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**PROYECTO INTERNACIONAL DEL MANTO SUPERIOR
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BUENOS AIRES, ARGENTINA, 26-31 DE OCTUBRE DE 1970

VOLUMEN II

**SIMPOSIO SOBRE LOS RESULTADOS DE
INVESTIGACIONES DEL MANTO SUPERIOR
CON ENFASIS EN AMERICA LATINA**

**SYMPOSIUM ON THE RESULTS
OF UPPER MANTLE INVESTIGATIONS
WITH EMPHASIS ON LATIN AMERICA**



Proyecto Internacional del Manto Superior
International Upper Mantle Project

Informe Científico N° 37 - II
Scientific Report N° 37 - II

- 1) The main phase of the Jacupiranga intrusion is remarkably synchronous with the main phase of the basaltic activity of the Paraná Basin, dated as being 125-130 m.y. old. This strongly suggests that upper mantle processes originated at the same time basaltic activity in the central portion of the basin and alkalic-ultrabasic activity around its borders, as indicated by potassium-argon age measurements for the Anitápolis, Serrote, Ipanema and Piedade Districts (AMARAL et al., 1967) and for Jacupiranga in this paper.
- 2) The histogram for the ages is strongly asymmetrical, with a large "tail" in direction to higher values. A careful study on the samples that yielded those higher ages indicates that most of them belong to fenites, originated by metasomatic effects on the enclosing rocks (which are 500 m.y. old). The processes of fenitization were not sufficiently strong to destroy the potassium-argon system of the enclosing rocks, leaving "inherited" radiogenic argon in minerals of the resulting fenites. Due to difficulties in distinguishing highly developed fenites from true alkalic rocks it was not possible to correlate rock type with stage of intrusion, the only exception being the carbonatites which are 130 ± 5 m.y. old, as indicated by K-Ar, Rb-Sr and fissiontrack determinations on phlogopites.

THE PRECAMBRIAN EVOLUTION OF SOUTH AMERICA

by

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GILBERTO AMARAL¹

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ABSTRACT

A general synthesis of the Precambrian evolution of South America has been made with the aid of about 1500 radiometric age determinations. In figure 1, the position of the Late Precambrian orogenic belts, as well as their platforms, is tentatively outlined.

The largest ancient core of the continent includes the Guyana Shield, the basement of the Amazon sedimentary basin, and the Guaporé craton to the south, covering an area of about 4.5 million square kilometers. Most of the rocks were affected by the Trans-Amazonian orogenic cycle, whose radiometric ages are close to 2000 m.y. The São Francisco craton of similar age crops out over an area of about one million square kilometers, in eastern Brazil. Smaller ancient nuclei, also reflecting the events of the Trans-Amazonian cycle, were found near the Atlantic coast, east of the mouth of the Amazon river (São Luis cratonic area), and surrounding the Río de la Plata (Río de la Plata cratonic area).

The old cratonic areas are separated from each other by metamorphic belts which belong to the Brazilian orogenic cycle of Late Precambrian age. The Caririan belt and the Sergipe geosyncline occur at the northeastern corner of Brazil, and the Paraíba belt along the Atlantic coast, to the south. Two symmetrical geosynclinal units were recognized in the central part of the continent: the Brasília and the Paraguay-Araguaia belts.

Within the areas of the Brazilian orogenic belts in many places Trans-Amazonian or even older ages occur, indicating a remobilized ancient basement. This seems to demonstrate that the sialic crust of the South American continent, 2000 m. y. ago, already exhibited an areal extent of more than 10 million square kilometers.

RESUMEN

Se ha efectuado una síntesis general de la evolución del Precámbrico de América del Sur, con la ayuda de aproximadamente 1500 determinaciones radiométricas de edad. En la figura 1 se indica tentativamente los límites de los cinturones orogénicos, como así también de sus plataformas, en el Precámbrico Superior.

