

## THE UPPER PRECAMBRIAN OF SOUTH AMERICA

by  
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### 1. INTRODUCTION

A great deal of stratigraphic, petrographic, structural, tectonic and geochronological data, as well as geological maps have been published in the past decade on the Precambrian in South America. Some synthesis has been made and the most important ones guided the elaboration of the Tectonic Maps of Brazil (Ferreira, 1972) and of South America (in print).

The Upper Precambrian (1) is the best known time interval because its geological

events and units are more easily recognized. The available data on the Middle and Lower Precambrian are still insufficient for an adequate reconstruction of their geological history.

This paper presents an approach of the structural framework and tectonic evolution of the South American Continent during the Precambrian, with emphasis on the Upper Precambrian time interval.

### 2. THE SOUTH AMERICAN PLATFORM (2)

The South American Platform is the ancient platform of South America and occupies the major part of the continent. Its western border was reworked by tecto-orogenic processes of the Andean Chain, and its boundary is covered by sediments. To the north and east, the platform's borders are sub-

merged under the Atlantic Ocean. The Patagonian Platform, consolidated in the Upper Paleozoic, is at the southern limit of the South American Platform. The sedimentary cover over this boundary difficults to trace its exact delineation, but it should be located south of the Sierras Australes and east of the Sierras Trans-

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(1) The division of the Precambrian adopted in South America is the one proposed by Almeida (1971): Upper Precambrian, 570 - 1800 m.y., Middle Precambrian, 1800-2600 m.y. and Lower Precambrian, more than 2600 m.y.

(2) South American Platform (Almeida, 1971) substitutes the name Brazilian Platform (Almeida, 1967).

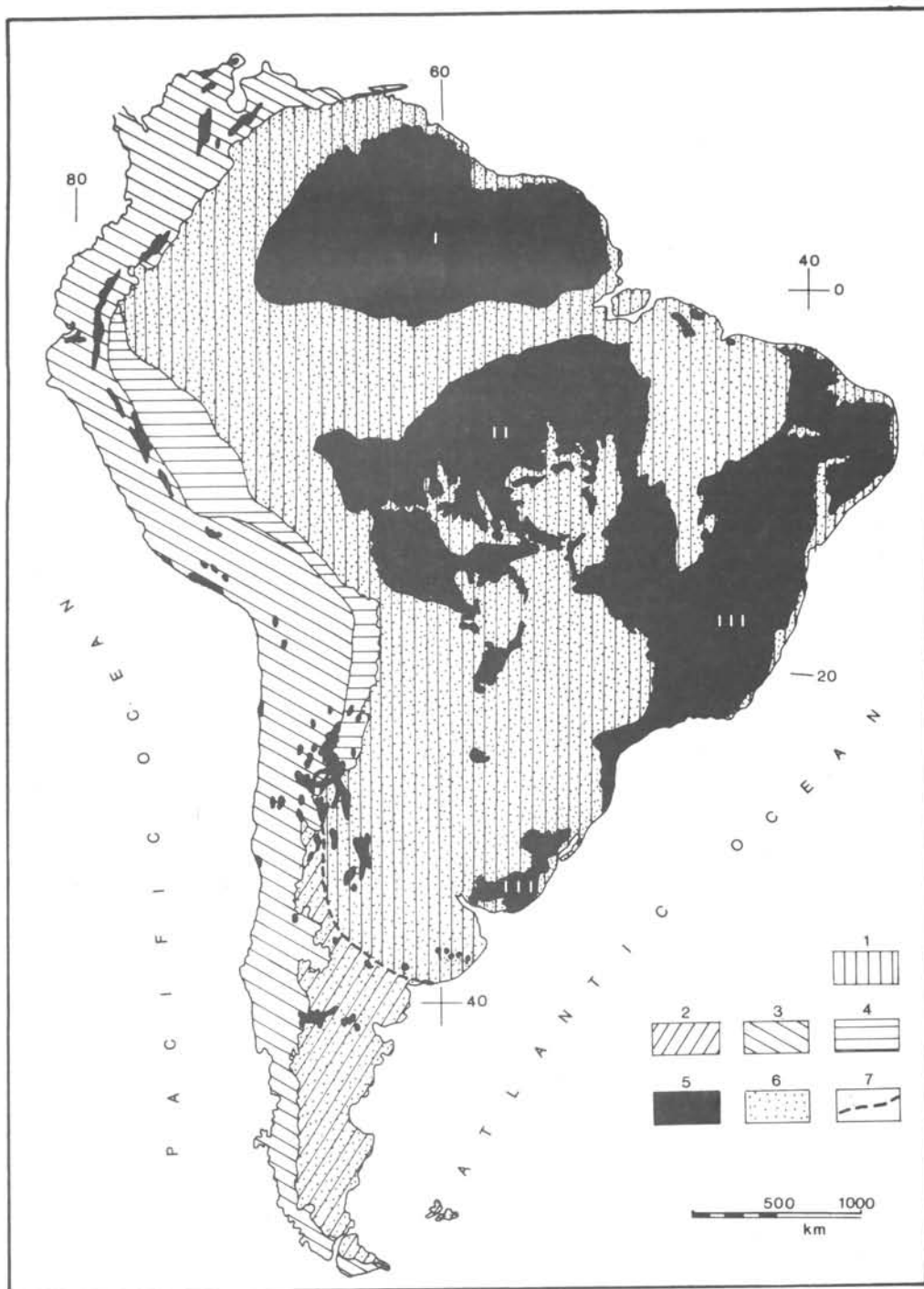


Figure 1 – THE MAJOR GEOTECTONIC UNITS OF SOUTH AMERICA

1 – South American Platform. 2 – Patagonian Platform. 3 – Andean Chain. 4 – Sub-Andean Fore-deep. 5 – Brasiliano and older exposed basement, remobilized in the Patagonian Platform and the Andean Chain; in the South American Platform: Guiana Shield (I), Central Brazil Shield (II), Atlantic Shield (III) 6 – Phanerozoic sedimentary and volcano-sedimentary covers. 7 – Southern limit of the South American Platform.

pampeanas, in Argentina (Fig.1).

The basement of the South American Platform is exposed in various massifs and in three shields. The massifs are found in the north of Argentina, in Eastern Paraguay and the central north of Brazil. The shields are the Guiana, Central Brazil and Atlantic Shields. In the last one is included the exposed area of Uruguay and Southern Brazil (Fig. 1)

The sedimentary or volcano-sedimentary covers were formed during the Silurian-Jurassic in orthoplatformal conditions, and since the Upper Jurassic they were formed during a tectono-magmatic reactivation of the platform. The Cisandean Dalle was formed on the Andean edge of the platform, during the Cenozoic. The evolution during Phanerozoic times of the South American Platform was analysed by Almeida (1969) and will not be discussed here.

In addition to these covers, there are those formed in the Upper Precambrian over the oldest areas.

The South American Platform consolidated as a result of the geosynclinal and tectono-orogenic processes which began ca. 1000 m. y. and ceased between the end of the Precambrian and the Cambro-Ordovician, included in the Brasiliano Cycle (Almeida, 1967)

Fig. 2 shows the major geotectonic units of South America.

The Uruaçu Belt (Fig. 2) presumably developed between 1300 and 1000 m.y. in the Uruaçuano Cycle (3).

The regenerations of the Upper Precambrian saved large areas of the formerly consolidated platform, which acted as the forelands with relation to the geosynclinal belts and regions evolved since then. These cratons (4) are shown in Fig. 2, as well as the fold belts and regions.

The several indicated units will be described in the next chapters.

### 3. THE CRATONIC AREAS AT THE BEGINNING OF UPPER PRECAMBRIAN AND THEIR EVOLUTION IN THIS TIME INTERVAL

#### 3.1. AMAZONIC CRATON

The Amazonic Craton (Amazonic Platform of Suszcynski, 1970) is the largest unit of the South American Platform. Its eastern border touches on the Paraguay-Araguaia Belt and the western border on the Andean Belt. Its basement is exposed on the Guiana Shield as well as on a large part of the Central Brazil Shield, where it was called Guaporé Craton (Almeida, 1964). Fig. 3

The Amazonic Craton is still little known, mainly as a result of the dense forests and deep weathering. Some studies were realized along rivers and in areas of economic interest,

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(3) This cycle was originally called Minas-Uruaçuano by Almeida (1968), but the Minas Supergroup showed to be older than 1300 m.y.

(4) Craton in the used sense means platforms with basement consolidated during pre-Brasiliano times; generally the geosynclinal development finished with the Trans-Amazonic foldings (ca-1800 - 1700 m.y.). This meaning is in accord with that one adopted for the second edition of the Tectonic Map of Europe and adjacent countries (1:2.500.000), as noticed in the Explanatory Note (UNESCO and Academy of Sciences of the USSR, 1973), and for the International Tectonic Map of the World in compilation by the Subcommittee for the Tectonic Map of the World.

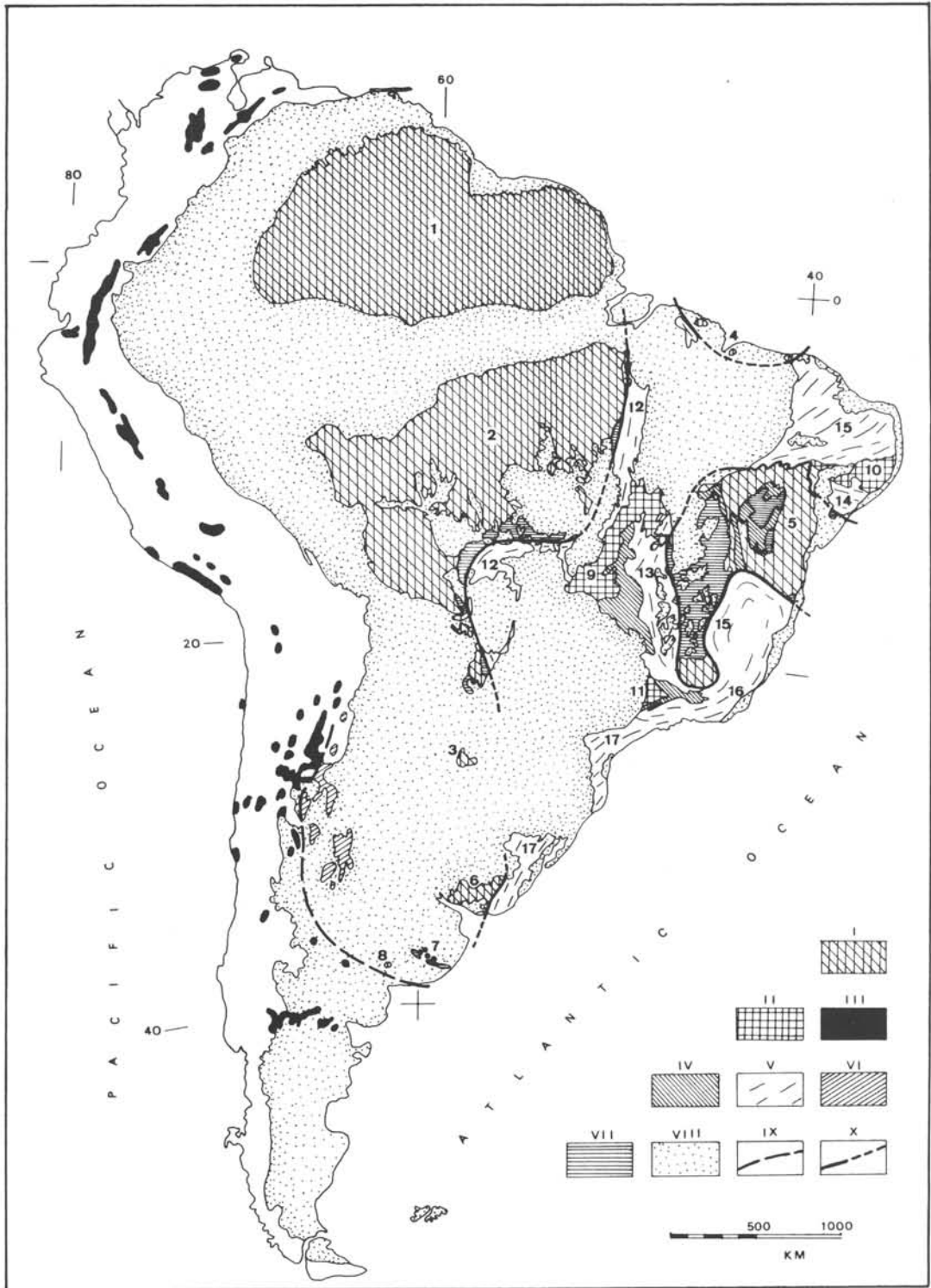


Figure 2 – THE MAJOR PRECAMBRIAN GEOTECTONIC UNITS OF SOUTH AMERICA:

1 – Craton basement expositions: Amazonic Craton in Guiana Shield (1), in western Central Brazil Shield (2) and in Eastern Paraguay (3); São Luis Craton (4); São Francisco Craton (5); Rio de La Plata Craton in Uruguay (6), Tandilia (7) and Sierras Australes (8). II – Major massifs: Goiás Central Massif (9), Pernambuco-Alagoas Massif (10), Guaxupé Massif (11). III – Precambrian massifs remobilized in the Andean Chain and Patagonian Platform. IV – Uruaçú and Espinhaço Fold Belts. V – Fold belts and regions of the Brasiliano Cycle: Paraguay-Araguaia Belt (12), Brasília Belt (13), Sergipano Belt (14), Araçuaí Belt (15), Northeastern Region (16), Southeastern Region (17). VI – Sierras Pampeanas Massifs. VII – Sedimentary covers correlative of the Brasiliano Cycle. VIII – Phanerozoic sedimentary and volcano-sedimentary covers. IX – Southern limit of the South American Platform. X – Craton limit.

