THE NATURE, DISTRIBUTION AND RELATIONSHIP OF ARCHAEOAN TERRANES
IN EASTERN BRAZIL

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ABSTRACT This is a study of the general geological characteristics, distribution and relationship of the major Archaean terranes of eastern Brazil. It also includes a concise description of several lithostratigraphic sequences of typical greenstone signature and associated granite-gneisses belonging the São Francisco Craton, which is interpreted as the only Archaean cratonic area within the region under consideration. The greenstone successions, however, present a poorly preserved stratigraphy, due mainly to the emplacement of gneissic tonalite, and granite plutons, and to the proportion of volcanics, particularly of komatiitic composition, is low, while aquagene tuffs and associated sediments form the most important lithological components.

The high-grade metamorphic terranes, subjected to granulite facies of regional metamorphism mostly during the late Archaean (~ 2.7 Ga), are represented by the Jequié and Goiás mobile belts, and the Santa Catarina and Santa Maria Chico complexes. In the first two belts, granite-greenstone nucleus display relatively well preserved stratigraphic sequences exist within the high-grade metamorphites as isolated remnants, while adjacent areas have been reworked by a intense tectono-thermal event. In comparison to Archaean terranes in other parts of the world, the Brazilian counterparts are rather different in features such as transitional boundaries, fragmentary patterns and poorly preserved greenstone sequences.

RESUMO Este trabalho estuda as características geológicas gerais, a distribuição e a relação dos principais terrenos arqueanos do Leste brasileiro. Ele inclui também a descrição de muitas seqüências estratigráficas do típico *greenstone-belt* e de gnaisses graníticos associados, pertencentes ao Cráton do São Francisco e que pode ser interpretado como a única área cratônica arqueana dentro da região em consideração. A sucessão dos *greenstones*, no entanto, apresenta uma estratigrafia pobremente preservada, devido principalmente à inserção de gnaisses tonalíticos e granitos plutônicos, e à proporção de vulcânicas, principalmente de composição komatiítica, ser baixa, enquanto que os tufos e sedimentos associados formam o mais importante dos componentes litológicos.

Os terrenos metamórficos de alto grau, sujeitos ao fácies granulítico, formados principalmente durante o último período arqueano (~ 2.7 Ga), estão representados pelos cinturões móveis de Jequié e Goiás e os complexos de Santa Catarina e Santa Maria Chico. Nos dois primeiros cinturões, os núcleos de terrenos de *greenstone*-granitos mostram seqüências estratigráficas bem preservadas, que existem dentro dos metamorfitos de alto grau como remanescentes isolados, enquanto que as áreas adjacentes têm sido retrabalhadas por um evento tectono-termal intenso. Em comparação com os terrenos arqueanos de outros lugares do mundo, os terrenos brasileiros apresentam certas diferenças, tais como, contatos transicionais, aspecto de fragmentação intensa e seqüências de *greenstone* pobremente preservadas.

INTRODUCTION The regional and detailed geological investigations carried out in the last ten years in the eastern part of Brazil, have resulted in the recognition of several major Archaean domains with confirmed radiometric ages older than 2.5 Ga (Fig. 1).

A high degree of uncertainty, however, remains with respect to the boundaries and relationship between these domains, due mainly to the lack of exposure in critical areas and also to the substantial reworking of the earlier lithostratigraphic sequences by the superimposition of younger tectono-thermal events. Thus, the definition and extent of cratonic and mobile zones of Archaean age in the eastern region of Brazil are inferred in some areas, rather than based on direct geological observation. However, despite the limitations, imposed by the nature of these terranes, there is evidence for separating a major cratonic area — the São Francisco Craton — and at least two mobile zones: the Jequié and Goiás belts. In addition, granite-greenstone nucleus and rather small high-grade metamorphic complexes are known within the various Archaean environments of eastern Brazil.

Most of the low-grade granite-greenstone belts in central eastern Brazil are integral members of the São Francisco

Craton, but a few relatively well preserved granite-greenstone nucleus also exist in the adjacent high-grade mobile areas bordering the craton. As their geological settings differ considerably, the latter areas will be described separately.