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El mayor núcleo antiguo del continente incluye el Escudo de las Guayanas, el basamento de la cuenca sedimentaria del Amazonas y el cratón de Guaporé, cubriendo un área de aproximadamente 4,5 millones de kilómetros cuadrados. La mayoría de sus rocas fueron afectadas por el ciclo orogénico trans-amazónico, cuyas edades son cercanas a 2.000 m.a. El cratón de San Francisco de edad similar aflora sobre un área de cerca de un millón de kilómetros cuadrados en el sur de Brasil. Núcleos antiguos más pequeños, que también reflejan haber sufrido los eventos del ciclo trans-amazónico, se hallaron cerca de la costa del Atlántico, al Este de la desembocadura del río Amazonas (área cratónica de San Luis) y rodeando al Río de la Plata (área cratónica del Río de la Plata).

Las áreas cratónicas antiguas están separadas entre si por cinturones metamórficos que pertenecen al ciclo orogénico brasiliano de edad precámbrica superior. El cinturón Cariri y el geosinclinal Sergipe afloran en el Noreste de Brasil y el cinturón Paraíba a lo largo de la costa del Atlántico, hacia el Sur. Dos unidades geosinclinales simétricas fueron reconocidas en la parte central del continente: los cinturones de Brasília y de Paraguay-Araguaia.

Dentro de las áreas del cinturón orogénico brasiliano aparecen edades del ciclo trans-amazónico y aún más antiguas, indicando una removilización del basamento más antiguo. Esto parece demostrar que la corteza silílica del continente sudamericano, 2.000 m. a. atrás, se extendía sobre una superficie de más de 10 millones de kilómetros cuadrados.

Introduction

The number of age determinations obtained so far on Precambrian rocks of South America is small. In a crude estimate, about 1500 radiometric dates are available, most of them by the potassium-argon method. Moreover, for large regions, like the Amazon region, the data are restricted to isolated determinations made as preliminary reconnaissances. Areas studied geochronologically in some detail, by different methods, are rare. However, the existing radiometric ages, together with the recent continued progress in geological mapping, already permit the outline of the major Precambrian structures and age provinces, and an attempt to explain the geologic evolution of South America.

Examining the whole of the available radiometric data, not taking into account the dating methods employed, it can be seen that most of them will be included in two principal age intervals. The older, with age values between 1800 and 2200 m.y., is related to what was called the Trans-Amazonian orogenic cycle (HURLEY *et al.*, 1967, CORDANI *et al.*, 1968). The younger, with results between 450 and 700 m.y., is related to the Brazilian orogenic cycle. Events of intermediate age, specially those in the 900 - 1400 m.y. age range, can sometimes be recognized in restricted areas. Events older than 2200 m.y. were also found, sporadically.

Due to the great importance of the Late Precambrian orogenic event in South America, figure 1 was drawn to show the geotectonic situation in Late Precambrian times. It brings the approximate positions of the orogenic belts of this age (the Brazilian belts), and their platforms.¹ It shows, in addition,

¹ In this article, the term "platform" is employed in the meaning of PEYVE and SINITSYN (1950), corresponding to a cratonic region of silic structure.

