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GEOLOGICAL AND METALLOGENIC PATTERNS IN THE ARCHEAN AND EARLY PROTEROZOIC OF BAHIA STATE, EASTERN BRAZIL

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ABSTRACT The territory of Bahia State is part of the São Francisco structural province. The basement of the province is characterized by granite-greenstone and high grade metamorphic terrains developed during the Archean and Early Proterozoic. The Early Archean is represented by small tonalitic-granodioritic and enderbitic-charnockitic nuclei 3,500 Ma old. Several portions of gneissic-migmatitic and granulitic terrains have ages of 3,000 Ma and Rb/Sr isochronic values of 2,700 Ma that represent the principal phase of the Jequié geotectonic cycle. During the Early Proterozoic, extensive areas of the basement of the São Francisco province underwent intensive remobilization, through granitization and K-metasomatism related to the Transamazônico geotectonic cycle (2,200-1,800 Ma).

Besides greenstone belts the granite-greenstone terrains contain volcano-sedimentary (greenstone belt like) and platform sequences developed since the Archean to the Early Proterozoic. The high grade metamorphic terrains contain remnants of supracrustal sequences and basic-ultrabasic complexes.

The metallogenic framework of Bahia shows that more important mineral deposits such as Au, Cr, Cu, Fe-Ti-V, Pb-Zn-Mn, magnesite and talc are related to Archean and Early Proterozoic evolution. Gold deposits are located in volcanic rocks of greenstone belt environments, and in conglomerates of Witwatersrand type. Economic deposits of Cr, Cu, Fe-Ti-V are associated with mafic-ultramafic complexes in high grade metamorphic terrains. Pb-Zn and Mn mineralizations occur in volcano-sedimentary (greenstone belt like) sequences and the platform sequences contain large deposits of magnesite and talc.

INTRODUCTION Bahia State, with an area of about 500,000 km^2, lies almost entirely within the *São Francisco Province* (Almeida *et al.*, 1977), an extensive cratonic nucleus stabilized at the end of the Transamazônico geotectonic cycle (2.700-1.800 Ma). It is surrounded by regions which suffered regeneration in geosynclinal environments during the Brasiliano geotectonic cycle (1,100-450 Ma).

Situated in the middle of the most easterly part of Brazil, it is limited by the *Borborema Province*, to the north; the *Parnaíba*, to the northwest; the *Tocantins* to the west; the *Mantiqueira* to the south and southeast; and, finally, by the *Coastal Province and continental margin* to the east (Fig. 1).

As component parts of the *Borborema*, *Tocantins* and *Mantiqueira Provinces*, which, however, represent the geological limits of the *São Francisco Province*, bordering geosynclinal structures occur, with polarity directed towards the interior of the Province. These structures are the *folded belts of Sergipe*, *Riacho do Pontal* (Brito Neves, 1975), *Rio Preto* (Inda and Barbosa, 1978), *Brasília* and *Araçuaí* (Almeida, 1968, 1977), which were established during the Upper Proterozoic Brasiliano Cycle (Fig. 2).

The geological limits of the *Province*, as defined by Almeida *et al.* (1977) are conventional, being based on transitional tectonic belts. Surface gravimetric surveys, undertaken by Gomes and Motta (1978, 1980), however, established good identification with the geological features, and confirmed these ideas, particularly those related to the *Sergipe*, *Riacho do Pontal*, and part of the *Brasília folded belts*. Significant displacements between surface geology and inferred gravimetric structures were found only in the northern part of the *Araçuai belt* (Fig. 3).

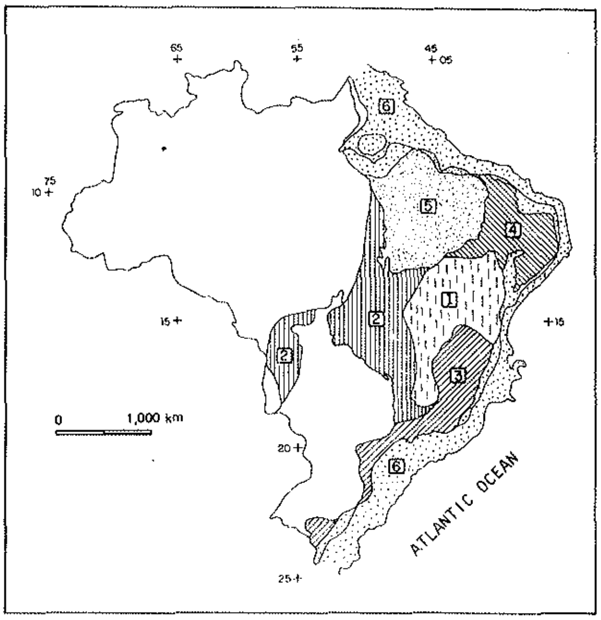

Figure 1 – Situation of the São Francisco province (**1**) *Relatively to Tocantins* (**2**), *Mantiqueira* (**3**), *Borborema* (**4**), *Parnaíba* (**5**), *coast and continental margin* (**6**) *Provinces* (*after Almeida* et al., *1977*)

As far as the *Sergipe belt* is concerned, the limit was established at the point of the great deflection of direction of the structural and isogalic alignments, which to the south have a N-S orientation which changes to NW-SE to the north of the limit.