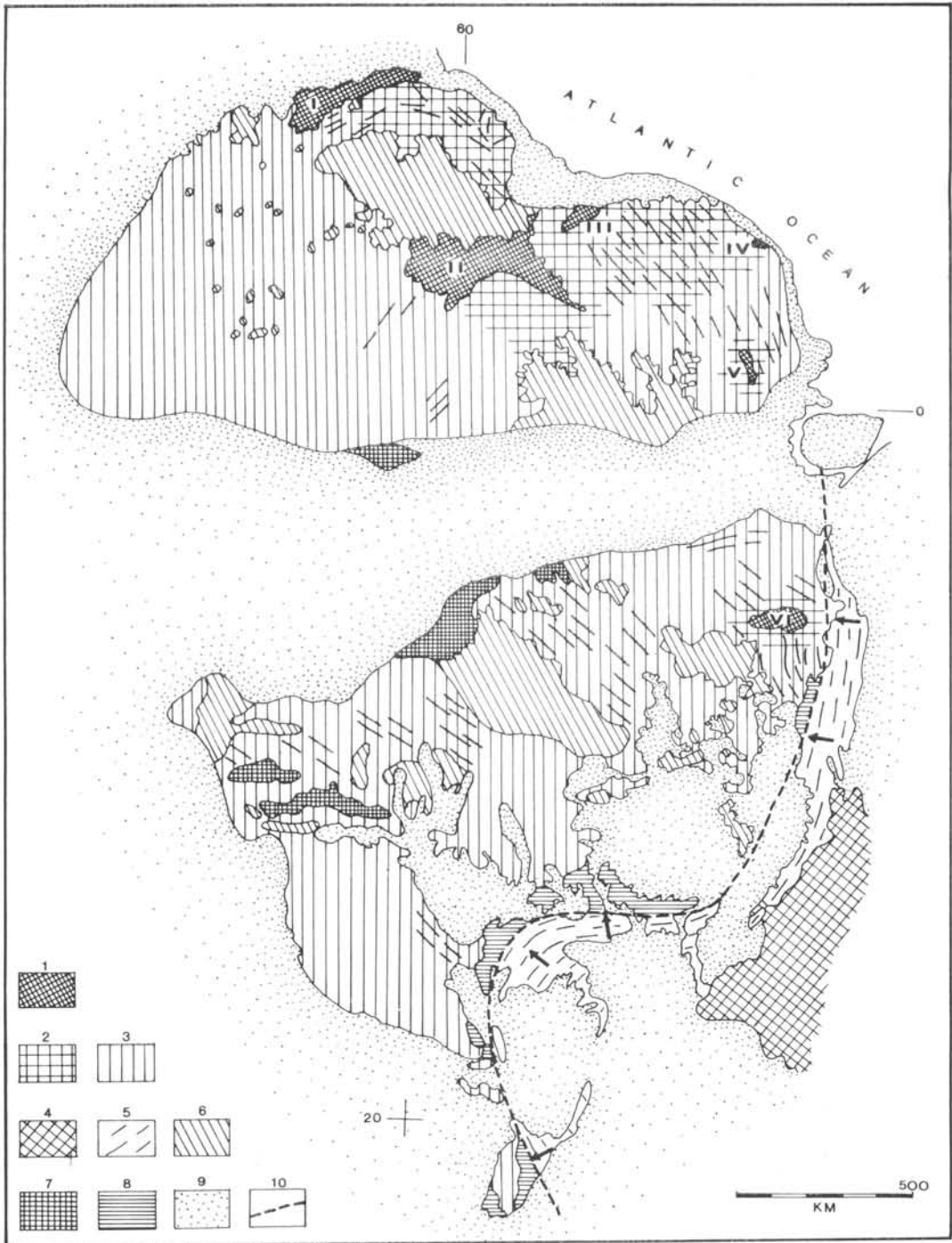


Figure 3 - THE AMAZONIC CRATON

1 - Guriense and Jequié units: Imataca (II), Kanuku (II), Coeroeni-Fallawatra (III), Ile de Cayenne (IV) Rio Falsino (V) and basement of the Grão Pará Group (VI). 2 - Trans-Amazonic areas. 3 - Undifferentiated Pré-Brasiliano areas. 4 - Goiás Central Massif. 5 - Paraguay-Araguaia Fold Belt. 6 - Sedimentary and volcano-sedimentary covers related to Upper Precambrian reactivations. 7 - Sedimentary covers related to the Brasiliano Cycle. 8 - Sedimentary covers correlativa of the adjacent Brasília geosyncline. 9 - Phanerozoic sedimentary covers. 10 - Craton border. Arrows indicate vergences.

with descriptions of stratigraphic sequences and radiometric analyses by K-Ar and Rb-Sr methods. Many synthesis papers are published, the most recent of which are those of Choubert (1974), Singh (1974), Amaral (1974), Issler (1974), Montalvão (1974) and Almeida (1974 a). There are numerous and profound controversies over the stratigraphic correlations and geological interpretations.

The oldest rocks are metasedimentary and metabasic rocks metamorphosed in amphibolite and granulite facies, frequently migmatized and penetrated by granitoid rocks. Their age corresponds to the Guriense (5) and Jequié and form the Coeroeni - Fallawatra (Suriname), Kanuku (Republic of Guiana), Île de Cayenne (French Guiana) and Imataca Complexes, as well as the basement of the Grão Pará Group (Serra dos Carajás, Brazil) and the granulitic rocks of Rio Falsino (Brazil).

Large areas of this region were subjected to geosynclinal evolution in the Middle Precambrian, during the Trans-Amazonic. Sedimentary and volcanic rocks may be found there, which were folded, metamorphosed and penetrated by abundant acidic intrusions. Among the various stratigraphic units, the Grão Pará (Beisiegel et al., 1973) and Amapá Groups (Brazil), Orapu-Bonidoro (French Guiana) and Armina-Rosebel (Suriname) Series, should be mentioned. The Pastora Group (Venezuela) and Barama-Mazaruni Complex (Republic of Guiana) were correlated to the above, but the data of Hurley et al. (1973) seem to indicate that they are pre-Trans-Amazonic materials.

The Trans-Amazonic rocks show ages of  $2000 \pm 200$  m.y. for the metamorphism and many granitoid intrusions. This was followed by the deposition of molassic sediments (Rio Fresco Formation, Brazil; Muruwa Formation, Republic of Guiana; Orapu and Bonidoro, French Guiana; Cinaruco Formation, Venezuela), acid to intermediary volcanism (Surumu, Cuchivero and Iwokrama Formations in the Guianas and northern Roraima, Brazil) and the intrusion of granitoid rocks dated ca. 1800 m.y.

In the Upper Precambrian, the Amazonic Craton underwent reactivations between 1700 and 900 m.y. With the resultant paraplatform conditions molassoid sediments were deposited along with associated acid and intermediate volcanism and granitic intrusions. The sedimentary and volcanic covers have been eroded and are not continuous, nor are observable complete sections, making difficult the stratigraphic study and correlations.

The radiometric datings of these volcanic and intrusive rocks are not yet sufficient. Nevertheless, an examination of the datings shows that at least in the Amazonic Craton exposed in the Central Brazil Shield, the older ages are concentrated in east, while the younger are in the west. There have been some attempts to distinguish the reactivation events in the Platform, and several were proposed, though not always convincingly.

The stratigraphic sequences suggest that two major events may be considered, with approximate ages of 1700-1400 m.y. and 1300-900 m.y.

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(5) Three major geotectonic cycles and complexes are considered for the evolution of South America during the time preceding the Upper Precambrian. The corresponding metamorphism and granitization epochs have been approximately dated and they were considered for the division of the South American Precambrian. They are: Guriense, of more than 3000 m.y.; Jequié, of more than  $2600 \pm 100$  m.y. and Trans-Amazonic, of more than  $1800 \pm 100$  m.y. As their beginning ages are unknown, these denominations are also employed to name the time intervals between the metamorphism and granitization epochs.



The first event is characterized by acid to intermediary lava flows, including restrict molassic intercalations and co-magmatic intrusions. The Sobreiro, Uatumã and Iri formations in Brazil, seem to have deposited during this period. The molassic continental or marine sediments that cover these units have diverse local designations, like Gorotire, Beneficente, Dardanelos, Mutum-Paraná and Roraima Formations. The latter presents in some locations basic intrusions of 1500-1700 m.y. At times they have been taken as indicators of the end of a reactivation process, but some granites covered by the Roraima Formation seem to be as young as 1490 m.y. (Bellizzia, 1975). Granitic intrusions also exist in that formation (Colvée et al., 1975).

The second event is called Rondoniense Event on the western side of the Central Brazilian Shield (Amaral, 1974), Jari-Falsino on the Brazilian side of the Guiana Shield (Montalvão, 1974), K'mudku in the Republic of Guiana (Barron, 1969), Orinoquense in Venezuela (Martin Bellizzia, 1968) and Nickerie in Surinam (Priem et al., 1971). During this event, molassoid sediments were deposited together with acid to basic effusives and granitic intrusives, many of which are tin-bearing. The Cadiueus, Cubencranquén, Palmeiral, Acari and Amogujá formations, among others, could be attributed to this event. Cataclastic zones developed in vast regions of the Guiana Shield with formation of breccia and mylonites (the K'mudku Event), as well as regional reheating, responsible for the isotopic rejuvenation which reflects on the radiometric ages.

At the end of the Upper Precambrian, or perhaps already in the Cambro-Ordovician, molassoid sediments were again deposited. They are interpreted as platform correlatives of the Brasiliano Cycle, which covered that area of the interior of the Amazonic Craton exposed in the Central Brazil Shield. The

Prainha, Riozinho do Afrísio and Prosperança formations would be of this type.

Marginal basins of the Paraguay-Araguaia geosyncline were formed at the edge of the Amazonic Craton, south of the 13°S parallel, until the end of the Brasiliano Cycle. The upper miogeosynclinal sequences extended to these basins, with less thicknesses, and has been idiomorphically folded and faulted. These basins extend up to 150 km within the interior of the craton. The oldest deposits of some basins include typical tillites related to the Late Precambrian glaciation that extended over a great region of Brazil and Eastern Paraguay.

As is evident, the oldest events in the Amazonic Craton are not clear, and the sedimentary and volcano-sedimentary covers present problems of interpretation and correlation. Geochronological datings have been of great value, though many are controversial and others have not always been accompanied by an adequate geological study of the analysed samples.

Table 1 tentatively outlines the described evolution of the Amazonic craton.