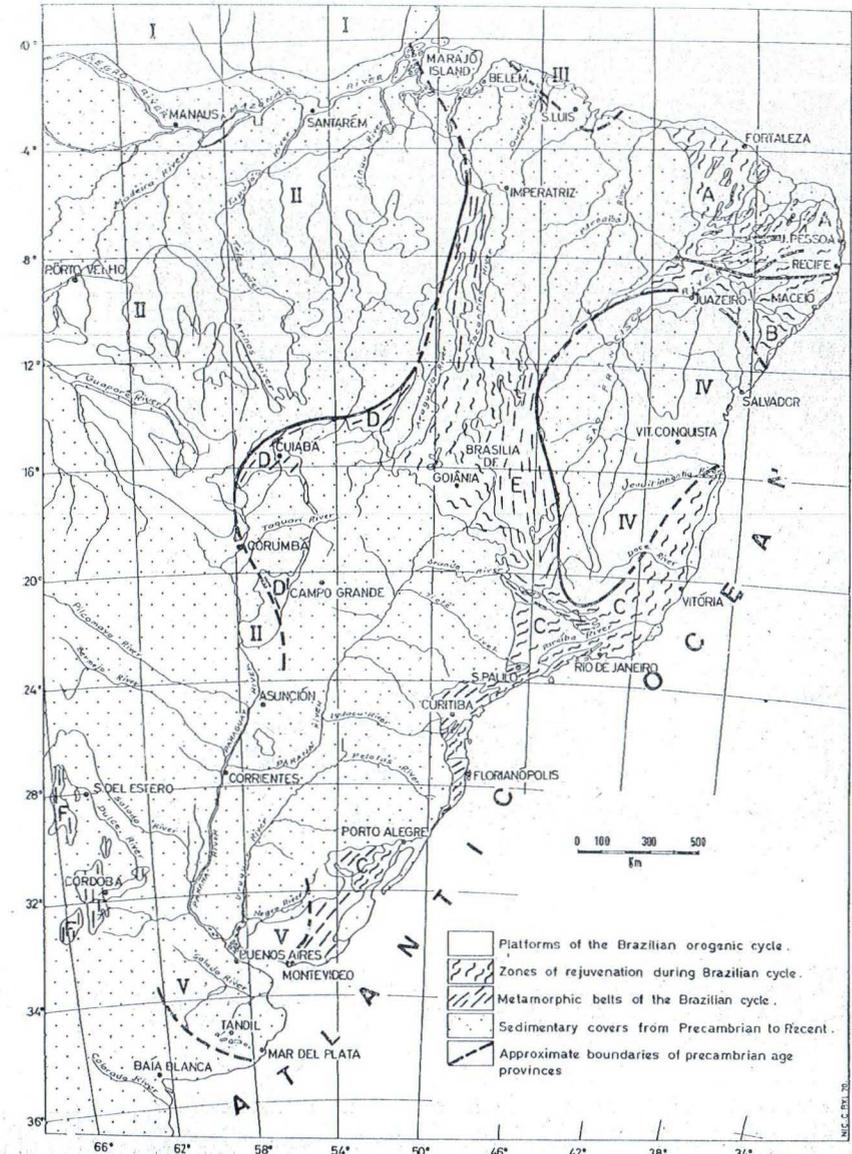


Fig. 1: Tentative outline of the main geotectonic units of eastern South America in Late Precambrian times.

- | | | | |
|------------|-----------------------------------|-----------------|------------------------------|
| Platforms: | I — Guyana Shield | Orogenic belts: | A — Caririan belt |
| | II — Guaporé cratonic area | | B — Sergipe geosyncline |
| | III — São Luis cratonic area | | C — Paraíba belt |
| | IV — São Francisco craton | | D — Paraguay-Araguaia belt |
| | V — Río de la Plata cratonic area | | E — Brasília belt |
| | | | F — Sierras Pampeanas massif |

the sedimentary platform covers of any age, from Precambrian to Recent. For the areas of the Brazilian belts, two different symbols were employed to distinguish the rocks formed during the Late Precambrian orogeny to those already existing, but rejuvenated at that time. The figure is concerned mainly with the Brazilian territory and adjacent regions, where the work of the São Paulo laboratory was concentrated. It represents the southern and eastern parts of the so called "Brazilian platform" (ALMEIDA, 1967), a large geotectonic unit that comprises the whole of the non-Andean part of South America.

The stable platforms in Late Precambrian times

Looking at figure 1, at least four ancient stable nuclei can be recognized:

- 1) A very large northern unit, which includes the entire Guyana Shield, the Amazon region, and its southern extension (Guaporé craton).
- 2) The São Francisco craton, in Minas Gerais and Bahia states of Brazil.
- 3) The São Luis cratonic area, in northern Brazil.
- 4) The Río de la Plata cratonic area, in Uruguay and northern Argentina.

The largest ancient core of the South American continent, which covers an area of about 4.5 million square kilometers, includes the Guyanas, part of Colombia and Venezuela, and the northern corner of Brazil. Its northern part has been usually called Guyana Shield, and its southern part was called Guaporé craton by ALMEIDA (1967). Most probably, the basement for the sediments of the Amazon basin also belongs to the same geotectonic unit.