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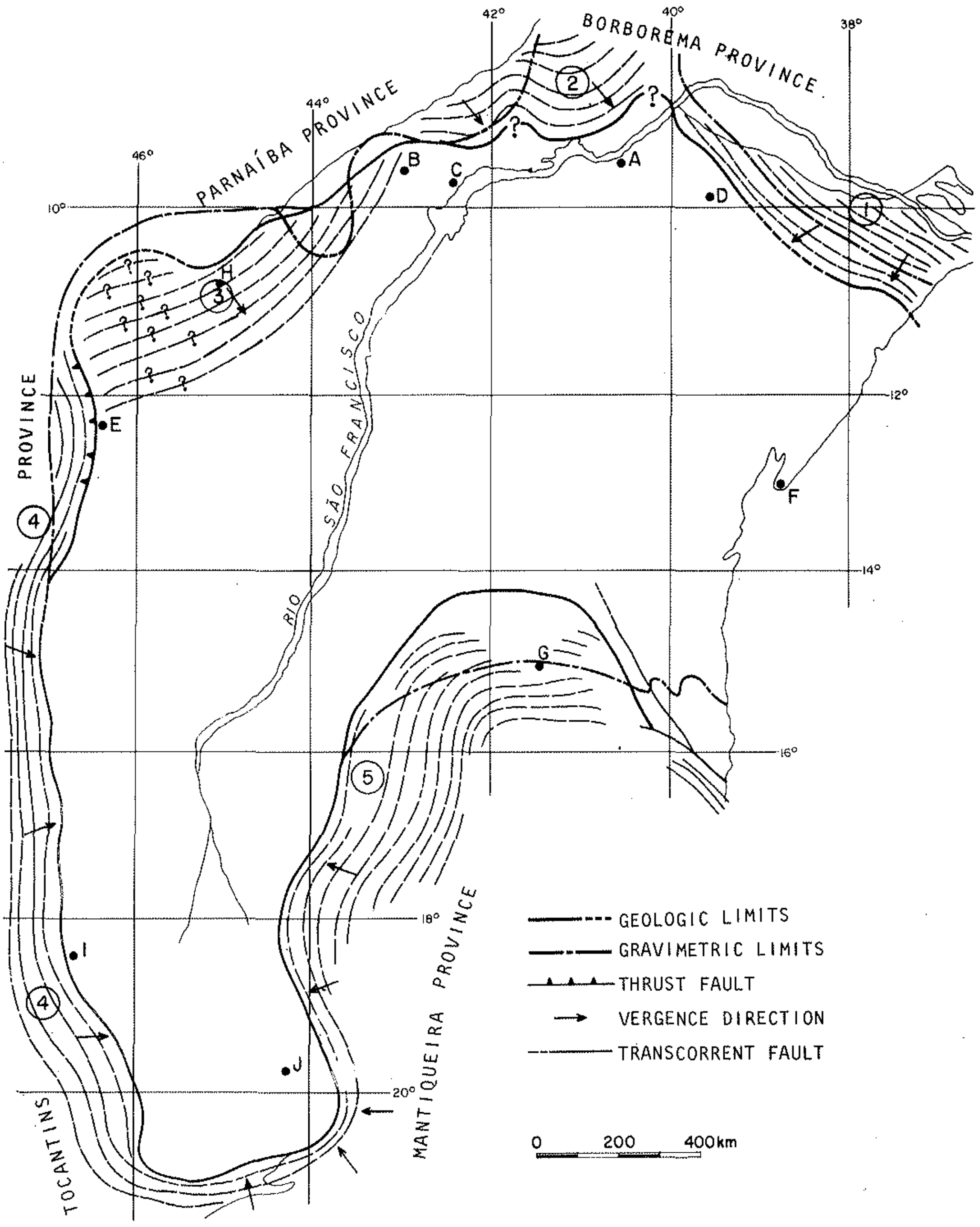

Figure 2 – Situation of the São Francisco province relatively to Brazilian fold belts: **1** *– Sergipana;* **2** *– Riacho do Pontal;* **3** *– Rio Preto;* **4** *– Brasília;* **5** *– Araçuaí; cities and villages:* **A** *– Juazeiro;* **B** *– Campo Alegre de Lourdes;* **C** *– Remanso;* **D** *– Uauá;* **E** *– São Domingos;* **F** *– Salvador;* **G** *– Vitória da Conquista;* **H** *– Formosa do Rio Preto;* **I** *– Patos de Minas;* **J** *– Belo Horizonte*

For the *Riacho do Pontal belt*, the limit was established as a function of the deep, WSW-ENE crustal faults, showing maximum Bouguer anomalies of +5 mgal, which are repeated only at the coast of Bahia (Motta, *in* Mascarenhas *et al.*, 1982). In the folded belt, the depth of the Moho is approximately 32 km (Motta, *op. cit.*).

For the *Brasília belt*, the gravimetric data are insufficient, but high Bouguer values, similar to those which characterize the Riacho do Pontal limit, continue into Goiás State, and accompany reasonably well the geological limit up to latitude 13°S.

To the north of the *Araçuaí belt*, the limit is marked by an accentuated gravimetric gradient, with values changing rapidly from – 50 mgal to the north of Itambé, to – 75 mgal at Vitória da Conquista, which corresponds to 1 mgal/km.