In eastern Paraguay, the Amazonic Craton's basement is exposed in two small massifs (Fig. 5). They are formed of meta-sediments and metabasites of amphibolite facies, with intruded granitoids. The age of these rocks were obtained by the K-Ar method (Comte and Hasui, 1971), and although not decisive, they indicate that the rocks are of pre-Brasiliano age and the Amazonic Craton extends to the south at least until 27°S latitude. Rhyolites whose ages correspond to the end of the Brasiliano Cycle (Cambro-Ordovician) are located over the cratonic rocks, in the Caapucu region. These Caapucu volcanics are associated with granitic intrusions and represent a volcano-plutonism in the Amazonic Craton next to the limit of the Paraguay-Araguaia Belt.

TABLE 1

Tentative outline of the evolution of the Amazonic Craton		
Age m. y.	Events	Lithostratigraphic units
500 - 1000	Brasiliano	Prosperança, Prainha and Riozinho do Afrisio formations (molassoids). Alto Paraguay Group (molasse).
		Jangada, Escobar, Araras, Corumbá, Bodoquena, Itapocumi Groups (marginal basins correlative to the Paraguay-Araguaia miogeosyncline).
900 - 1300	Reactivation	Cubencraquém, Cadiueus, Palmeiral, Acari, Amoguijá formations (acidic-intermediary effusives and molassoids).
1400 - 1700	Reactivation	Grotire, Beneficente, Dardanelos, Mutum-Paraná, Roraima formations (molassoids).
		Uatumã, Sobreiro, Iri formations (acid-intermediary effusives).
1800 - 2600	Trans-Amazonic	Surumu, Kuyuwimi, Iwokrama, Cuchivero, Rio Fresco, Muruwa, Orapu, Bonidoro and Cinaruco Formations (molasses and acid to intermediary effusives)
		Amapá and Grão Pará Groups, Arminarosebel, Paramaca, Paramaka and Morowijne Series.
more than 2600	Jequié and Guriense	Barama-Mazaruni, Coeroeni-Fallawatra, Kanuku, Imataca Complexes, the basement of the Grão-Pará Group and other nuclei

### 3.2. SÃO FRANCISCO CRATON

The São Francisco Craton (according to Almeida, 1967) is a unit that has been intensely studied, but the data reflect above all the disperse areas of economic interest.

It was the foreland of the fold belts of the Brasiliano Cycle, located on its borders. Fig. 4.

The Caraiba and Jequié Complexes appear on the northeastern part of the craton. The Caraiba Complex (Barbosa, 1970) is formed of granulites, basic rocks and migmatites with basic paleosome. Its structures are complexes, generally trending N-S. Associated granitoids have given ages of 2500-2700 m.y. At approximately the 13°S parallel, the Caraiba Complex gradually passes to the Jequié Complex (Cordani, 1973). The later extends



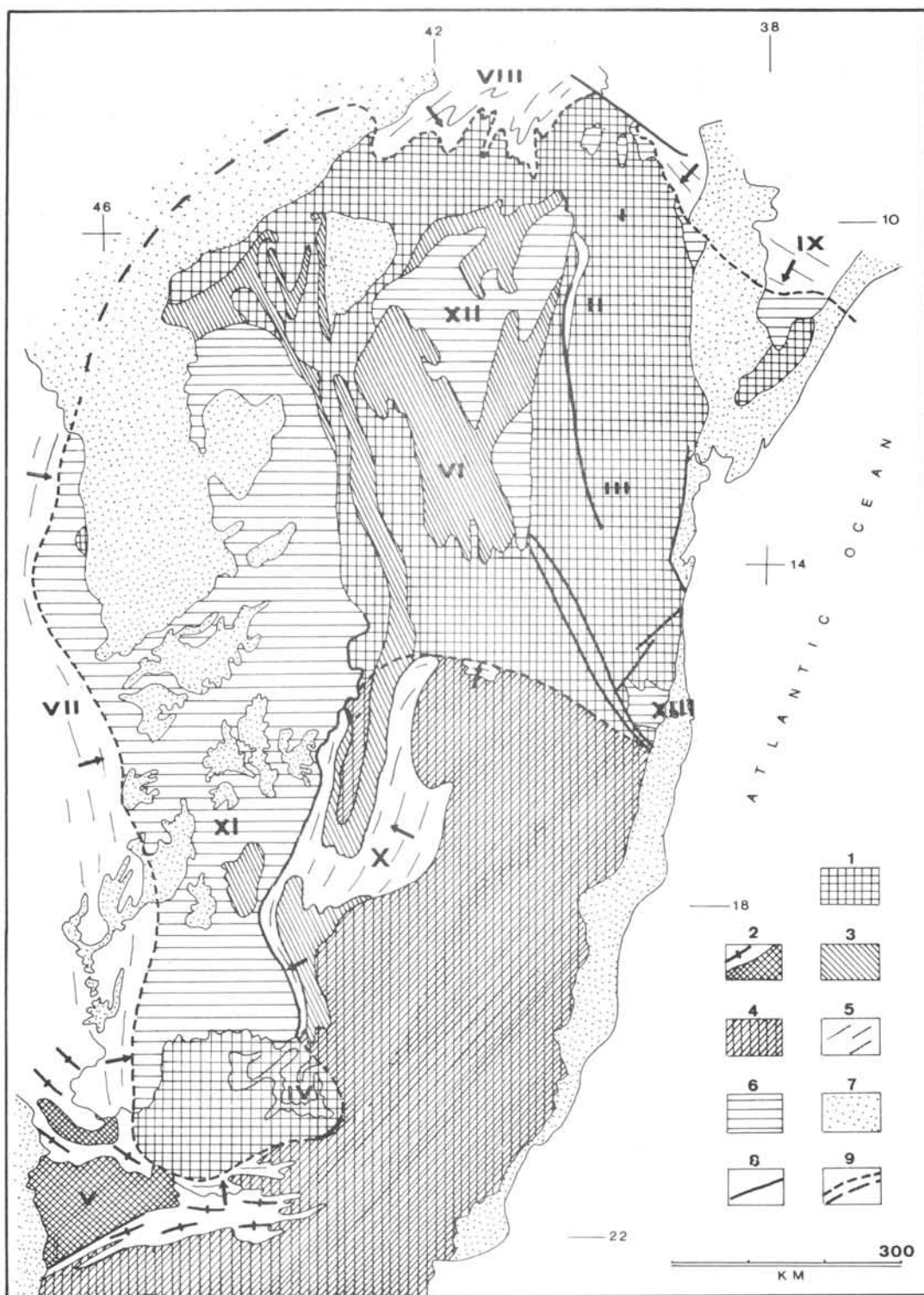


Figure 4 – SÃO FRANCISCO CRATON

1 – Pre-Trans-Amazonic and Trans-Amazonic undifferentiated areas. Caraiba Complex (I) Jacobina Group (II), Jequié Complex (III), Quadrilátero Ferrífero (IV). 2 – Uruaçu Folded Belt and Guaxupé Massif (V). 3 – Espinhaço Belt and related covers on the Diamantina Plateau (VI). 4 – Trans-Amazonic areas rejuvenated during the Brasiliano Cycle. 5 – Brasiliano units: Brasília Fold Belt (VII), Northeastern Fold Region (VIII), Sergipano Fold Belt (IX), Araçuaí Fold Belt (X). 6 – Sedimentary covers correlative of the Brasiliano Cycle; Bambuí Group in the São Francisco Basin (XI) and in the Salitre-Jacaré Basin (XII) Rio Pardo (XIII). 7 – Phanerozoic sedimentary covers. 8 – Major faults. 9 – Craton limit. Arrows indicate vergences.

to the 16°S parallel (Mascarenhas, 1973) and its granulites have ages around 2700 m.y. and were migmatized at the end of the Trans-Amazonic Cycle (ca. 1800 m.y.).

Irregular bands of schists, quartzites and gneisses, which seem to be the segments saved by the migmatization, appear in these complexes. Only the narrow N-S Jacobina belt almost 220 km long seems to be Trans-Amazonic. It is composed of quartzites and schists of amphibolite facies, with isoclinal folding, faults and overthrusts toward west over the Caraiba Complex.

Migmatites and granitoids of minimum age of 2800 m.y. of the Bação Complex are found in the southern part of the São Francisco Craton (Quadrilátero Ferrífero). This complex is covered by detritic metasediments, itabirites and dolomites, metamorphosed in greenschist and amphibolite facies of the Rio das Velhas Supergroup. Granitoid and basic-ultrabasic rocks are associated to it. Datings for these rocks show age around 2700 m.y.

The Minas Supergroup covers the Rio das Velhas, unconformably. The former is constituted of a sequence containing banded ironstones over and underneath detritic sequences. The Minas Supergroup is observed in overtuned and faulted synclinoria (Dorr, 1969); the superposed deformations can be attributed to several phases (Barbosa, 1968). The metamorphism was of greenschist and amphibolite facies. The minimum age obtained by Herz (1970) was 1300 m.y., and recent datings (Cordani, unpublished) furnished Trans-Amazonic ages.

The Minas Supergroup is locally covered by folded metasediments of greenschist facies (essentially quartzites) whose geotectonic significance is not known (Itacolomi Group). Possibly they may be correlated to the Espinhaço Group.

The situation is more complex in the southeastern region of the São Francisco Craton. There, the Uruaçu and Brasília Belt end, as well as the Southeastern Folded Region. The lithology was described by Rosier (1965) and Ebert (1968) as represented by gneisses, migmatites, granulites and granites, attributed to the Mantiqueira, Paraíba, Juiz de Fora and Serra dos Órgãos Séries. The datings of Cordani et al. (1973) showed that the rocks are aged 2780 m.y. (Mantiqueira Séries) and 1980 m.y. (Paraíba and Juiz de Fora Series); they were remobilized in the Brasiliano Cycle, and have been migmatized and intruded of granites and pegmatites. The remobilized area seems to correspond to the infrastructure of the Southeastern Folded Region (Hasui et al., 1975a).

Dykes of non-metamorphosed diabase and pyroxenite exist in the northeastern region of the craton; they are intrusives in granulites and with K-Ar ages of 1300 to 1700 m.y. In the eastern region, more than a dozen stocks of alkaline rocks occur (Pedreira et al., 1969) with K-Ar ages of ca. 760 m.y. (Cordani, 1973). There is a special undelineated belt, with one or two hundred kilometers wide, extending from the region at 16°S and 42°W coordinates to the southeastern border of the Parnaíba Syncline. Along this belt, there were isotopic rejuvenation in the Brasiliano Cycle and K-Ar ages of 500-600 m.y. were obtained systematically on rocks with higher Rb-Sr age. It seems to have been simply a termo-tectonic reactivation along the belt, and that it is not an extension of the infrastructure of the Southeastern Folded Region.

The most important feature, however, is the Espinhaço Belt, a N-S one in the central part of the São Francisco Craton, extending over than 2200 km. Detritic metasediments, above all quartzites and phyllites, are found there with hundreds of meters in eastern part and thousands meters in western part. The sedimen-

tation had frequent repetitions of environmental conditions, and the stratigraphic subdivisions and correlations are difficult.

A sequence at the meridional end of the belt (Espinhaço Group) shows folding of intermediate-type and a low-degree metamorphism. These characteristics are also observed in Diamantina Plateau (Chapada Diamantina Group), which is located in the central-northern region of the craton. The same sequence in the central and northern portions of the belt (Santo Onofre Group), shows isoclinal linear folding and intense faulting and its metamorphism is more intense toward the west, reaching greenschist facies paragenesis. Acid volcanic rocks occur in the sequence, and basic dykes are common as well. Vergences seem to turn towards the west, but in the region of western Diamantina Plateau, it turns to east.

These units cover the Caraiba Complex and are covered in turn by the Bambui Group, with angular unconformities. They were initially related to an Espinhaço Cycle (1800 - 1300 m.y. Ferreira, 1972). However, the Chapada Diamantina Group (Brito Neves, 1968) is correlated to the Santo Onofre Group (Schobbenhaus, 1972) which metasediments and volcanic rocks gave a metamorphism age of  $1000 \pm 100$  m.y. (Rb-Sr isochron, Brito Neves, to be published). This dating may be attributed to the Uruaçuano Cycle, and, so, the possibility of an extension of the Uruaçu Belt to the Espinhaço Belt would not be rejected.