Most of the rocks of this ancient region were affected by the events of the Trans-Amazonian orogenic cycle, and their radiometric ages fall into the 1800-2200 m.y. interval (SNELLING and McCONNELL, 1966; MARTIN-BELLIZIA, 1968; SNELLING and PERRANGÉ, 1969). This orogenic episode, widespread over the Guyana Shield, was called "Akawaian orogeny" by SNELLING and McCONNELL (1966). Older ages were also found, like the 2600 m.y. age of a granitic intrusion into the Iwokrama Formation of Guyana, or the about 3000 m.y. Rb-Sr whole-rock age of the Imataca Complex of Venezuela (POSADAS, 1966).

The large region was covered several times by cratonic sedimentary-volcanic sequences, as the Roraimá Formation (about 1700 m.y.), or the Surumu and Uatumá Groups (about 1200 m.y.). The volcanics of the latter groups, or correlated rocks, cover a very large area, from Rio Branco territory of Brazil in the north, to the Fresco river, over the Guaporé cratonic area, in the south. As drilling indicated, volcanic rocks also covered a substantial part of the basement of the Amazon basin. Some anorogenic granites, associated with tin mineralization, were found in Rondonia, cutting through rocks of the Guaporé craton. In these granitic rocks, radiometric ages of about 950 m.y. were found by PRIEM *et al.* (1966), by various methods.

The São Francisco craton extends over a great part of eastern Brazil, covering an area of about one million square kilometers. Its gneissic and granulitic rocks, in Bahia, exhibit Trans-Amazonian ages around 2000 m.y. (CORDANI *et al.*, 1968). Such apparent ages, obtained by various methods, can be found in all the northern part of the geotectonic unit, from the São Francisco river to the coast, south of Salvador. Younger results were found in a region striking N-S, from the Quadrilátero Ferrífero near Belo Horizonte, up to the central part of Bahia State, along the Espinhaço mountains, which follow approximately the 43° meridian (HERZ *et al.*, 1961; TAVORA *et al.*, 1967). In this area many K-Ar results indicated Late Precambrian events (500 - 600 m.y.), characteristic of the Brazilian orogenic cycle, but other results clustered around 1100 - 1400 m.y. Sediments of Brazilian age are not known in the region, and the Late Precambrian results are interpreted as rejuvenation phenomena accomplished in a tectonically unstable environment in Late Precambrian times. The significance of the 1100 - 1400 m.y. results is still obscure. They might be related to some post-orogenic episodes of the Minas diastrophism, which is well defined geologically in the region of the Quadrilátero Ferrífero, but whose age still remains questionable.

In central Bahia, the São Francisco craton is covered by a Precambrian sedimentary sequence, which includes the clastics of the Lavras Formation, followed by the pelites and the limestones of the Bambuí Formation. The latter can be found also covering a large area to the west of the Espinhaço mountains. Rb-Sr whole rock isochron work on the Bambuí sediments demonstrated an age of around 600 m.y. (AMARAL and KAWASHITA, 1967).

A smaller ancient nucleus is located along the northern coast of Brazil, between Belém and São Luis. Some of its gneissic and amphibolitic rocks were dated by K-Ar and Rb-Sr methods, and exhibited always Trans-Amazonian apparent ages (HURLEY *et al.*, 1967). The last important cratonic area of the Brazilian platform surrounds the Río de la Plata cropping out in the southern part of Uruguay, and being covered by recent sediments in the Buenos Aires province of Argentina. It extends to the south at least until the Sierra del Tandil. Again, the rocks from this ancient region exhibit radiometric ages of about 2000 m.y., by different analytical methods (STIPANICIC y LINARES, 1969).

The importance of the Trans-Amazonian orogenic cycle for the South American continent is unquestionable. Rocks formed during this cycle or affected by it, are found in all the ancient cratons defined so far. In all of them, the geochronological pattern is similar. The Rb-Sr whole rock isochrons indicate frequently age values near 2000 m.y., and initial Sr^{87}/Sr^{86} ratios of about 0.705-0.710. Such characters are interpreted as being typical of syntectonic rocks. K-Ar ages on amphiboles are frequently similar, or a little younger than the Rb-Sr whole rock age values. Finally, the Rb-Sr and K-Ar apparent ages on micas cluster around 1800 m.y., a value which indicates the time of a general stabilization of the ancient regions after the uplift and erosion of the Trans-Amazonian folded belts.