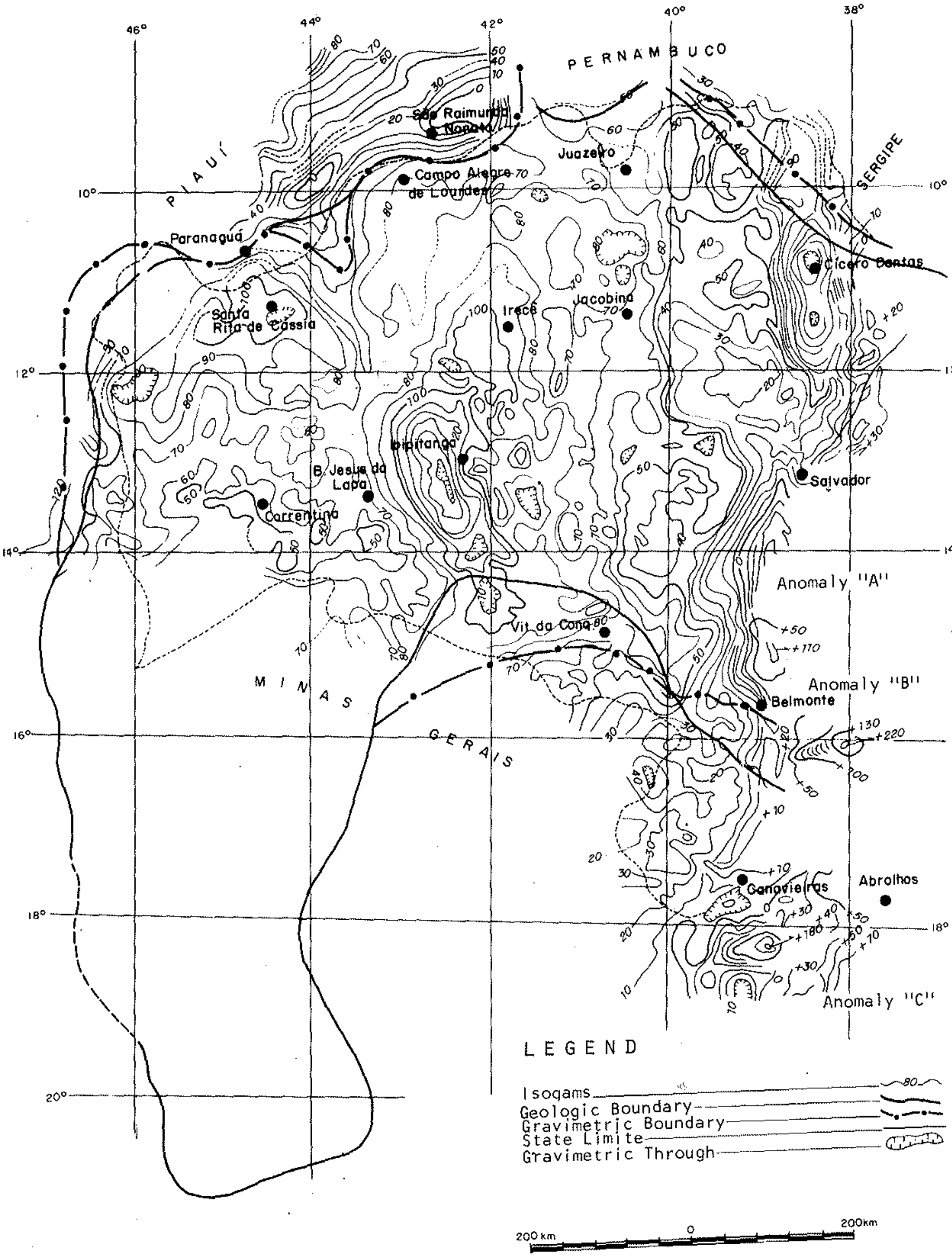

Figure 3 – Bouguer map of Bahia after: DNPM CPRM – Proj. Levantamento Gravimétrico no Estado da Bahia. Ref. final 1980 A C. MOTTA 1981

CHARACTERISTICS OF THE SÃO FRANCISCO PROVINCE IN BAHIA STATE Referring to the Archean and Lower Proterozoic, in Bahia State the *Pre-Espinhaço Assemblage* is defined as the products of all lithostratigraphic processes as late as the start of the Middle Proterozoic (1,800-1,100 Ma), when paraplatform sequences of rifts and intracratonic basins, which correspond to the Espinhaço Supergroup, were deposited.

Generically, the *Pre-Espinhaço Assemblage* includes granite-greenstone and high-grade metamorphic terrains. Because of the particularities of each one, they are described separately (Fig. 4).

