tend to be slightly higher, averaging 640 million years, as seen in Fig. 4. In Fig. 4, also, are plotted (circles) the whole-rock rubidium-strontium measurements made on samples from the Pan-African Orogenic Cycle in Nigeria, which follow a similar 640-million-year isochron. The potassium-argon values for these Nigerian samples averaged close to 500 million years (as determined by N. J. Snelling). Thus there appears to be an almost exact correspondence in the two age groupings (500 million years for potassium-argon and 640 million years for whole-rock rubidium-strontium) for the Caririan and the Pan-African orogenies in these two locations which are opposite each other at the point of the hypothesized juncture.

Age measurements of samples from Maceió south to Salvador (Fig. 2) show that the activity of the Caririan Orogeny fades off, leaving ancient gneissic basement exposures of 2000-million-year age overlain or intruded by rocks which give various age values down to 500 million years. At the corresponding location on the African side there is a similar transition from the 500-million-year-old rocks in Nigeria-Cameroun to the 2000-million-year-old rocks of the Congo Craton in Gabon (*10*). Thus there is the possibility of another correlation between the continents in this region (*22*).

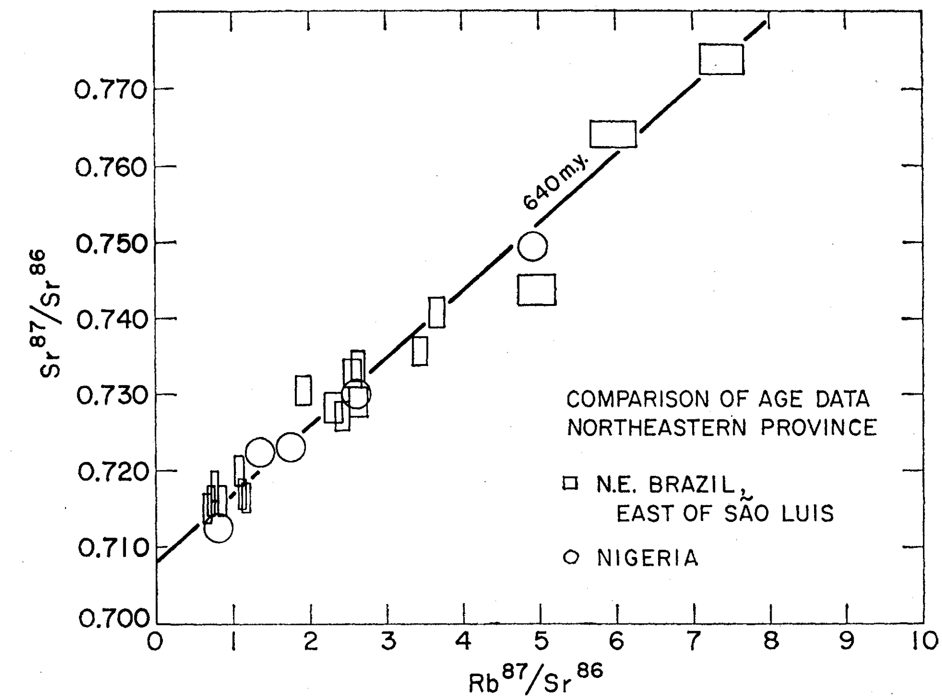

Fig. 4. Caririan Orogeny in Brazil, to the east of São Luis, showing data from rubidium-strontium whole-rock analyses relative to the 640-million-year isochron. Data for samples from a comparable region in Nigeria representing the Pan-African Orogenic Cycle are indicated by circles, for comparison.

Summary and Conclusions

1) The distribution of age values obtained by potassium-argon determinations and whole-rock rubidium-strontium determinations appears to be almost identical for West African rocks of the pervasive Eburnean Orogenic Cycle and basement rocks at opposite locations in South America.

2) There is also a close correlation, with respect to potassium-argon age determinations on micas, rubidium-strontium determinations on total-rock samples, and the extent to which these two sets of values differ, between rocks of the Pan-African Orogenic Cycle and rocks of the Caririan Orogenic Cycle in Brazil, where these two groups of rocks lie opposite each other in the two continents.