The Espinhaço Ridge was associated to a miogeosyncline by Pflug et al. (1969). In the northern region, this miogeosyncline should contour a presumed massif at Diamantina Plateau (Lençóis Craton). Moreover, they considered the Quadrilátero Ferrífero as an extension of the Espinhaço miogeosyncline and, in the eastern region, they supposed the existence of an eugeosyncline.

The São Francisco Craton presents sedimentary covers of the Bambui Group, and of Mesozoic and Cenozoic ages. The Jequitaiá Formation of Minas Gerais State and the Bebedouro Formation of Bahia State are homologous and have typical tillites, which represent deposits of continental glaciers related to the Upper Precambrian glaciation. At least two tillite levels were recognized. A thin varvite deposit is known between them in the Brumadinho quarry (Cabral Ridge, Minas Gerais) and pavements with striations and grooves produced by the ice exist at Água Fria Ridge (South of Jequitaiá, Isotta et al., 1969; Ponçano and Paiva, 1975) and at Cabral Ridge.

The Bambui Group which extends over the craton, is an extension of the Brasília, Sergipano and Northeastern upper geosynclinal units. It covers a vast area to the west of the Espinhaço Ridge, where it was not appropriately attributed to the "São Francisco Basin". To the east from Espinhaço Ridge, it covers the Chapada Diamantina Group and was attributed to the "Salitre-Jacaré Basin". The minimum extension of that cover is 420.000 km<sup>2</sup> in both "basins". The thickness does not exceed 1000 m, and almost all of the Brasília miogeosynclinal formations are present, with less thickness and some faciological variations. The deformations of this cover are idiomorphic. The only linear folding areas are located on the borders of the craton turned towards the Brasília miogeosyncline, and in the region bordering the Espinhaço Ridge. To the east of the Espinhaço, there are even isoclinal folds, with E-W trending, and axial planes dipping towards the north. This occurs in narrow belts, separated by undeformed zones. The general metamorphism is null or of very low degree, but in folded zones it reaches greenschist facies.

Table 2 outlines the described evolution of the São Francisco Craton.

TABLE 2.

Tentative outline of the evolution of the São Francisco Craton		
Age m.y.	Events	Lithostratigraphic units
500 - 1000	Brasiliano	Três Marias Formation (molasse)
		Bambui Group (platform cover correlative to the geosynclinal units)
500 - 800	Reactivations	Alkaline intrusions (ca. 680 m.y.) Isotopical rejuvenated belt (500-600 m.y.)
1300 - 1000	Uruaçuano	Espinhaço, Chapada Diamantina, Santo Onofre Groups (metamorphism ca. 1000 m. y.) Itacolomi Group (?)
1300 - 1700	Reactivations	Basic and ultrabasic intrusions.
1800-2600	Trans-Amazonic	Minas Supergroup, Paraíba and Juiz de Fora Séries (?) and Jacobina Group.
2600 - 3000	Jequié	Mantiqueira Series, Rio das Velhas Supergroup and Jequié-Caraíba Complexes
more than 3000	Guriense	Baço Complex and other nuclei

### 3.3. SÃO LUIS CRATON

The São Luis Craton (Almeida, 1967; Hurley et al., 1967) is located at the central northern border of the South American Platform. It is almost entirely covered by the sediments of the Parnaíba Syncline and small meso-cenozoic basins. The basement is exposed in small massifs and seems to be formed of metasediments of amphibolite facies, with migmatization and intrusion of granites. The eastern massif (Granja Massif, Brito Neves, 1975) represents the craton's border neighboring the Northeastern Fold Region. The available datings are of 1850-2470 m.y. (K-Ar). Although  $2000 \pm 200$  m. y. figures predominate, it is not excluded the possibility of pre-Trans-Amazonic age.

### 3.4. RIO DE LA PLATA CRATON

The Rio de La Plata Craton (Almeida et al., 1971) is almost entirely covered of sediments of the Paraná Syncline and post-Paleozoic basins. Its basement is exposed in three regions: southeastern Uruguay, Tandilia and Sierras Australes in Argentina. Fig. 5.

In Uruguay, Ferrando and Fernandez (1971) distinguished three belts of metasediments of greenschist and amphibolite facies. These were separated by migmatitic belts with granitic intrusions. The structures trend E-W with variations to N70E. The ages obtained for them are  $2000 \pm 200$  m.y. Only one granite intrusion at north of Montevideo shows 560 m.y. and it is attributed to the influence of the Brasiliano Cycle

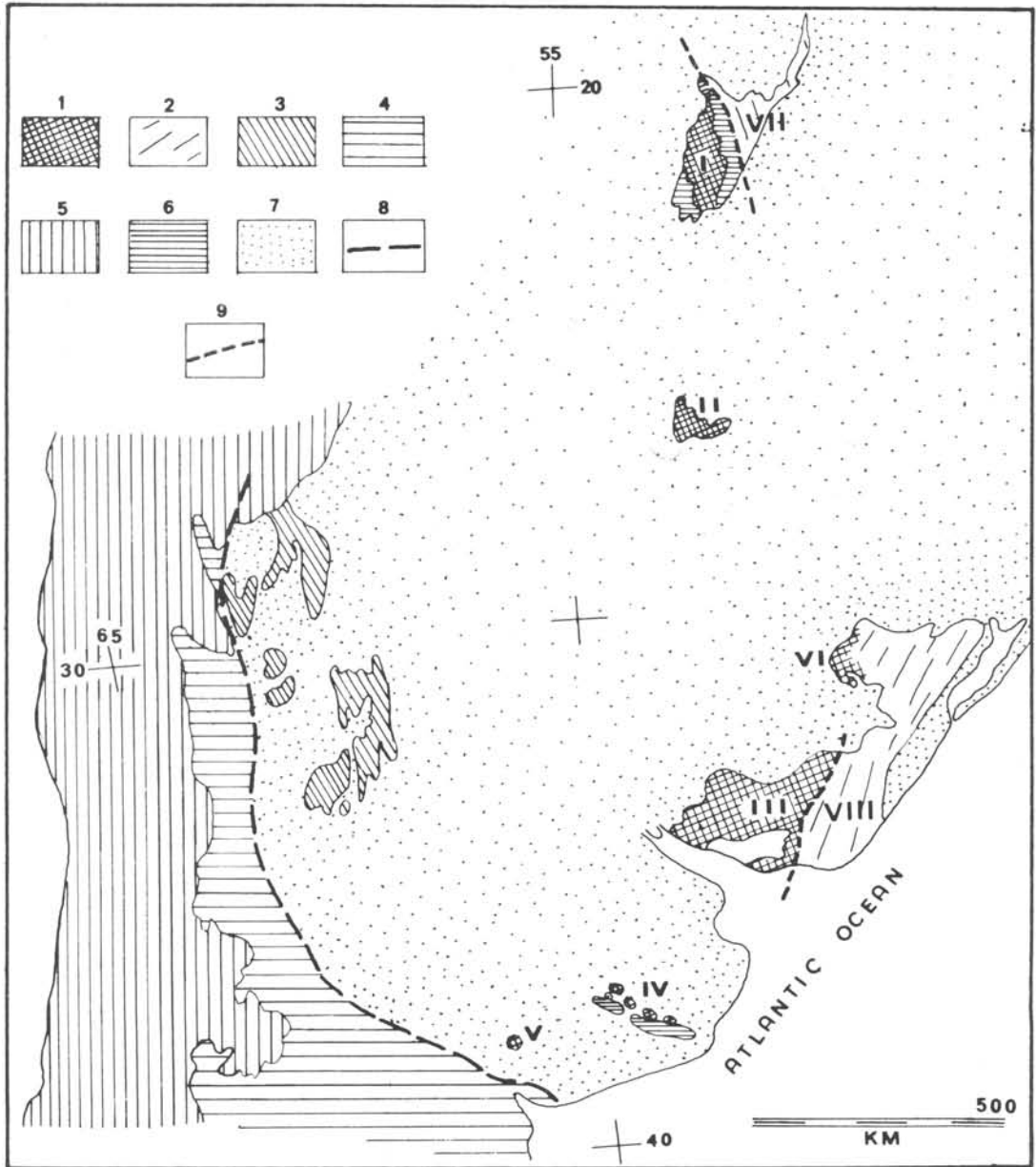


Figure 5 – SOUTHERN REGION OF THE SOUTH AMERICAN PLATFORM

1 – Craton basement expositions. Amazonic craton: Apa River (I) and Eastern Paraguay massifs (II) Rio de La Plata craton: Uruguay (III). Tandilia (IV), Sierras Australes (V) and Rio Grande do Sul (?) (VI). 2 – Fold belt and region of the Brasiliano Cycle: Paraguay-Araguaia Belt (VII), Southeastern Region (VIII). 3 – Sierras Pampeanas massifs. 4 – Patagonian Platform. 5 – Andean Chain. 6 – Sedimentary covers correlative of the Brasiliano Cycle. 7 – Phanerozoic sedimentary and volcano-sedimentary covers. 8 – Southern limit of South American Platform. 9 – Craton border.

at the border of the craton.

The relation between the Rio de La Plata and Amazonic Cratons is hidden under the sedimentary cover, though they may possibly be parts of only one large unit.

The mountains that stand out in the Tandilia region's quaternary plain are formed by gneisses, migmatites and granitoids whose age is  $2160 \pm 60$  m.y. (Halpern, 1972). Amos et al. (1971) described sandstones and stromatolitic limestones (La Tinta Group), covering the plutono-metamorphic basement. These rocks represent a platform cover of the Brasiliano Cycle, similar to the Bambui Group.

Granites and associated rhyolites occur at the Sierras Australes, with Brasiliano and pre-Brasiliano ages (Amos et al., 1971; Halpern, 1972). These are the most meridional of the Rio de La Plata Craton's basement.

#### 4. UPPER PRECAMBRIAN FOLD BELTS

##### 4.1. URUAÇU BELT

The Uruaçu Belt developed between the Amazonic and the São Francisco Cratons (Fig. 6). It is formed of metasediments and metabasites of high greenschist and amphibolite facies of high pressure type of metamorphism. These rocks are included in the Araxá Group, with thicknesses exceeding 1500 m. The folding is of linear type, trending parallel to the axis of the belt. The vergence turns towards the São Francisco Craton. The pre-tectonic magmatism occurred in the inner part of the belt, generating several small basic-ultrabasic intrusions. This peridotitic belt shows Cr, Ni and asbestos mineralisations. The

sintectonic and post-tectonic acid magmatism was very discrete, forming small bodies along the inner zone of the belt.

Certain problems arise with no solutions at moment. The first one is with respect to the borders of the Uruaçu Belt. Traditionally, it was considered to be formed essentially by micaschists; gneisses and migmatites are thought to be pre-Uruaçuano. However, these rocks show gradual transitions. Angular unconformities were identified locally, between the two types of lithology, but this is not rule even in the Araxá Group type-area. Thus, it is sometimes difficult to delineate the border between the Uruaçu Belt and the Goiás Central Massif without a careful mapping.

The eastern limit would be a thrust fault that carried the Araxá Group over the Brasilia Belt's units. The existence of that fault has not been proved, although there may be local thrusts. The Araxá Group looks like to pass gradually to the metamorphites of the Brasilia Belt; as a result, the border between the two units is not easily marked.

The available datings of the Uruaçu Belt (Hasui and Almeida, 1970) are not conclusive. The K-Ar figures indicate that the Brasiliano Cycle rejuvenated the Uruaçuano rocks, but there are significant results of 1000 m.y. which would correspond to a minimum age for the metamorphism. From the other side, some intrusive granites in the Central Massif of Goiás furnish a reference Rb-Sr isochron of 1400 m.y., which would indicate a magmatic event in the massif immediately preceding the Uruaçuano regeneration. Thus, the approximate figures of 1300 and 1000 m.y. could correspond to the limits of the regeneration and tecto-orogenic evolution of the Uruaçuano Cycle (6).

(6) Recent Rb-Sr isochron age determinations confirm the 1000 m.y. age for the metamorphism of the Araxá Group (Hasui and Almeida, in press).



The structures of the Uruaçu Belt show deviations in the central region, adapted to the Pirenópolis structural feature. This is a N60W trending lineament, with structural meaning not yet understood. In the northern block, the structures have a general SSW trend, but they deviate gradually to N60W near the Pirenópolis feature. In the southern block the structures have a N45W trend and also show a deflection to N60W.