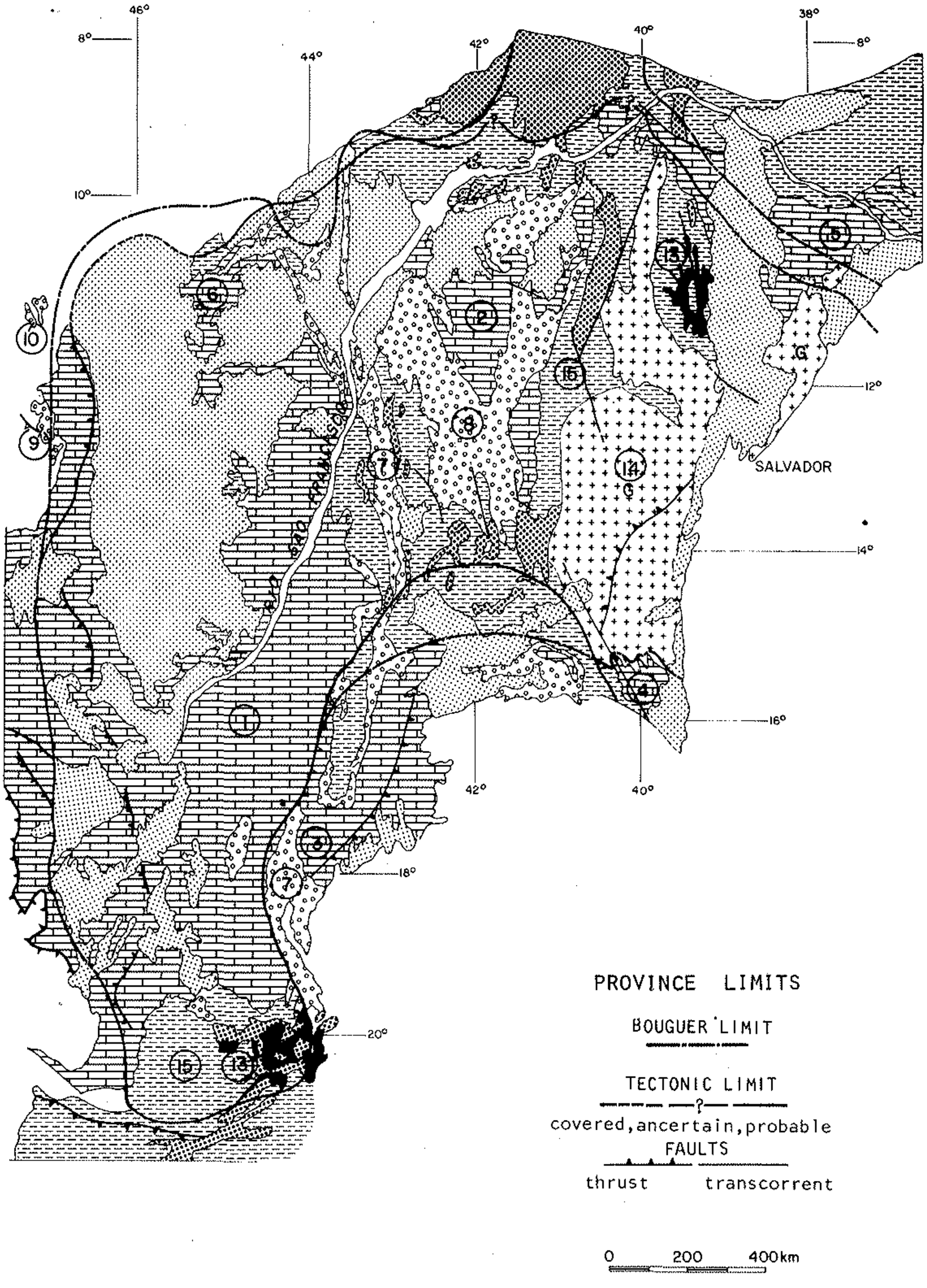

Figure 4 – São Francisco province simplified geologic map ░ *I. Phanerozoic covers* ▤ *II. Upper Proterozoic: São Francisco* ***Supergroup;*** *1)* ***Bambuí Group;*** *2)* ***Una;*** *3)* ***Macaúbas;*** *4)* ***Rio Pardo;*** *5)* ***Canudos-Vaza Barris;*** *6)* ***Rio Preto.*** ⁘ *III.* ***Middle Proterozoic: Espinhaço Supergroup;*** *7)* ***Septentrional and meridional Espinhaço;*** *8)* ***Chapada Diamantina;*** *9)* ***Araí Group;*** *10)* ***Natividade Group.*** ▩ 12 ■ 13 ⊞ 14 ▤ 15 *IV. Early Proterozoic to Archean: 12) Probable Greenstone Belts and/or Magmatic-Sedimentary and Sedimentary Sequences; 13) greenstone Belts; 14) high-Grade Metamorphic Terrains; 15) granite-Greenstone Terrains.*

Granite-greenstone terrains These are characterized by large areas of gneissic and migmatitic granitic rocks in which there occurs an infinity of rock types the natures of which reflect the presence of volcanic, plutonic and sedimentary components under various forms and over various extensions. The better-preserved sequences, which form keels within host rocks of amphibolite or granulite grade, show contact metamorphic aureoles, which are the result of the granitizing processes operating in an environment of lower (greenschist) grade. These sequences are of greenstone-belt type, or are "probable" greenstones, or are volcano-sedimentary sequences of uncertain genetic origin.

Less well-preserved fragments occur as lenses or levels disposed along narrow, elongated crests, or in ameboid, oval or curved patterns which suggest the former existence of true magmato-sedimentary sequences, now well scattered.

Since they have been affected by granitization, gneissification or migmatization, over and above tectonic forces, these remnants are structurally concordant with the regional foliations, and have a metamorphic grade similar to that of the host rocks.