The Late Precambrian orogenic belts

The old cratonic areas outlined in figure 1 are separated from each other by metamorphic belt that were affected by the Brazilian orogenic cycle, in Late Precambrian times. The principal geotectonic units of this cycle can be classified as follows:

- 1) The Caririan folded belt, and the Sergipe geosyncline, in northeastern Brazil.
- 2) The Paraíba belt, along the eastern Atlantic coast of South America.
- 3) The Brasília and the Paraguay-Araguaia belts, in the central part of the continent.

The Caririan folded belt covers the northeastern corner of Brazil, a large area for which more than 100 age determinations are presently available (HURLEY *et al.*, 1967; ALMEIDA *et al.*, 1968). This belt probably extends below the sediments of the Paraíba basin, thus separating the São Luis from the São Francisco cratonic areas. The region comprises epi to mesozonal metamorphic rocks, associated to various types of granitic intrusions. Some of these granites were dated by Rb-Sr whole rock isochron work, with results close to 650 m.y. Other results, by K-Ar or Rb-Sr methods on separated minerals, indicated apparent ages in the 450-650 m.y. range. Some older results, up to typical Trans-Amazonian values, were obtained on rocks of some anticlinoria, where basement rocks are exposed.

To the south of the Caririan belt, along the northern and northeastern borders of the São Francisco craton, a narrow geosynclinal belt occur, with WNW-ESE structural trends. It was called Sergipe geosyncline by ALMEIDA (1967), and it is mainly composed by epizonal metamorphic rocks, associated to granulite intrusions. The radiometric data obtained so far could not yet be conveniently interpreted. Many of them are in the 500-600 age range, thus reflecting events of the Brazilian orogeny. However, some Rb-Sr whole rock determinations seem to indicate older events, of geologic significance, at about 1200-1400 m.y. Moreover, some basement rocks exhibited still older results, up to about 2500 m.y.

The Paraíba orogenic belt occurs along the Atlantic coast of South America, from the southern part of the state of Bahia, as far as Uruguay. Its structural trends are typically parallel to the coast line, and its metamorphic rocks range from greenschist to granulite facies. They are associated to different types of granitic intrusions. From this belt, more than 200 age determinations are available, by various methods. The general geochronological pattern is similar to that of the Caririan belt. However, more intense work by Rb-Sr whole rock isochron method, and by the U-Pb method on zircons (DELHAL *et al.*, 1969), could demonstrate that a great part of this geotectonic unit, on the states of Rio de Janeiro and Minas Gerais, is made up of older rocks, of Trans-Amazo-

nian age, rejuvenated by the Late Precambrian orogeny. On the other hand, sediments belonging to the Brazilian orogeny can be clearly recognized in various places of the Paraíba belt. One of them corresponds to the epizonal metamorphic rocks of the Açungui Group, in the states of São Paulo and Paraná, in southern Brazil (CORDANI and BITTENCOURT, 1967).

The geosynclinal deposits of the Paraguay-Araguaia orogenic belt are exposed for a distance of at least 1600 kilometers, along the border of the Guaporé craton, in western Brazil and in Paraguay (ALMEIDA, 1967). The rocks are epimetamorphic, and some of the few granitic intrusions were dated at about 500 m.y. Along the western border of the São Francisco cratonic area, the epimetamorphic rocks of the Brasília belt occur. Their structural trends are parallel to those of the Paraguay-Araguaia belt, and they exhibit similar Late Precambrian apparent ages. In a general way, the two metamorphic belts are equivalent and symmetrical.

They are separated by a central region in which large basic and ultrabasic intrusions of Alpine type occur. Some of these rocks were dated by the K-Ar method, with results around 1100 m.y., which were interpreted as their age of formation. In the central region, the most common rock types are granites and gneisses, with Late Precambrian K-Ar apparent ages. However, some whole rock Rb-Sr results, as well as some K-Ar ages on amphiboles, indicated much older values, up to about 3000 m.y. (HASUI and ALMEIDA, 1969). A Late Precambrian rejuvenation effect is thus clearly indicated. On the other hand, some of the granitic rocks might actually have formed during the Brazilian orogenic cycle.