In the southern part of the São Francisco Craton, the Andrelândia Series (Ebert, 1956) represents the extension of the Uruaçu Belt. It is formed of detritic sediments, arkosic at the base, with some associated limestones. The metamorphism of high pressure type was of greenschist and amphibolite facies and its intensity increases from N to S and W to E. Folding was intense with vergence towards the N.

The Andrelândia Series seems to branch off, with one branch extending towards SW (Itapira Group). The two branches are separated by the triangular Guaxupé Massif. Its western border is covered by the Paraná Syncline sediments. This massif is constituted by granulites, migmatized and intruded by granites. The structures have NW trends, and a superposed NE trend exists in part (Oliveira and Alves, 1974, Oliveira, 1973). The northeastern border of the massif is concordant with the structures of the Uruaçu Belt, but in the southeastern edge their NW structures are truncated at right angle by the Jacutinga transcurrent fault (Ebert, 1974), through which the massif contact the SW trending Uruaçu branch (Itapira Group).

In this fault zone, it has been recognized a molassic deposit (Eleutério Group, Ebert, 1974) which seems to be related to the Brazilian Cycle.

#### 4.2. PARAGUAY-ARAGUAIA BELT

The Paraguay-Araguaia Belt evolved on the eastern edge of the Amazonic Craton (Fig. 6). It has a curved form and extends over 3200 km, disappearing under the Paraná and Amazon Synclines sediments.

In the central region of Brazil the belt is covered by modern sediments (Bananal Island). This resulted in the independent development of studies on the southern and northern segments of the belt.

Almeida (1968) distinguished two phases of miogeosynclinal evolution in the meridional segment. The first one produced flyschoid sediments of the Cuiabá Group, which were folded and metamorphosed. The second corresponds to the sedimentation of a marine regression conglomerate and glacial-marine deposits, which total over 1000 m of thickness (Jangada and Escobar Groups). The upper unit is a carbonate sequence with more than 2000 m of thickness (Araras, Corumbá, Bodoquena and Itapocumi Groups), with 1000 m of pelitic rocks at the top. Stromatolitic structures are present in the Corumbá limestones.

These units exhibit metamorphism of greenschist facies and folding of holomorphic-type trending parallel to the belt axis. The vergence turns towards the Amazonic Craton. The known magmatic intrusions are restricted to the inner part of the belt; they are granitic post-tectonic stocks aged of 500 m.y.

The final stratigraphic unit corresponds to molasse deposits (Alto Paraguay Group), accumulated in a foredeep 800 km long. It lies over the Amazonic Craton's cover and partly extends to the fold belt in its curved area. The sediments possibly reach 5000 m of thickness and are of clastic nature accumulated in a transitional environment. At the top they are continental. (Almeida, 1974b).The

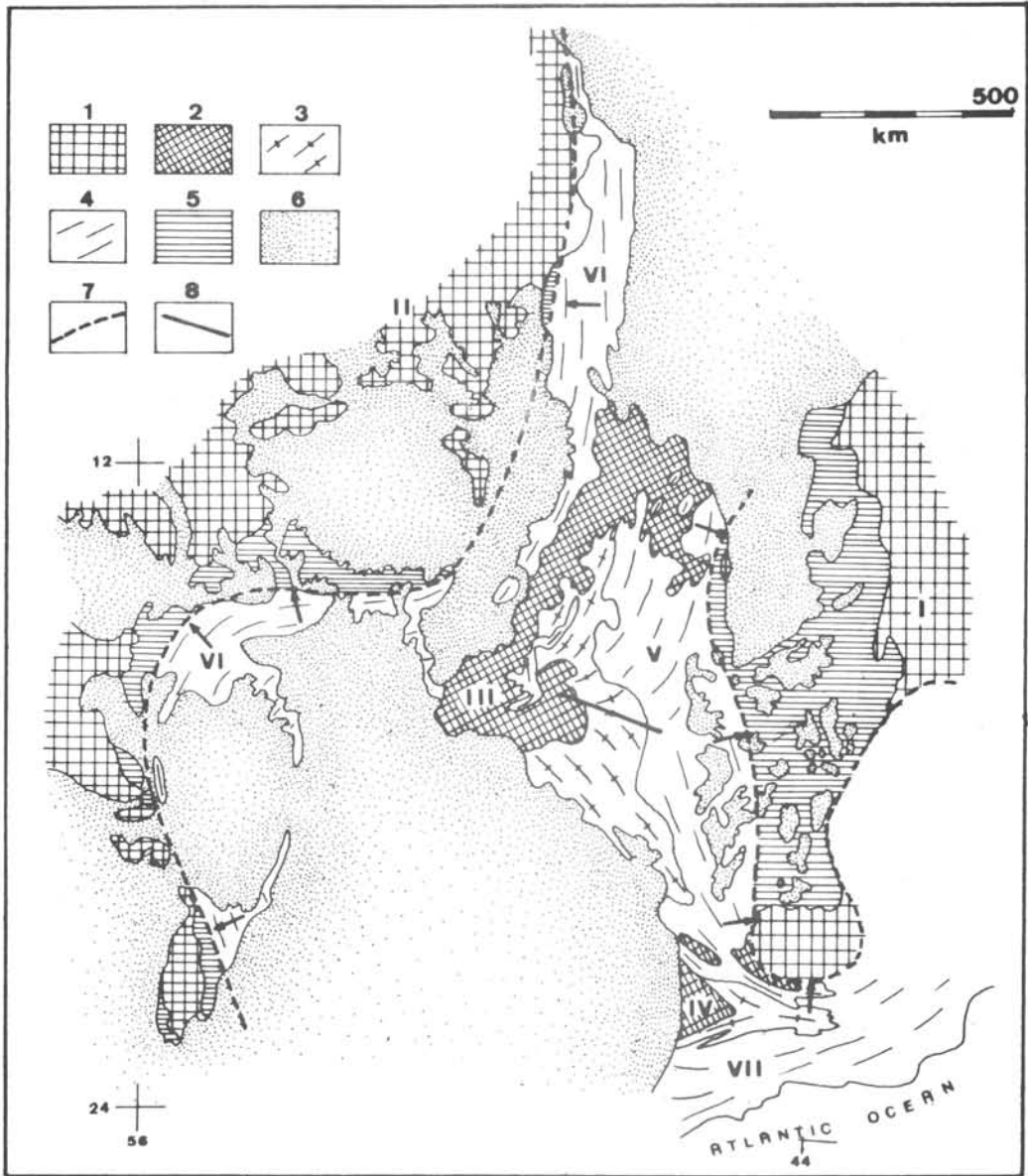


Figure 6 – CENTRAL BRASILIAN REGION OF THE SOUTH AMERICAN PLATFORM

1 – Cratons: São Francisco (I) and Amazonic (II). 2 – Massifs: Goiás (III) and Guaxupé (IV). 3 – Uruaçú Fold Belt. 4 – Fold belts and region of the Brasiliano Cycle: Brasília (V), Paraguay-Araguaia (VI), Southeastern (VII). 5 – Sedimentary covers correlative of the Brasiliano Cycle. 6 – Phanerozoic sedimentary and volcano-sedimentary covers. 7 – Craton border. 8 – Pirenópolis structural feature. Arrows indicate vergences.

Alto Paraguay Group shows holomorphic folding only in the farthest area from the cratonic border, as well as very low grade of metamorphism.

The units of second phase of geosynclinal sedimentation and the molassic deposits partially covers the Amazonic Craton. One occurrence should be mentioned: the deposition of the Jacadigo Group occurred in a basin on the edge of the craton at the end of the Brasiliano orogenesis, at the Corumbá (Brazil) and Mutum (Bolivia) regions. This unit is formed of arkoses at the base, and of alternating layers of ferruginous jaspilite, hematite and cryptomelane, with intercalations of clastic sediments.

In the northern segment, Almeida (1974c) described the Tocantins-Araguaia geosuture. The Brasiliano regeneration permitted the intrusion of several basic and ultrabasic bodies, as well as a volcanism of basic composition. These magmatic rocks occur in a N-S belt of tens kilometers of width and 500 km of extension. The geosuture also allowed the arrival of geosynclinal conditions to the east.

The Tocantins Group accumulated in this regenerated zone, being constituted of pelitic sediments transformed in greenschist facies. It shows linear folding, trending N-S and with vergence towards the Amazonic Craton. The Tocantins Group is correlated to the Cuiabá Group.

Eastward, the Tocantins Group shows gradual transition to rocks of high greenschist and amphibolite facies, which was not appropriately correlated to the Araxá Group. It was named Estrondo Group (Hasui et al., 1975b), and would corresponds to the filling of the inner zone of the geosyncline. Its folding is of linear type, trending N-S, and the vergence is towards W. Migmatization and granitoid intrusions occurred in the eastern part. The

Estrondo Group extends to the South, bordering the Bananal Island (Fig. 6), but its continuation under the Paraná Syncline is not known.

#### 4.3. BRASILIA BELT

The Brasília Belt was formed at the western and southern border of the São Francisco Craton in the Brasiliano Cycle, and extends over 1100 km (Fig. 6).

Miogeosynclinal conditions with deposition of medium and fine-grained detritic sediments occurred with the regeneration (Canastra and Araí Groups). This was followed by the accumulation of the Bambuí Group, which is formed of psammites at the base (Paranoá Formation), limestones, dolomites and pelites (Paraopeba Formation), at the top. These units, more than 3000 m thick, show linear folding and thrust faults. The vergence is turned towards the São Francisco Craton. The metamorphism was weak, not exceeding the low greenschist facies. No evidences of magmatism are known in connection with the evolution of the Brasília Belt.

To the south of the craton, Ebert (1968) gave the name São João del Rei Group to the clastic sediments and limestones, metamorphosed in greenschist facies. It shows linear folding and vergence towards the north. This unit represents the extension of the Brasília Belt and, around the 44° W meridian, it disappears.

The Bambuí Group is transgressive over the craton, as described above. Near Sete Lagoas, Marchese (1974) described stromatolites of the *Gymnosolenida* Supergroup and Cloud and Dardenne (1973) recognized *Conophyton* of Vazante region.

The upper sedimentary unit is represented by molasses of the Tres Marias Formation which filled the marginal Pirapora basin, partially over the craton's cover (Bambuí Group) and partially over the folded zone in the west Minas Gerais.

The evolution of the Brasília Belt compared to that of the Paraguay-Araguaia Belt shows perfect analogy (Almeida, 1968).

The mineral resources of the Brasília Belt are in the Bambuí Group, with the marked presence of sedimentary phosphates, and Pb-Zn deposits of syngenetic origin and remobilized towards fault zones.

The Brasília and Uruaçu Belts are separated from the Paraguay-Araguaia Belt by the Goiás Central Massif (Fig. 6). This unit has heterogeneous composition. Basic gneisses, kinsigites, charnockites and granulites appear on the eastern part, with ages exceeding 2600 m.y. On the rest of the massif there are intensively migmatized metasediments of amphibolite facies, with apparent Trans-Amazonic age (Hasui and Almeida, 1970). All these lithologies are grouped on the name Goiano Basal Complex (Almeida, 1968).

Three large basic-ultrabasic massifs stand out in the eastern part of the complex: the Cana Brava, Tocantins and Barro Alto massifs. They are elongated, with up to 3000 km<sup>2</sup>, and are characterized by a petrographic zoning, with the zones parallel to each other and deeping westward. Ni, Cr, Cu and asbestos mineralizations have been described there (Berbert, 1970). Their K-Ar ages vary from over 3000 to 600 m.y., indicating that they are very ancient massifs, rejuvenated in subsequent events.

The Goiano Basal Complex was affected by the younger tectono-orogenic cycles, undergoing fracturing, diaphoresis, isotopic rejuvenation and some granitic intrusions (Ferreira, 1972).

The Goiano Basal Complex structures trend generally N30E, and show some influence of the Pirenópolis feature. The Barro Alto massif is inflected and has a boomerang shape.

In the central southern part of the

Massif, at Serra Dourada, Danni et al. (1973) recognized two stratigraphic units over the Goiano Basal Complex. The first one is composed of metasediments of greenschist facies (quartzites, schists and phyllites), with about 300m thickness. It is gently folded and covers unconformably the second unit, which includes schists, gneisses and migmatites and is correlated with the Araxá Group. It shows many little basic-ultrabasic intrusions. It seems that the Araxá Group has had extension till the Serra Dourada region. The upper unit may be interpreted as a cover correlative of the Brasiliano Cycle, constituted over the central massif.