The granite-gneiss-migmatite rocks show structural and textural patterns which vary from isotropic to highly foliated. In general, they are fine to coarse-grained or augen varieties, and are leucocratic, showing variable compositions of granite, adamellite, granodiorite and tonalite. Usually, biotite is more abundant than hornblende. Metamorphic grade ranges from greenschist to high amphibolite or even granulite, but medium-grade associations are more frequent. Banded, foliated ophthalmitic and migmatitic gneisses occur, the latter with stromatic, folded, agmatic and dictionitic structures. Diatexites with nebulitic and schlieren structures are also observed.

Close to the magmato-sedimentary sequences, the granite-gneiss-migmatites develop oval structures or mantled gneiss domes which result from diapiric processes.

In those areas where isochron Rb/Sr ages are older, there is a general tendency for the Na_2O/K_2O ratio to be high; where the ages are younger, the inverse is true, although there are exceptions. Where extensive K-metasomatism has occurred, the ages of the rocks tend to be Transamazônico.

The few geochemical studies on these rocks lead to the conclusion that, in part, they are derived by parametamorphic transformations, as is the case of the gneisses to the east of the Jacobina Mountains and in the Caraíba area (Figueiredo, 1980).

Similar problems have been the subject of world-wide discussion by several authors, who consider either the existence of thick arkose-graywacke sequences with intercalated marly horizons (Ket *et al.*, 1976; Arth, 1976) or of volcano-sedimentary sequences with predominance of ultrabasic, basic and intermediate volcanics and tuffs (Clark, 1979). Yardley (1978) showed that gneisses might be produced by *lit-par-lit* injection, but Myers (1978) assumed that many fine-grained gneisses are the products of tectonic distortion of magmatic and volcanic bedding, of bodies such as pillow lavas, of fragments such as igneous-derived crystals or rock fragments in volcanic and plutonic breccias, and of igneous cumulate textures or of dyke swarms.

The detailed study of the relationships of trondhjemitic gneisses, migmatites and xenoliths of the greenstone belt of Barberton, South Africa in its southeastern and southern parts, led Anhaeusser and Robb (1978) and Anhaeusser (1980) to conclude that the migmatites are formed by the interaction of granite with greenstone, tonalitic-trondhjemitic magma being responsible for the rafting of greenstone xenoliths and their subsequent modification by processes which include granitization, metasomatism, assimilation and partial fusion.

Greenstone belt structures At present, only one structure with typical greenstone make-up is known in Bahia State. This is the Serrinha (Mascarenhas, 1973) or Itapicuru (Kishida, 1979; Kishida and Riccio, 1979) belt.

The latter authors grouped the volcano-sedimentary sequence into three principal rock units: at the base, the mafic metavolcanic unit; in the middle, the felsic metavolcanic unit; and, at the top, the metasedimentary unit (Fig. 5).

These units enclose domes of granodiorite-tonalite the borders of which show potassification, with abundant pegmatite veins. Contact metamorphic effects are observed locally.

The *mafic metavolcanic unit* is composed of basalts, usually schistose, with ocean-floor tholeiite geochemical characteristics, and also small sedimentary intercalations, with a predominance of chemical components (banded iron formations, metachert and carbonate beds) which vary from 0.5 to 100 m in thickness.

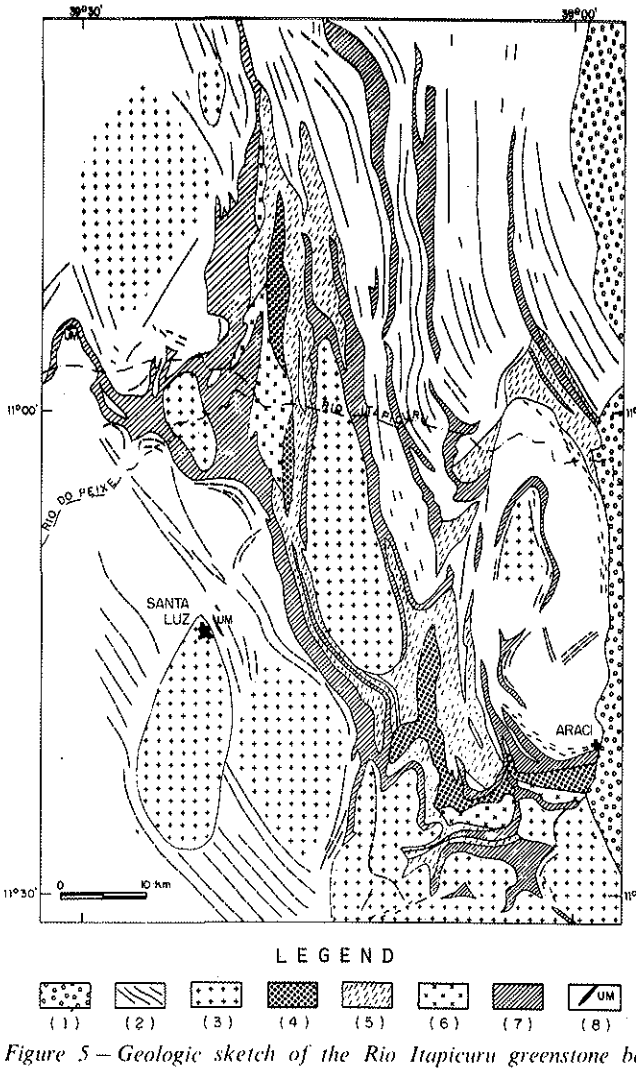

Figure 5 – Geologic sketch of the Rio Itapicuru greenstone belt **(1)** *Sedimentary covers (Tucano Basin)*; **(2)** *Gneissic rocks*; **(3)** *Granitic rocks*; **(4)** *Coarse and quartzose sediments*; **(5)** *Fine and graphitic sediments*; **(6)** *Felsic metavolcanic rocks*; **(7)** *Mafic metavolcanic rocks*; **(8)** *Ultramafic rocks after: Kishida, 1979*