THE SÃO FRANCISCO CRATON Although this Archaean domain is regarded as one of the best investigated areas among Brazilian ancient terranes, there are still many doubts, especially in relation to its boundaries and its structural relationship with adjacent Precambrian terranes, due basically to the presence of extensive sedimentary cover sequences of Precambrian and Phanerozoic ages. In a recent review (Bernasconi 1983) applying the Anhaeusser *et al.* (1969) cratonic criterion, the boundaries of the craton as defined by Almeida (1967) and latter revised by Almeida (1977) were substantially modified, such that a large part of its northeast extension was separated and redefined as probably forming part of two different geotectonic units, the Jequié Mobile Belt and the São Luís-Paramirim Province (Figs. 2 and 3).

A significant portion of the exposed areas of the São Francisco Craton is occupied by a variety of granite-gneiss

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Figure 1 - Map geotectonic units

rocks, which have received relatively less attention than the areas of greenstone-type lithostratigraphic units. Migmatitic rocks associated with granitoid-gneisses are also present in the southeast part of the craton.

Apart from the better studied southeast region, radiometric age determinations have only been carried out on rocks from a small area north of Colinas, on the central west flank of the craton, giving a Rb-Sr isochron of approximately 3.2 Ga (Tassinari *et al.* 1981).

Much of the geological data, presently available for the craton, is derived from areas containing partly preserved greenstone successions such as Piñi, Fortaleza de Minas, Quadrilátero Ferrífero (Iron Quadrangle), Gouveia, Riacho dos Machados and Dianópolis (Fig. 2). These sequences commonly show rather depleted stratigraphic successions in which komatiitic rocks and acid volcanics are only present in restricted quantities, and well developed metatholeiite units may also be lacking. Conversely, tuffaceous lithologies and associated metasediments are comparatively abundant.

The Piñi succession is described (Fritzens *et al.* 1980, Biondi & Schrank 1980) as a volcano-sedimentary sequence largely composed of metatholeiitic basalts, with intercalated tuffaceous material and minor acid to intermediate metavolcanics.

The main lithostratigraphic characteristics of the Fortaleza de Minas belt (Teixeira & Danni 1979 a,b) include the presence of significant quantities of greenschists (metatuffs) with oxide-facies banded-iron formations and minor serpentinized ultramafic rocks of a possible komatiitic affiliation. Besides, several small differentiated mafic to ultramafic intrusives are known in this belt.

The largest of the greenstone successions, known within the craton, is the Rio das Velhas greenstone belt, which underlies the Proterozoic sequences of the Iron Quadrangle district. It is composed of two major units, the Nova Lima Group and the overlying Maquiné Group (Dorr *et al.* 1957, Dorr 1969). The former group consists essentially of a schistose assemblage mainly developed from a volcano-sedimentary sequence rich in alumina, iron and silica subjected to a low-grade regional metamorphism (Herz 1978). Various types of banded iron-formation, small bodies of deeply altered mafic to ultramafic rocks, including a prominent serpentinite unit displaying spinifex texture south of Santa Barbara, Quebra-Oso Group, and subordinate pillowed mafic volcanics, are also present in the Nova Lima Group.

The Maquiné Group is almost entirely formed by psammitic metasediments, making its lithological characteristics similar to the Lower Proterozoic sequences, also present in the area. Thus, in the author's opinion, the Archaean age of this group remains uncertain.

Archaean granite-gneiss rocks are also well exposed in this area, and some of them, particularly the Bação Complex, show excellent field evidence of their intrusive character in the rocks of the Nova Lima Group. The available geochronological data (Herz 1970, Cordani & Teixeira 1979) indicate Rb-Sr age between 2.8 and 2.7 Ga.

The other greenstone successions of Gouveia, Riacho dos Machados and Dianópolis (Fig. 2), are relatively less investigated and they seem to represent only poorly preserved relics. However, a schistose sequence, partly similar to that of the Nova Lima Group, is exposed at Gouveia and Riacho dos Machados, and in the latter area sheared greenstones, probably metatholeiitic volcanics, are also present (Bernasconi 1983).

The existence of an Archaean volcano-sedimentary sequence of greenstone affiliation in the vicinity of Dianópolis (Goiás) was reported by Costa *et al.* (1976). In general, this belt is composed of mica schists, oxide-facies banded iron-formation, and irregular outcrops of massive basic metavolcanics. Large granitic bodies of possible Archaean age appear to intrude the volcano-sedimentary sequence.

HIGH-GRADE GRANULITE-GNEISS TERRANES The presence of high-grade metamorphic terranes has been confirmed in several areas of eastern Brazil, including the Jequié and Goiás mobile belts, and the Santa Catarina and Santa Maria Chico complexes (Fig. 1).