3) When Africa and South America are "fitted together," the sharply defined boundary between the Eburnean and the Pan-African age provinces in West Africa strikes directly toward the corresponding age boundary in northeast Brazil.

4) The transition from the 550-million-year Pan-African age province to the 2000-million-year age province in the Congo Craton in Cameroun-Gabon is matched in the rocks near the corresponding part of the east coast of Brazil. However the geological and age data are insufficient to do more than suggest the possibility of another age-boundary correlation here.

5) The evidence reported here supports the hypothesis of continental drift.

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2. During the field and laboratory work connected with this investigation we received generous help from many persons and institutions, whom we wish to thank. In Brazil, samples from several localities were made available by Professor Octavio Barbosa, by geologists Gilberto Amaral, Arlindo Calux, Eduardo C. Damasceno, and Helmut Born, and by the Brazilian Petroleum Company PETROBRAS. The Brazilian Geological Survey and the U.S. AID Agency in Brazil provided facilities for a sampling trip in Bahia. Professor Sylvio Queiroz Mattoso from Bahia and geologists Francisco Baptista Duarte and Antonio L. S. de Almeida from the Brazilian Geological Survey kindly accompanied one of us (G.C.M.) on this

trip. The SUDENE (Superintendência do Desenvolvimento do Nordeste) organization at Recife also aided in the collection of samples. The unpublished results of age determinations made by Professor John H. Reynolds, Professor Homero Lenz Cesar, and geologist Gerhard O. Schrader on rocks from Ceará are cited in this article. Geologist Luciano Isotta gave valuable help in preparing the report of the Brazilian work. Those who have collaborated in the broader program include G. W. Leo and M. G. White of the U.S. Geological Survey AID Missions to Liberia and Brazil, respectively; G. O. Allard and V. J. Hurst (both of the University of Georgia) and F. L. Humphrey, who are mapping and correlating stratigraphy and structure between Brazil and Gabon in the region of the Sergipe geosyncline near the east coast of Brazil; N. J. Snelling of the University of Oxford and the British Overseas Surveys, who has been long engaged in age determination in West Africa and Guiana; F. W. Wright, Jr., Orinoco Mining Company, Venezuela; and J. Kalliokoski, Princeton. Literature and maps were kindly supplied by the Biblioteca, Departmento Nacional da Produção Minerals, Rio de Janeiro, Brazil.

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4. The strontium- and rubidium-isotope age determinations at M.I.T. were made with a mass spectrometer of 12-inch radius, with expanded scale recording. The Sr^{87}/Sr^{86} ratios were normalized on the basis of $Sr^{86}/Sr^{88} = 0.1194$. The instrument gave an average value of 0.7078 for the ratio of Sr^{87}/Sr^{86} in the Eimer and Amend standard sample of $SrCO_3$. The precision is indicated, by replicate analyses, to be roughly 0.0005 standard deviation for a single complete analysis. However, to make ample allowance for sample inhomogeneity and for use of ratios calculated from isotope-dilution analyses, we have plotted all points in Figs. 3 and 4 with an error of $2\sigma = 0.002$ for Sr^{87}/Sr^{86} ratios and $\pm$ 5 percent for Rb/Sr ratios, representing 95 percent confidence limits in both cases. Age values were calculated on the basis of $Rb^{87}\lambda = 1.39 \times 10^{-11}$/yr, and for consistency, data from the literature were recalculated on the basis of this decay constant.
5. The range of Sr^{87}/Sr^{86} ratios for common (initial) strontium in metamorphic rocks is not yet known with certainty, but it appears to be higher than that for igneous rocks and probably approaches the value for seawater. We have therefore used values of 0.705 and 0.707 for the ratios for Middle Precambrian and Late Precambrian metamorphic rock, respectively, on the basis of a value of 0.709 for modern seawater. To offset this uncertainty in cases with a low Sr^{87}/Sr^{86} value, we have presented the data as plots in the figures, instead of actual age values, so that the reader can judge the age value of the samples as a group.
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23. The geochronology program at the University of São Paulo was initiated in part through the generous aid of J. H. Reynolds of the University of California and was supported by a grant from the National Science Foundation. The investigations at M.I.T. and some of the field expenses were supported by the U.S. Atomic Energy Commission [under contract At(30-1)-1381 to P. M. Hurley].