The *felsic metavolcanic unit* occurs as lenticular bodies, and is formed of calcalkaline rocks similar to those of active continental margins and including andesite and dacite lavas, pyroclastics and intercalated metasediments.

Preserved magmatic structures including pillow lavas, flow breccias, and variolitic, porphyritic and amygdaloid textures are present in the mafic rocks. In the felsic rocks, breccias, agglomerates, crystal tuffs, tuffaceous chert, and pyroclastic and chemical components occur.

The *metasedimentary unit* is a flysch, which includes: **1)** schistose intraformational polymict conglomerates, composed of milky quartz, felsic volcanics, chert and pelites; rare fragments of metabasites; granitic fragments are absent; **2)** arkosic meta-arenites; **3)** meta-arkose, argilite and siltite; **4)** graywackes, alternating with dark shales; **5)** intraformational breccias; **6)** well-laminated, dark or light argilites and siltite, with chlorite and rich in graphite, and with thin chert beds.

The unit can be divided into *arkosic-conglomeratic* and *graywacke-pelitic* associations, both of which are typical turbidites.

Small bodies of ultramafic rocks are composed of cumulate euhedral serpentinized olivine grains in a post-cumulate clinopyroxene matrix. Needles and plates of altered clinopyroxene give a texture similar to that described in some peridotitic komatiites of the Belingwe greenstone belt by Nesbit *et al.* (1977, cited by Kishida, 1979). Serpentinized and chromitiferous ultramafic rocks are also found near Santa Luz and Queimadas (Fig. 5).

According to Kishida (*op. cit.*) the calc-alkaline metavolcanic unit can be correlated geochemically with the Yilgarn greenstone belts, which are characterized by a lack of basaltic andesites and by the geochemical gap between the tholeiitic metabasalts and the upper volcanic rocks.

Mascarenhas *et al.* (1976, 1979), Pires *et al.* (1976), Inda and Barbosa (1978), Mascarenhas (1979) and Figueiredo (1980) assumed that the volcano-sedimentary sequence, associated with gneisses, migmatites and granulites, which extends to the north of the Serrinha greenstone belt into the Uauá and Caraíba areas, may be partly correlated with the units related to this belt, and partly, with its basement, but in a higher metamorphic grade than greenschist, which is typical of the belt.

Probable greenstone belts and/or magmato-sedimentary and sedimentary sequences Within the granite-greenstone terrains, there occur many localized assemblages which show similarities to greenstone belts. Other sequences, with a greater similarity to supracrustals, are frequently deposited over these assemblages. Yet others have unknown geotectonic significance, but are always present in predominantly amphibolite grade (Fig. 6).

Similarities to, and differences from greenstone belts are as follows:

a) The sequences are older than the Espinhaço Supergroup.

b) They are situated in granite-greenstone terrains, in the sense that they show many of the features of such terrains, such as a gneiss-migmatite environment, mobility-plasticity, internal or peripheral oval domes with, sometimes, contact metamorphic aureoles.

c) Their metamorphic facies is greenschist.

d) The volcano-sedimentary association is compatible with known crustal evolution during the Archean and Lower Proterozoic.

e) They have suffered from a strong Transamazônico influence.

f) Because of the deformation and remobilization, it is difficult to establish their limits with the older rocks, and to deduce the stratigraphic column.

g) The geochronological data do not yield Lower Proterozoic ages, with the exception of some imprecise or unreliable values between 1,900 and 2,200 Ma.

h) Although, locally, some features may be absent, the sequences generally have a lower magmatic component, with serpentinized ultramafic rocks, some of which with the characteristics of flows, passing to basalts in the middle part and massive, porphyritic and volcaniclastic felsic rocks at the top, intercalated with fine-grained pelitic and chemical metasediments including phyllites, graphitic schists, local phyllite-graywacke sequences metacherts, calc-silicates, marbles, banded iron formations etc.

i) The basaltic rocks have tholeiitic, and the felsic, calc-alkaline affinities.

Locally, where weak deformation has permitted, characteristic igneous features, such as massive and porphyritic lavas, volcanic breccias, lapilli-tuffs, vesicular and amygdaloidal textures, etc., are preserved.

Nevertheless, until now, no examples of *pillow lavas* or of *spinifex textures* have been found. The most important examples of such structures are as follows:

- In the *Rio Capim complex*, identified by Winge and Danni (1980) and Winge (1981) as a greenstone belt-like structure, the *basal parts* are composed of an association of amphibolitized mafic flows or tuffs, with intercalations of silico-ferruginous and silicic sediments (metachert, itabirites with magnetite and amphibole) and, *at the top*, volcaniclastic (agglomerates, lapilli-tuffs and ignimbrites) and volcanochemical rocks, related to an explosive, intermediate to felsic phase.