The Goiás Central Massif was part of the Amazonic Craton during the Uruaçuano Cycle. During the Brasiliano Cycle, it became an axial zone of the divergent polarities of Paraguay-Araguaia and Brasília Belts.

#### 4.4. SERGIPANO BELT

The regeneration of the northeastern part of the São Francisco Craton allowed the development of the Sergipano Belt. (Fig7) Its limits are the craton and the Pernambuco-Alagoas massif (Brito Neves, 1975). The central and eastern portions of the belt are covered by meso-cenozoic sediments.

During the geosynclinal stage (Propriá Geosyncline, Humphrey and Allard, 1969), an outer and an inner zones developed, separated by a geanticline (Brito Neves, 1975).

In the outer zone, adjacent to the São Francisco Craton, the sedimentation had a miogeosynclinal character, and includes a lower terrigenous (Itabaiana, Jacarecica, Capitão and Palestina Formations), a carbonate (Jacoca, Olho d'Água formations), an upper terrigenous and a molassic sequences. The latter appears in a graben over the geanticlinal zone (Juá Formation), as well as in a foredeep (Estância Formation) inserted in part over the cratonic area and in part over the folded zone.

In the inner zone, the sedimentary sequence is more complex, with quartzites (Santa Cruz Formation), followed by medium and fine immature clastics, with some intercalations of limestones.

Metamorphism in these sediments was of greenschist facies in the outer zone and of amphibolite facies in the inner one. It was of low-pressure type. Migmatites are found in the inner zone, adjacent to the Pernambuco-Alagoas Massif.

In the geanticline some basement segments are exposed, more or less reworked, as well as in the nucleus of domical structures found in the outer and inner zones.

The linear folding developed during the Brasiliano Cycle trends NW-SE and the vergences are towards SW in the outer zone and towards NE in the inner zone, the geanticline being the axial zone of divergence. In the western part of the Sergipano belt, this divergence is not observed; in both zones, the vergence turns to SW.

The basic-ultrabasic as well as the acid sintectonic magmatism was very discrete in the belt, restricted to the inner part.

The outer belt's units extend over the São Francisco Craton, where they show discontinuous folding and metamorphism restricted to the folded areas. The covers have been referred as Bambuí, Miaba and Canudos Formations.

Mineral resources are scarce in the Sergipano Belt, limited to the internal zone. They may be summarized as asbestos related to carbonated intercalations, magnetite and vanadium perhaps associated with ultrabasic rocks, and minerals of complex pegmatites (beril, columbite, lepidolite, lithiophilite).

#### 4.5. ARAÇUAÍ BELT

Almeida (in preparation) proposes the name Araçuaí for the fold belt at the southeastern edge of the São Francisco Craton, Fig. 4. It has an extension of more than 500 km and is related to the Brasiliano Cycle.

After the consolidation of the Espinhaço Belt at about 1000 m.y., new miogeosynclinal conditions developed in the region and the deposition of the Macaubas Group detritic sediments occurred probably with more than 2000 m thickness. In the best known zone, at the southern part of the belt, this group has quartzites and conglomerates of the Califorme Formation (Karfunkel and Karfunkel, 1975) at the bottom and conglomeratic metagreywackes of the Terra Branca Formation at the upper part. These metagreywackes with maximum thickness of 250 m represent glacial-marine deposits (Hettich, 1975) related to the Late Precambrian glaciation. The marine drifts correspond to the tillites of the Jequitaiá Formation, known over the São Francisco Craton. The Bambuí Group, which covers the foreland located to the west from the fold belt, probably has a synchronous sedimentary equivalent in the upper part of the Macaubas Group.

The metamorphism of the Araçuaí Belt shows polarity, increasing from the craton border and reaching the amphibolite facies, with kyanite. Granite intrusions are present, and volcanic rocks are known in the upper part of the Macaubas Group (Gorlt, 1972).

The Araçuaí Belt shows holomorphic folding trending parallel to the craton edge, with vergence turned towards it. South of 18°S latitude, a great system of thrust faults raised a portion of the basement setting it over the craton cover (Bambuí Group). So, in this region the Macaubas Group has been eroded.

Towards the Atlantic coast, the inner tectonofacies of the Brasiliano geosyncline are exposed. They are not yet well studied and the relationships with the Southeastern Fold Region are not known.

The structures of the Araçuaí Belt at 16°S latitude turn to ESE. Although deeply eroded and greatly covered by cenozoic sediments, they are recognized in windows till the coastal region. In this region they form the Salobro Formation of the Rio Pardo Group (Pereira et al., 1969). The upper portion of this group is formed by detritic carbonate beds, accumulated in a basin next to the craton edge; these beds are equivalent of the Bambuí Group. Radiometric datings (Cordani, 1974) indicate age of 630 + 170 m.y. for them.

#### 4.6. GURUPI BELT

Metasediments of greenschist facies are exposed along the Gurupi and Guamá rivers in the north central region of Brazil. Outside these valleys, they are covered by sediments of the Parnaíba Syncline.

They show NW trending structures and the contact with the migmatites of the São Luiz Craton is by faults.

Hurley et al. (1967) obtained K-Ar ages of  $600 \pm 60$  m.y. and associated these rocks to the Gurupi Belt, developed around the São Luiz Craton in the Brasiliano Cycle. Actually, the significance of those ages is not yet clear, because similar figures were obtained from the migmatites attributed to the craton.

If the existence of this belt is still uncertain, so are the correlations with the Paraguay-Araguaia Belt or with the Northeastern Fold Region.

## 5. UPPER PRECAMBRIAN FOLD REGIONS

### 5.1. NORTHEASTERN FOLD REGION

The Northeastern Fold Region is the name here given to the unit formerly known as the Caririana or Eastern Northeast Fold Region. It is limited by the Parnaíba Syncline, the São Francisco Craton, the São Luiz Craton (Granja Massif, Brito Neves, 1975) and Pernambuco-Alagoas Massif. (Fig. 7).

Its observable structure is more complex than that of the Southeastern Region, because it is composed of several fold systems separated by median massifs and geanticlines, which show parts of the pre-Brasiliano basement.

The entire fold region is fragmented by enormous deep and ancient faults, reactivated in the Brasiliano Cycle, mostly with transcurrent character. The fault movements markedly influenced the design of the Brasiliano structures. Some of the faults border the fold systems and others lie within the geotectonic units of the fold regions. The most important are the Pernambuco and Paraíba Faults, trending E-W. They had mainly dextral transcurrent movements and limit the so-called Transversal Zone (Ebert, 1967).

The median massifs generally have polygonal shapes, elongated parallel to the fold system. They are formed of gneisses, migmatites and granitoid rocks, whose complicated structures are due to the polycyclic evolution. Brasiliano migmatites of early consolidation appear in some median massifs. Datings show Trans-Amazonic and Jequié ages for the older nuclei.

The geanticlines are structural highs of lesser importance, and like the median massifs show an important incidence of granitoid intrusions.

The folded systems have oval, rhombic



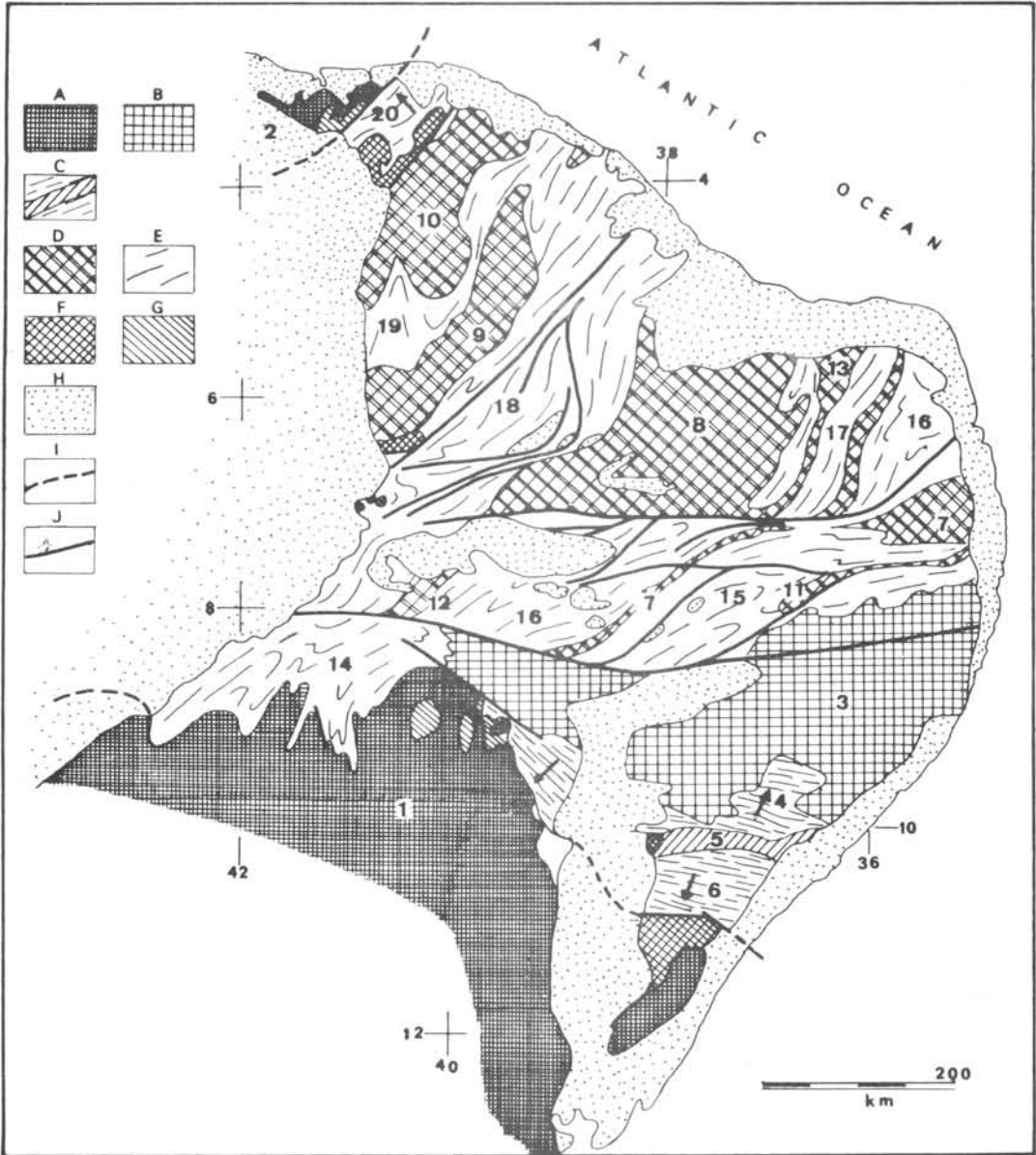


Figure 7 – NORTHEASTERN REGION OF THE SOUTH AMERICAN PLATFORM

A – São Francisco (1) and São Luís (2) Cratons. B – Pernambuco-Alagoas Massif (3). C – Sergipano Fold Belt: inner zone (4), geanticline (5) and outer zone (6). D – Northeastern Fold Region Median massifs: Teixeira (7), Rio Piranhas (8), Troia (9), Santa Quitéria (10). Geanticlines: Camalau (11), Nova Floresta (12), Acari (13). E – Northeastern Region Fold Systems: Riacho do Pontal (14), Pajeú-Paraíba (15), Piancó-Alto Brigida (16), Seridó (17), Jaguaribe (18), Curu-Independência (19), Médio Coreau (20). F – Molasse basins of the Brasiliano Cycle. G – Sedimentary covers correlative of the Brasiliano Cycle. H – Phanerozoic sedimentary covers. I – Craton limit. J – Major faults. Arrows indicate vergences.

and linear shapes, always more or less sigmoidal, reflecting transcurrent fault movements.

The sedimentary fillings of the geosynclinal region included: a lower terrigenous sequence, mainly psammitic (Caicó, Equador, Cabrobó, Parelhas and other groups), an intermediary carbonate sequence with fine detritics associated (Quixaba Formation), and an upper terrigenous pelitic sequence, essentially pelitic, with some associated psammites and limestones (Salgueiro, Seridó, Cachoeirinha Groups).