The Jequié Mobile Belt A substantial portion of eastern Bahia state is underlain by high-grade metamorphic rocks, mainly within the granulite and upper amphibolite facies (Fujimori 1968, Sighinolfi 1970, Oliveira *et al.* 1982). In the northern part of this belt, the folded structure of the Caraíba Complex (Barbosa 1970), which consists predominantly of migmatites, banded gneisses, schists and subordinate mafic to ultramafic bodies, seem to coexist

Figure 2 — Localization of Greenstone-lithostratigraphic sequences associated of the São Francisco Craton

(Figueiredo 1980) with the low-grade (upper greenschist facies) Rio Itapicuru sequence (Fig. 2).

The Rio Itapicuru sequence, a partially reworked greenstone belt, is restricted to a synclinorium with a length of approximately 100 km. The poorly preserved volcano-sedimentary assemblage consists of three major lithostratigraphic units: a Mafic Metavolcanic Unit, a Felsic Metavolcanic Unit and a Metasedimentary Unit. A gneissic-granite to granodiorite bodies also occur (Kishida 1979, Kishida & Riccio 1980). Metatholeiitic volcanics are abundant in the basal Mafic Unit, while intermediate pyroclastics are essential components of the overlying Felsic Unit. The Metasedimentary Unit includes conglomerate, arkose, greywacke, and siltstone.

The high-grade metamorphic rocks of the southern part of the belt form the so-called Jeiquié Complex (Cordani 1973), which includes granulites of various compositions, minor marble horizons and carbonate-rich lenses.

Although geochronological data are relatively abundant for the entire belt, the most reliable determinations were presented by Cordani & Iyer (1979), based on a review of

numerous Rb-Sr ages from granulitic rocks of the Jeiquié Complex. These latest results suggest the presence of three distinctive sets of radiometric ages probably related to different events, i.e. a pre-Jequié cycle of approximately 3.2 Ga, interpreted as an older basement, the Jeiquié event at ~ 2.7 Ga, and a set of younger ages between 2.45 and 2.3 Ga of rather doubtful interpretation.

To the west, the Jeiquié belt is flanked by a poorly exposed gneiss-migmatite assemblage (Pedreira *et al.* 1978) affected by the Transamazônico event (~ 2.0 Ga) and generally referred to as the Paramirim Complex. It is difficult to define the boundary between these two major geotectonic units, which are separated by a transitional zone with a mixture of high-grade metamorphic rocks from both complexes.

Intensive magmatic activity developed in the Paramirim Complex, during the Transamazônico cycle, with the generation of numerous granite, granodiorite and syenite bodies intruding the gneiss-migmatite assemblage. In the southern part of this area, several rather small complexes of uncertain association and age, such as the Contendas-

Figure 3 – Geotectonic outline of eastern Brazil

Mirante, Ibitira-Brumado and Urandi complexes (Fig. 2), are exposed as relic volcano-sedimentary sequences within the Transamazônico granite-gneiss terranes (Mascarenhas & Silva Sá 1982).

The geochronological pattern of this domain covers a rather wide time span, reflecting the effects of several superimposed events from the early Archaean to the Middle Proterozoic. The Paramirim Complex is partly similar to the Jequié belt and it becomes difficult to determine if this complex represents the western extension of this belt or whether it should be considered as a separate geotectonic unit. Based on certain lithological differences, as well as the grade of metamorphism and structural setting, the author would favour the second option, and this large area between the Jequié Mobile Belt and the São Francisco Craton would constitute the São Luís – Paramirim Province of Transamazônico age (Fig. 3).

The Goiás Mobile Belt This belt is exposed as scattered segments partly covered by supracrustal rocks of the Araxá Group of Middle Proterozoic age, and it is therefore difficult to assess to what extent it represented a major mobile zone between the São Francisco and Guaporé Cratons in the late Archaean. However, it is suspected that a significant portion of the state of Goiás is underlain by high-grade metamorphic lithologies, generally within the granulite facies, belonging to this geotectonic unit (Fig. 2).

Granitic to granodioritic-gneiss, migmatite, granulite, amphibolite, calc-silicate rocks and subordinate marble lenses form the central part of the belt, which has been previously referred to as the Goiás Granulitic Belt (Wernick

& Almeida 1979, Wernick 1981). The high-grade, more basic assemblage of the Goiânia-Trindade region (Nilson & Motta 1969), and the high-grade metamorphic rocks mapped in the vicinities of both the Barro Alto and Niquelândia (Tocantins) mafic to ultramafic complexes (Lindenmayer 1970, Baeta *et al.* 1972, Motta *et al.* 1972) are also considered to be part of this mobile belt.