- In *the Contendas-Mirante complex*, there occurs a *lower unit* of mainly *ultramafic-mafic* rocks, and an *association of mafic and felsic volcanics with immature metasediments* (Cunha *et al.*, 1981; Pedreira and Marinho, 1981). The former is represented by serpentinites, tremolitites-actinolitites, hornblendites and metabasites with intercalations of oxide or silicate-facies banded iron formations, carbonates, metacherts and graphitic schists. In the latter, the basal subunit is composed mainly of fine tuffs and lapilli tuffs, with less expressive massive and porphyritic felsic lavas, massive and amygdaloidal mafic lavas, metachert horizons, banded iron formations, carbonates, graphitic schists and graywackes. The upper subunit has fine pyroclastics with metachert, banded iron formations and graywacke intercalations, which become more abundant towards the top. Petrochemically, the rocks of the lower unit have low-K tholeiitic character with a predominance of basalts and andesites over rhyolites.
  The *upper unit* is formed of fine to coarse metaclastics, meta-arenites with abundant cross-bedding, phyllites and schists, which were deposited in environments from delta-front to marine, with prograding resulting from periods of basin subsidence (Menezes Filho *et al.*, 1978).

- The complexes of Umburanas, Brumado, Urandi-Licínio de Almeida, Boquira, Riacho de Santana, Salitre, Barreiro and Jacobina are somewhat similar to the assemblages already described, each with particularities which are a function of the area of occurrence and of the predominance of some lithologies over others.