The regional metamorphism is of greenschist and amphibolite facies of low to medium pressure-type. Migmatization occurred in the lower stratigraphic level.

Linear foldings are observed in the folded systems, with undefined vergences. The direction of the structures vary greatly, with sinuosities introduced by fault displacements. Nevertheless, the general trend is NE.

Basic magmatism occurred in all the phases of the fold region evolution, always very poorly. The acid magmatism is the most notable; Almeida et al. (1967) and Brito Neves and Pessoa (1974) described and classified the various types of bodies. The most abundant are the sintectonic batholiths aged of  $650 \pm 30$  m.y. There are also late-tectonic bodies of  $540 \pm 25$  m.y. and post-tectonic of  $460 - 510$  m.y. These values are furnished by numerous K-Ar and Rb-Sr datings.

Molasse deposits occur in small fault-basins, with associated effusive acid and basic rocks. The sequences reach 3000 m thickness.

With respect to mineral resources, the deposits are associated to the pegmatite provinces of Seridó and Jaguaribe, with beryl, spodumene amblygonite, tantalite-columbite and cassiterite. Scheelite, associated to wol-

framite and molybdenite, are also found in the Seridó Fold System and in Rio Piranhas Massif.

## 5.2. SOUTHEASTERN FOLD REGION

The Southeastern Fold Region is located on the Atlantic edge of the continent, from Uruguay to the  $16^{\circ}\text{S}$  approximately (Fig. 8). The name is proposed to substitute the designation Ribeira Fold Belt.

The fold region, at south of the  $21^{\circ}\text{S}$  parallel, is largely covered by the Paraná Synclise sediments. However, in the exposed basement three fold systems separated by two median massifs are identified (Hasui et al., 1975a).

The fold systems are constituted of geosynclinal sequences, diversely named in different regions (Açungui Group in the Apiaí System, the Brusque, Porongos and Lavalaja Groups in the Tijucas System and Rocha Group in the Eastern Uruguay System). In the best studied areas, it has been distinguished a lower terrigenous unit, with pelites, psammites and limestones at the top, and an upper terrigenous unit. These rocks show metamorphism in greenschist and amphibolite facies, of low to intermediate pressure type series, including the development of migmatization process.

The folding was intense, with axis trending N30E. The vergence is not clearly defined, turning to both senses. The pre-tectonic magmatism was basic and very poorly developed. The sintectonic magmatism, by the other hand, formed great number of large granitoid batholiths, with age of ca. 600 m.y. and high affinity for the median massifs.

The median massifs are formed of ancient nuclei of Middle and Lower Precambrian ages, like those dated by Girardi et al. (1974) and Minioli (1972). They are constituted of granulites, migmatites and basic-ultrabasic rocks.

These nuclei are contoured by migmatites, generated in the Brasiliano Cycle. In the Pelotas Massif only this kind of rocks has been recognized till now.

Several small molasse basins have been formed in the final stage of evolution. They are located on the folded systems and at their borders and received molassic sediments and acid to intermediate flows, with thickness up to 5000 m. The lower molasses are folded (Maricá and Camarinha Formations), while the upper ones show only block-tilting due to faults (Almeida, 1969).

Granitic intrusions are formed during the orogenesis or the stage of transition. They are small, post-tectonic bodies with age  $500 \pm 50$  m.y., as inferred from the results of Cordani et al. (1974) and Cordani and Kawashita (1971).

Between the parallels of 21 and 24°S, the Southeastern Fold Region is characterized by a block structure, with several deep and ancient faults. The system of faults is only partially known, but it was reactivated in the Brasiliano Cycle, mainly in the Cambro-Ordovician, with transcurrent movements with a regional dextral slip. The Apiaí System and the Joinville

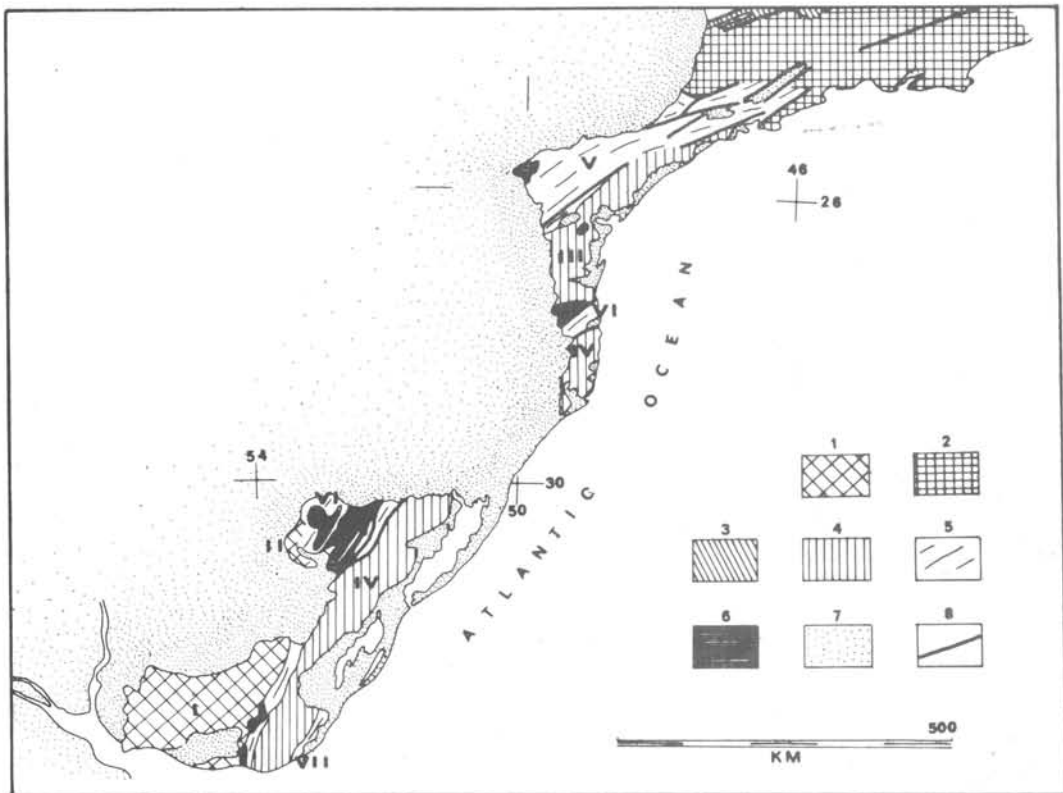


Figure 8 – SOUTHEASTERN FOLD REGION

1 – Rio de La Plata Craton: Uruguay (I) and Rio Grande do Sul (?) (II). 2 – Pré-Uruçuano areas, remobilized during the Brasiliano Cycle. 3 – Uruçu Fold Belt. 4 – Southeastern Region Median Massifs: Joinville (III) and Pelotas (IV). 5 – Southeastern Region Fold Systems: Apiaí (V), Tijucas (VI) and Eastern Uruguay (VII). 6 – Molasse basins of the Brasiliano Cycle. 7 – Phanerozoic sedimentary and volcano-sedimentary covers. 8 – Major faults.

Massif structures show deflections from the regional N30E to N60E as they approach the block-structured zone.

The western blocks are formed by meta-sediments of greenschist and amphibolite facies (São Roque Group), with many sintectonic granitoid intrusions. The eastern and northern blocks are constituted by rocks of amphibolite and gran. lite facies, with certainly pre-Uruaçuano ages, migmatized and intruded by granitoids during the Brasiliano Cycle. These lithologies has been described by Wernick (1967) and Ebert (1968) and included in the Amparo and Paraíba Groups. So, the blocks show Brasiliano units as well as remobilized older rocks. The structures in the blocks show various directions, predominating a N60-70E trend. These units extend till the southern border of the Uruaçu Belt and the limits are at least in part by faults. At the Jacutinga Fault Zone there is the molassic Eleutério Formation, related to the Brasiliano Cycle.

To the north of 21° S parallel, the exposed rocks are of Trans-Amazonic and older ages, remobilized during the Brasiliano Cycle (Cordani et al., 1973; Cordani, 1973). That area seems to correspond to the exposed infrastructure of the Southeastern Fold Region. The structures generally trend NNE, except in the part near the faulted-block region, where they inflect to N60E. The limit of remobilized area is not yet defined.

With respect to mineral resources, the Southeastern Fold Region has Pb-Zn deposits in the Apiai System, Au and Cu in the molasse basins and in the Apiai System, and complex pegmatites with Sn, W, and Li-bearing minerals.

## 6. THE PRECAMBRIAN IN THE ANDEAN CHAIN AND IN THE PATOGONIAN PLAT-FORM

The Southeastern Fold Region borders the Rio de La Plata Craton in Uruguay and disappears under the Atlantic Ocean. As will be shown below, it presumably returns and penetrates the continent through the Colorado River valley (Argentina).

In Sierras Australes, post-tectonic granites occur (Quartino and Villar-Fabre, 1967), with a K-Ar age of  $575 \pm 10$  m.y. (Halpern et al., 1972). The granites are intrusive in a metamorphic basement in which occur rhyolites recently dated by Rb-Sr with  $671 \pm 35$  m.y. (Varela and Cingolani, 1975). This plutono-volcanic magmatism may be compared to that of Caapucu in Eastern Paraguay. These rocks at Sierras Australes are covered by folded Paleozoic sediments, considered as a platform cover, possibly filling an aulacogene (Harrington, 1970), and deformed in the Mesozoic.

The Pre-Cordillera and the Cordillera Frontal (Province of Mendoza, NW Argentina) expose part of the Sierra Pintada System, formed by the San Rafael Block and by the Mendocino-Pampeano Belt (Criado Roque, 1972a,b). In the San Rafael Block, the presence of Precambrian or Cambrian metasediments and eruptives is highly probable (La Ventana Formation). These rocks are covered unconformably by Cambro-Ordovician limestones. Towards the southeast, in the Province of La Pampa, the existence of Precambrian rocks presumed by Criado Roque needs to be confirmed. The dated occurrences are Paleozoic: Lihuel-Calel is Upper Permian (Halpern et al., 1971) and Pichi Mahuida has  $550 \pm 35$  m.y. (Halpern et al., 1972). The Mendocino-Pampeano Belt seems to have developed after the regeneration of the structures related to the Brasiliano Cycle. These structures follow the southern edge of the Rio de La Plata Craton and are exposed in small nuclei on the

north-Pampean Plain. The geosynclinal evolution took place in Eo- and Meso-Paleozoic.

Farther south, in the Provinces of Rio Negro, Neuquén and Chubut, the exposed basement is constituted of metasediments considered of Precambrian age. They are penetrated by granites of Paleozoic age, till Permian (Halpern, 1968). The possibility that the metasedimentary complex is older, should not be overlooked; this would confirm the existence of an Upper Precambrian-Cambrian folded belt around the southern border of the South American Platform, regenerated in the Paleozoic. This belt would coincide with the 500-600 m.y. geochronological province that Halpern et al. (1972) suggested to cross the Argentina territory.

The Sierras Pampeanas, the Pre-Cordillera, the Eastern Cordillera and the Puna, in NW Argentina, and neighboring regions of Chile and Bolivia, show clear evidences of a geosynclinal evolution related to the Brasiliano Cycle. Borello (1969) distinguished a monoliminal geosynclinal evolution in that region, including an eastern miogeosyncline and a western eugeosyncline with ophiolites. This evolution took place in the Upper Precambrian and Lower Cambrian, with deposition of flysch in both zones and limestones in the miogeosyncline. Molasses constituted at the end of the cycle in the Provinces of Catamarca and Cordoba (Ambato Group). The flysch is intensely folded and re-folded, having been generally metamorphosed in greenschist and amphibolite facies, with intensity growing from E to W. Migmatization and granite intrusions took place in the inner zone; some of these rocks provided pebbles for the Cambrian and Lower Tremadocian conglomerates. Amphibolite facies is observed in the Puna, Eastern Cordillera and Sierras Pampeanas (Caminos, 1972, Gordillo and Lencinas, 1972).