The geochronological investigations carried out within the region of Itapirapuã (Tassinari *et al.* 1981) yielded radiometric ages by the Rb-Sr method of 2651 ± 27 Ma, related to the Jequié tectonothermal event.

Although numerous mafic to ultramafic differentiated intrusions, including the three largest bodies of Barro Alto, Niquelândia (Tocantins) and Cana Brava are present within the area occupied by the Goiás Mobile Belt (Fig. 2), there is insufficient geological evidence as yet to support their probable Archaean ages, or any genetic relationship of these complexes with the Jequié event. The ages, origins and affiliations of these major intrusions thus remain highly controversial.

The granite-greenstone nucleus of the Tocantins Province

The Tocantins Province is an extensive and geologically complex structural domain in central Brazil, including a variety of Precambrian stratigraphic units. The presence of greenstone relics within the Tocantins Province is a common feature in numerous areas, occupied by older rocks underlying the Araxá Group lithologies, but only two of them present sufficient lithostratigraphic elements to merit separate description, namely the Crixás and the Iporá greenstone belts (Fig. 2). These belts are bounded by the high-grade metamorphites of the Goiás mobile belt to the east, while the Crixás belt is bordered to the west by basement with extensive shearing and reworking in the late Precambrian.

The Crixás greenstone sequence is particularly significant as it contains substantial amounts of komatiitic rocks within three slightly arcuate belts, trending approximately north-south. It is intruded by granitic rocks and partially covered by the Araxá Group.

Three main stratigraphic units have been recognized (Sabóia 1979, Sabóia & Teixeira 1983) mostly from mapping in the westernmost belt. A relatively thick sequence of approximately 4.5 km of mainly ultrabasic rocks comprises the Basal Unit, which is characterized by the presence of significant amounts of komatiitic varieties (Kuyumjian 1981) exhibiting spinifex textures and polyhedral jointing (Sabóia & Teixeira 1980 *et al.* 1981).

A Middle Unit composed mainly of metatholeiites, with interbeds of graphite schist, iron formation, and quartz-sericite schist, is mainly exposed to the south of the town of Crixás. Towards the north, this unit is flanked by a metasedimentary succession of quartz-sericite schist, chert, graphitic schist, banded iron-formation and carbonate rocks which together constitute the Top Unit.

The intrusive granites, which occupy the areas between the volcano-sedimentary belts, have a radiometric age of 2929 ± 105 Ma (Rb-Sr reference isochron, Tassinari & Montalvão 1980).

The Iporá belt, which is exposed in separate outcrops, partly covered by Proterozoic and Devonian sediments, presumably extends for about 30 km in a north-south

direction and consists of mica schists, banded iron-formation and scattered outcrops of massive metatholeites, and minor acid-intermediate volcanics and tuffs. The sequence also includes a differentiated mafic to ultramafic body outcropping south of Iporá.

Although the cover rocks of the Araxá Group preclude the investigation of the exact relationship between these low-grade metamorphosed greenstone sequences and the gneissic-granulitic rocks of the Goiás belt, it also seems that both metamorphic facies coexist in a relatively small area, resembling the coexistence of the Rio Itapicuru greenstone sequence within the Jequié mobile belt. Thus the Crixás and Iporá greenstone sequences are interpreted as Archaean segments belonging to an earlier cratonic domain, which was largely reworked by the late Archaean Jequié tectono-thermal event and subsequent rejuvenation Proterozoic.

The Santa Catarina Complex The presence of an ancient nucleus with Archaean radiometric ages has been confirmed in Santa Catarina State of southern Brazil (Fig. 1). Although high-grade metamorphic rocks were earlier described by Albuquerque *et al.* (1971), Hartmann (1976) and Almeida *et al.* (1976), it was only during recent studies, carried out by Hartmann *et al.* (1979) and Silva & Dias (1981), that these rocks were recognized as an integral part of an ancient mobile zone and subsequently termed the Santa Catarina Granulite Complex.

The outcrop area of this complex is rather small, not exceeding 9,000 km², but it may continue towards the west under the Paraná basin, while the high-grade metamorphites in Rio Grande do Sul State some 600 km to the south and could also form part of the same domain. To the north and south the complex is flanked by the late Precambrian sequences affected by the Brasiliano cycle.