Another Late Precambrian metamorphic belt seems to occur to the west of the Rio de la Plata cratonic area, with outcrops in the Sierras Pampeanas of Argentina. In this area, metamorphic rocks of amphibolite facies are intruded by Eopaleozoic granites (STIPANICIC y LINARES, 1969). However, some results indicated Late Precambrian ages for the metasedimentary rocks, which might have been part of an orogenic belt of the Brazilian cycle.

The geochronological data obtained so far, in all of the Brazilian orogenic belts, seem to demonstrate a good synchronism of the orogenic episodes. In all belts, the main metamorphic phase, and the formation of most syntectonic granites, can be identified at about 650 m.y. Such is the value found for many Rb-Sr whole rock isochrons, whose initial Sr^{87}/Sr^{86} vary, in general, from 0.708 to 0.720. Late to post tectonic intrusions, when recognized, exhibited different apparent ages, ranging between 650 and 500 m.y. However, in all the Brazilian belts, it seems that a 540 m.y. post tectonic event is significant and widespread.

The Rb-Sr and the K-Ar mica apparent ages cluster around 450-500 m.y. This indicates the final stages of the consolidation of the entire Brazilian platform, which acted as a stable unit during the Phanerozoic evolution of the

Andean geosyncline. Within all the Brazilian belts, older rocks of granitic character occur, more or less rejuvenated during the Late Precambrian orogeny. They were found essentially in the cores of large anticlinoria, indicating that the basement for the Brazilian geosynclines was of sialic "continental" character.

Summary of the Precambrian evolution of South America

To summarize, most of the Brazilian platform was already consolidated about 1800 m.y. ago, after the events of the Trans-Amazonian orogenic cycle. By this time the continental crust of South America exhibited an areal extent of at least 10 million square kilometers. This is indicated by the basement found in all the Brazilian belt, of granitic character.

It is difficult at this moment to recognize clearly events prior to the widespread Trans-Amazonian orogeny. Some older ages were found occasionally, in restricted areas, mainly by the use of refined geochronological methods. Orogenic events of intermediate age (1100-1400 m.y.) are also poorly characterized, and are anyhow of subordinate areal extent. To this intermediate orogeny possibly belongs the Minas diastrophism, recognized in the Quadrilátero Ferrífero area of Minas Gerais.

Finally, in Late Precambrian times, a large part of South America was affected by the very important Brazilian orogenic cycle. The Brazilian belts, including rocks formed or rejuvenated during this orogeny, cover about 50 % of the territory of Brazil, a total area of more than 4 million square kilometers.

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QUESTIONS AND COMMENTS

DEN TEX, E.: Is the Brazilian event a truly orogenic event, or is it a purely thermal event? Is there a specific geosynclinal facies connected with this event? In many other regions of the world a thermal event of similar age appears to have occurred without an indication of true orogenesis, but related possibly to rifting in the continental crust and upper mantle.

CORDANI, U. G.: The Brazilian cycle is a very important orogenic event for South America. In many places, like the Quadrilátero Ferrífero, or the Espinhaço mountains, it seems to correspond to a regional heating, as you mentioned. However, geosynclinal sediments of Brazilian age can be recognized in all the mentioned belts: the metasediments of the Cuiabá Group for the Paraguay-Araguaia belt, of the Canastra Group for the Brasília belt, of the Açungui Group for the Paraíba belt, etc.

HERZ, N.: Do you have any results from the Serra da Jacobina to suggest that the formations and mineralization is older than 3000 m.y.? Similar rocks and mineralization have this age in the Witwatersrand, South Africa, and Blind River, Canada. Do you have any dates older than 3000 m.y.?

CORDANI, U. G.: The epizonal rocks of the Jacobina Group, in northern Bahia, are a part of the São Francisco craton, and were dated at about 2000 m. y., by the K-Ar method. It seems that these rocks were formed in a Trans-Amazonian geosyncline. Some radiometric ages older than 3000 m.y. were registered in central Bahia, on some metabasites of the Serra de Macaúbas. However, their geological significance is still obscure.