Almost all of the Sierras Pampeanas mas-

sifs are constituted by a crystalline basement, which shows metasedimentary rocks metamorphosed in greenschist and amphibolite facies, partially migmatized and intruded by granitoids. Its age was determined by Rb/Sr isochrons corresponding to the Upper Precambrian; the results point out effects of the Brasiliano Cycle and remobilization of older, probably Upper Precambrian, rocks (Cingolani and Varela, 1975).

Several granitoid rocks of the Sierras Pampeanas have been dated. There are granites related to the Brasiliano Cycle and others related to a tectono-magmatic reactivation with intense acid and intermediate plutono-volcanic magmatism (Stepanic and Linares, 1969, Halpern et al., 1970, Gonzalez and Toselli, 1974). This process affected a zone extending at least between the Provinces of San Luis and Catamarca. It seems to be a reflected reactivation constituting an effect on the platform of the tectonic and magmatic processes which took place in the Paleozoic geosynclines at its border. Thus, the Sierras Pampeanas must be considered a reactivated area of the South American Platform.

The Sierras Transpampeanas shall be excluded from the South American Platform; they present Ordovician metasediments of a Paleozoic geosyncline.

The problem of the Precambrian-Cambrian limit surges in considering the stratigraphic relations, which in northwestern region of Argentina are the closest to that limit in South America. In the Sierra Villicun and the Sierra Chica de Zonda (Province of San Juan) there are non-metamorphic limestones, of Lower Cambrian, containing fossils of the *Ollenelus* fauna (Borello, 1964). The basement of these layers, thought not in direct contact with them, is exposed in the area. It is constituted by intensely metamorphosed and even migmatized rocks (Sierra Pie de Palo, 35 km E of Villicun).

In the Eastern Cordillera (Province of Salta) the Puncoviscana Formation is of Infra-cambrian age. It has flysch character, is little or non-metamorphosed and contains fossil remains with no stratigraphic value (Oldhamia, bilobites). It is penetrated by the Quesera granodiorite, dated of  $530 \pm 20$  m.y. The Puncoviscana Formation and the intrusion are covered unconformably by the Mesón Group (Ramos, 1973), of probable Upper Cambrian age. This group is under the fossiliferous Lower Tremadocian beds.

In Peru, Precambrian rocks are exposed in the south (Cordillera de la Costa and Western Cordillera) and in the center and north (Eastern Cordillera and the Maranhão River valley). In the south, schists, gneisses and migmatites are exposed and were dated at 600 m.y. (Western Cordillera, Stewart et al., 1974), seeming to testify that Brasiliano episodes occurred in the region. In the center and north, the exposed Precambrian rocks are very extensive. They are diverse metasediments of geosynclinal origin, including local basic eruptives, showing superposed folding and metamorphism of low pressure, even of amphibolite facies (Audebaud et al., 1971) with migmatization and granitization. These rocks form elevated, faulted nuclei, and are covered unconformably by the fossiliferous Ordovician beds (Dalmayrac, 1970).

In Ecuador, the basement of the Andean Belt seems to be exposed in a small area in the south, next to the coast, and in the axial region of the Eastern Cordillera. This is a little known area where elevated fault blocks, tilted towards east, expose metamorphic rocks of greenschist and amphibolite facies, showing local migmatization and granitization. These rocks are considered to be Precambrian although there are no stratigraphic and radiometric datings to prove it.

In Colombia, there are various regions in the Andean Cordillera where the Upper

Precambrian rocks occur: Sierra de Santa Marta, Guajira Peninsula, Central and Eastern Cordillera. The presence of Cambrian and Ordovician fossils and the low-medium degree of metamorphism in the Paleozoic rocks facilitate the distinction between them and the Precambrian rocks. The latter are schists, gneisses, migmatites and granites. In the Sierra de Santa Marta (Radelli, 1962), the Precambrian complex is formed of lithologies of high amphibolite to granulite facies, with acid intrusions dated of 1400 m.y. (Rb/Sr isochron) and 753 m.y. (Pinson et al., 1962; Irving, 1971; MacDonald and Hurley, 1969). The lithologic nature and the radiometric values suggest the existence of an ancient nucleus, perhaps even older than 1400 m.y., which seems to have been rejuvenated in the Upper Precambrian. The Eastern Cordillera in Colombia forks of into two branches that penetrate Venezuela. Upper Precambrian rocks exist in both.

The oldest rocks of Venezuelan Andes are included in the Iglesias Group (Kunding, 1938) of Upper Precambrian age. They are schists, gneisses, migmatites and amphibolites, very well developed in the Barinas State, where they have been described by Schubert (1968). The Bela Vista Formation shows a lower degree of metamorphism than that Group and is older than  $660 \pm 30$  m.y., which is the minimum age of the migmatitic gneisses associated to it (Martin Bellizzia, 1968). Rocks of the Yumare Complex occur in the western Caribe Range, similar to those of the Santa Marta Massif of Colombia. These rocks show metamorphism of amphibolite and granulite facies and have associated anorthosites in the San Quentin Massif (Bellizzia, 1973). Age of 1250 m.y. has been obtained for the Precambrian rocks from Guajira Arch (Bellizzia, 1973).

There are doubts with respect to the existence of Precambrian rocks in Chile. There are metamorphic rocks attributed to a crystalline basement in the coastal region between



Valparaiso and the Taitas Peninsula, as well as other locations in the north and south. Bonorino (1971) considered them Neo-Paleozoic, while other authors suppose them to be Eo-Paleozoic or Precambrian (Miller, 1973). This would be the case for the occurrences north of the Santiago parallel (Miller, 1973) which are noted in Fig. 1.

## 7. CONCLUSIONS

The South American Platform consolidated at the end of the Brasiliano Cycle, attaining orthoplatform conditions after the Cambro-Ordovician. Its southern and western borders, respectively adjacent to the Patagonian Platform and the Andean Chain, are hidden under the sedimentary cover. To the north, and east, its borders form a continental margin of Atlantic type.

A very extensive cratonic area was consolidated after the Trans-Amazonic. During the Upper Precambrian, regeneration and geosynclinal evolution occurred, along marginal belts and regions between the not regenerated portions. These acted as forelands during the Uruaçuano and Brasiliano Cycles. Some portions also constitute median massifs, geanticlines and fault-blocks; they were remobilized with intensity in inverse relation to their size.

The Pre-Uruaçuano structures are scarcely known, though they seem to have been remobilized through tectonic, magmatic and thermal processes of the Trans-Amazonic. The oldest rocks are metasediments of high amphibolite and granulite facies, with associated ultrabasites. The Trans-Amazonic processes affected vast areas; they seem to include belts of geosynclinal evolution and other areas only isotopically rejuvenated.

The cratons became the settings for extensive tectonic-magmatic reactivation processes, with the formation of volcano-sedimentary covers. Intrusions of acid and alkaline mate-

rials as well as ruptural phenomena and re-heating also took place on these cratonic areas.

The Brasiliano fold belts have several characteristic features in comparison with the fold regions.

The fold belts occupied a marginal position in relation to the cratons and show narrow, elongated forms, simple structure and rare expositions of the basement within them. The fold regions are located among different cratons, occupying extensive polygonal areas of thousands of square kilometers; they show a complex structural organization, involving various geosynclinal or fold systems, separated by several median massifs and geanticlines; within them, the pre-Brasiliano basement is frequently exposed.

Regarding the sedimentary filling, the belts include essentially detritic-chemical sequences, with few volcanic contributions; some stratigraphic units are transgressive over the cratons. In fold regions, terrigenous sediments predominate, limestones being rare, and the total thicknesses are smaller.

The belts present holomorphic folding trending parallel to the cratonic border, towards which the polarities are directed. The metamorphism is of greenschist facies, seemingly of low-intermediary pressure type. The pre-tectonic magmatism was practically absent; acid magmatism generated only some post-tectonic stocks restricted to the inner zones. In the fold regions, each system shows holomorphic folding with longitudinal trend, but the polarities are undefined or badly defined. Reactivations of deep and ancient faults were important in the development of the regions and their tectogenesis. Metamorphisms was of greenschist and amphibolite facies, of low-medium pressure type. Migmatization was frequent. The pre-tectonic magmatism was poorly developed, but the sintectonic was extremely

active and shows affinity to the geanticlines and median massifs.

In the fold belts, molassic sediments fill foredeeps, intradeeps and marginal troughs. Subsequent volcanism did not occur. Molasse deformations become less intense as they go from the interior of the belt towards the cratonic areas. In fold regions, intradeeps are superimposed to the folded systems and their borders. The molasses show different structural and stratigraphic stages; to the intermediary stage are associated acid-intermediate and subordinate basic volcanic rocks, with important mineralizations. Molasse deformations are much more intense in the lower units than in the upper.

In the regions and belts, the analysis of the lithology of the orogenic period reveals that the Brasiliano Cycle produced only moderate reliefs.

The mineral resources of the folded belts are syngenetic, stratiform and remobilized ones. In the folded regions they are more varied, with lithophile and siderophile elements of granitic affinity associated to pegmatites, skarnites and greisens. In addition, there are metals in vein deposits, concentrated from the sediments.

The facts and inferences presented for the Patagonian Platform and Andean Chain, seem to indicate that the succeeding fold belts developed in Phanerozoic times, along the southern and western border of the South American Platform, were established over an extensive Upper Precambrian folded unit around the Amazonic-Rio de La Plata cratons. There is not sufficient information on the number of Precambrian tectono-magmatic cycles, but the youngest one certainly can be correlated to the Brasiliano.

The rocks of the Andean Chain and of the southern border of the South American

Platform, related to the Brasiliano Cycle, show linear folding and metamorphism of greenschist-amphibolite facies of low-medium pressure type, including migmatization and active anatexis. These characteristics are similar to those of other Brasiliano fold regions, contrasting notably with those of Uruaçu Belt. The latter is characterized by a scarcity of migmatites and granites, high pressure metamorphism and the development of basic-ultrabasic bodies.

The fold belts and regions developed at the east of Amazonic-Rio de La Plata cratons finished their evolution in Cambro-Ordovician times. After the consolidation, it followed a typical platformal evolution, characterized by the development of the large Paleozoic Paraná and Parnaíba Synclises, which may be figured as frustrated geosynclines.

Phanerozoic sedimentary areas show a marked influence of Precambrian structural framework, particularly that of the Upper Precambrian. Generally, the belts and regions consolidated as a result of the Brasiliano Cycle show subsidence tendencies, while the cratonic nuclei, geanticlines and median massifs show a tendency for positive movements.

#### SUMMARY

This paper deals with the structural organization and tectonic evolution of South American Continent basement during the Upper Precambrian.

The South American Platform is the old platform of South America. It has more than half of this extension covered by sediments and volcanic rocks of Phanerozoic age; the basement is exposed in three vast shields and several little massifs.

In the exposed basement some cratonic

nuclei have been distinguished, with structures developed in the Middle Precambrian (Trans-Amazonic) and Lower Precambrian (Jequié and Guriense). The Lower Precambrian structures are described in small scattered nuclei, all the rest seeming to have been remobilized by tectonic, magmatic and thermal processes of Trans-Amazonic age. These processes affected large areas but are still insufficiently understood.

In the Upper Precambrian, these cratonic nuclei underwent intense process of reactivation, in large areas, with formation of volcano-sedimentary covers, acid, basic and alkaline intrusive rocks, cataclastic zones and thermally affected zones.

During the Upper Precambrian, geosynclinal evolution processes developed at the borders and between the cratons, generating fold belts and regions. The firstly developed belt is located in Central Brazil, related to the Uruaçuano Cycle (ca. 1300-1000 m.a.). The Espinhaço and Uruaçu Belts are attributed to this cycle.

The other units are related to the Brasileiro Cycle ( 1000 m.y. to Cambro-Ordovician time). The fold belts are located in marginal po-

sition and the fold regions are between cratonic areas: both show different characteristic of organization, sedimentation, structures, tectonism, metamorphism, magmatism and metallogenesis.

In the southern border of the South American Platform a fold region developed, which possibly represents the extension of the Southeastern Fold Region, and continues to the Andean Belt .

The South American Platform consolidated during Cambro-Ordovician time. Its western and southern adjacent areas were places of geosynclinal evolution up to the Devonian in the Patagonian Platform and up to the Cenozoic in the Andean Chain. The eastern half of the South American Platform had a platformal evolution since the Silurian.

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