This high-grade metamorphic complex comprises a suite of rocks in which leucocratic granulitic gneisses are the most common lithology, probably representing up to 80% of the suite, accompanied by metaquartzites, calc-silicate rocks, oxide-facies banded iron-formation, and mafic to ultramafic bodies, with minor kinzigites and anorthosites. The metamorphic mineral assemblage of these rocks indicates that the complex was affected by granulite to amphibolite facies regional metamorphism during the Jequié cycle, since the available Rb-Sr radiometric data from granulitic gneisses indicate an approximate age of 2.7 Ga (Hartmann *et al.* 1979, Kaul & Teixeira 1982).

The Santa Maria Chico Complex In the State of Rio Grande do Sul, granulite facies metamorphic rocks appear in several as also poorly investigated segments in a relatively small area (Fig. 2) between the late Precambrian units and the Paraná basin (Nardi & Hartmann 1979, 1980, Hartmann & Nardi 1980). These various segments, which together comprise the Santa Maria Chico Complex, are separated by granite intrusions belonging to the Brasiliano cycle (~ 550 Ma) and are also partially covered by a Eopalaeozoic volcano-sedimentary molassic sequence. The granulitic rocks may possibly extend for a considerable distance under the Paraná basin sediments.

The most important lithological component of the complex is formed by quartz-felspar gneisses, which mainly show granoblastic rather than typical granulitic textures.

Basic gneisses, with ultrabasic and anorthositic intercalations, and garnet-rich sillimanite gneisses, are present in reduced quantities. In addition, charnockitic rocks have been identified in some of the high-grade metamorphic segments (De Ros & Fernandez 1981).

DISCUSSION The data compiled and reviewed in this study indicate the presence of several domains older than 2.5 Ga within the eastern region of Brazil. However, only one of these domains, the São Francisco Craton, of rather small size, seems to indicate all the relevant features pertaining to a cratonic area as defined by Anhaeusser *et al.* (1969) and Anhaeusser (1975).

In contrast with many ancient cratonic areas in other continents, the greenstone nuclei enclosed within the São Francisco Craton present, in general, poorly preserved stratigraphic sequences, occurring mostly as relics, with reduced amounts of volcanics, especially of komatiitic and acid composition. Conversely, they contain a significant contribution from aquagene tuffs and clastic and chemical sediments. In addition, partial removal of some lithostratigraphic units in these successions seems to have taken place during the emplacement of gneissic tonalite intrusions and granitic plutons, during a period of intense magmatic activity, which, according to available geochronological data, could have started prior to 3.2 Ga and lasted for at least 400 Ma, since it probably ceased about 2.8 Ga.

The remainder of the presently known Archaean terranes of eastern Brazil, *i.e.* the Jequié and Goiás belts, and the Santa Catarina and Santa Maria Chico complexes, have geological characteristics typical of mobile zones, similar to those described by Anhaeusser *et al.* (1969) Mason (1973), McGregor (1973), Park (1973), Anhaeusser (1975), Kröner (1977) and Windley (1981). However, the existence within the high-grade metamorphic terranes of the Jequié and Goiás belts of low-grade granite-greenstone nuclei with relatively well preserved stratigraphic sequences, seems to be a notable feature of these two mobile zones.

Intense reworking effected by the superimposition of at least two major Precambrian tectono-thermal events, namely the Jequié and Transamazônico, equivalent respectively to the Limpopo-Liberia and Eburnian events in Africa, was probably responsible for the obliteration of a substantial portion of the early granite-greenstone terranes, and only isolated greenstone relics were preserved.

The subsequent development of other mobile belts during the Uruçuano (1.7-1.1 Ga) and Brasiliano (750-550 Ma) cycles, in areas partly underlain by Archaean terranes, reduced the extent of these terranes considerably, producing a rather fragmentary pattern. Nevertheless, a geological reconstruction showing the distribution of these early Precambrian terranes (Fig. 3) can still be attempted, despite the restrictions caused by the superimposition of tectono-thermal events and also by the lack of good exposure.

Features such as transitional boundaries, fragmentary patterns, and poorly preserved greenstone sequences, partially distinguish the Brazilian Archaean terranes from the better preserved major Archaean domains of other continents.

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MANUSCRITO

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O velho mundo da laplaciana certeza está morto e sem possibilidade de volta. O desafio enfrentado pelos cientistas modernos e outras pessoas é operar racionalmente numa área de irreduzível incerteza.

Robert G. Colodny, Introdução de *Faces of Science*, de Nalimov, ISI Press, 1981.