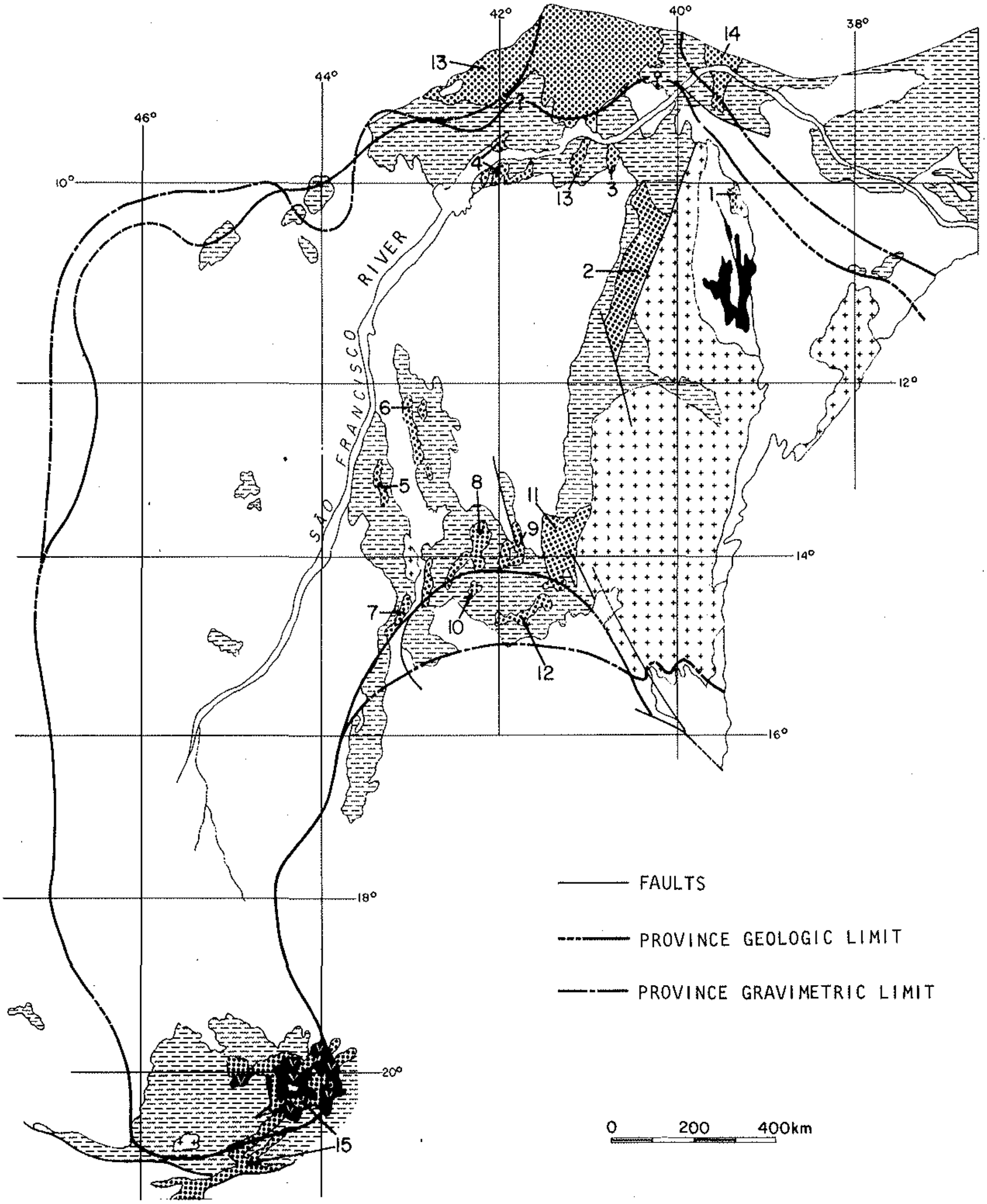

Figure 6 – □ *Phanerozoic and early to middle proterozoic covers;* ■ *Greenstone belt: Serrinha;* ᵛᵥ *Greenstone belt: Rio* ***das Velhas Lafaiete;*** ▨ ***Probable*** *greenstone belts and/or magmatic-sedimentary sequences: 1) Capim; 2) Jacobina; 3) Salitre; 4) Barreiro/Colomi; 5) Riacho de Santana; 6) Boquira; 7) Urandi/Licínio de Almeida; 8) Brumado/Serra das Éguas; 9) Umburanas; 10) Guajeru; 11) Contendas/Mirante; 12) Bate-pé; 13) Casa Nova; 14) Ibó; 15) Minas Supergroup/São João del Rei Group, Lafaiete Formation* ▤ *Granite-greenstone terrains.* ⊞ *High grade metamorphic terrains*

As was described in the case of the *Contendas-Mirante complex*, in the *Brumado*, *Barreiro* and *Salitre* complexes intracratonic platform basins developed, with thick clastic and chemical sequences, and some volcanic contributions, deposited over a basal magmatic-sedimentary unit, repeating the contrast between *upper* and *lower* units. Although the upper sequences to the east of Bahia State have larger clastic components*, to the west chemical components tend to predominate, with thick carbonatic and iron formation sequences, which sometimes contain thick magnesite deposits (Serra das Éguas and Colomi Groups).

In this latter case, similarities with sequences of the Dharwar region in southern India as described by Naqvi, Rao and Narain (1978) are noted, while for the former cases an analogy with the thick clastic sequences of the Moodies Formation of the Barberton greenstone belt of South Africa (Anhaeusser, 1971) are suggested.

Given the difficulties faced in establishing geotectonic models for the sequences in question, it is believed that the sub-division established by Naqvi, Rao and Narain (op. cit) can be used, and they can be considered as being "pseudo-greenstone belts", or rather, "greenstone belt-like geosynclinal piles".

As well as the sequences previously described, there exist lithostratigraphic units with wide area of exposure and morphological prominence which allow them to be characterized. Situated within granite-greenstone terrains, their essential features are a lithostratigraphic assemblage in high greenschist or amphibolite facies represented by chlorite-muscovite - biotite - garnet - plagioclase - staurolite - kyanite schists, lenses of marble, quartzites with thin conglomeratic levels, which suffered intense granitization, migmatization and pegmatization.

They are defined locally as the *Casa Nova*, and *Ibó Groups*, and the *Bate-pé unit*. There have been various attempts to correlate them to the lower or upper units of the pseudo-greenstone belts (Pedreira and Marinho, 1981), or as units contemporary with the greenstones, but laid down in platform environments (Lima *et al.*, 1981) or as platform units related to the granite-greenstone terrains but of obscure connotation (Mascarenhas, 1979) or even are correlated with the Minas Group of the Quadrilátero Ferrífero of the Lower Precambrian (Jordan, 1973). More recently, Mascarenhas *et al.* (1982) related them to the *schists belts* described in the Canadian shield, following the ideas elaborated by Pettijohn (1972).

High-grade terrains These are characterized by rocks of the charnockite suite, granulites and migmatites which extend as a continuous belt along the Atlantic coast of the State of Bahia. Close to the parallel of Salvador, the belt bifurcates into the western branch, which continues almost to the São Francisco river, and the eastern branch, which continues along the Atlantic coast in a northeastern direction.

Other lesser occurrences of high-grade metamorphic rocks are found in restricted areas within the granite-greenstone terrains, to the east of the *Rio Capim complex*, in the Brumado-Ibitira region, and in the *Santa Isabel complex* of the Guanambi region.

In the high-grade rocks, magmato-sedimentary sequences are common and preserved as remnants in narrow belts. Thus, they appear to represent subcrustal zones, brought to the surface by tectonic-orogenic means.

The parageneses represented in the high-grade terrains are: quartz-orthoclase-perthite and antiperthite, microcline-plagioclase (oligoclase to labradorite), orthopyroxene, clinopyroxene, garnet, hornblende, biotite, sillimanite and cordierite. Biotite and hornblende can be either primary, or along with bastite, chlorite and white mica, represent the products of retrograde metamorphism.

The compositions are syenitic, granitic, granodioritic and tonalitic, which under the influence of the high-grade, produce charnockites, charnoenderbites, enderbites, leptynites, pyroxene granulites, hornblende-garnet-pyroxene granulites and hornblende granulites the textures of which vary from isotropic to oriented, massive or foliated, in large part with migmatitic features, in which schlieren, nebulitic, folded, ophthalmitic and stromatitic structures are prominent.

Associated with this assemblage, basic-ultrabasic parts, represented by amphibolites, gabbro-norites, anorthosites, pyroxenites and serpentinites occur as enclaves, lenses, thin horizons, with or without transitional contacts. Many of the elements are differentiated intrusive products with localized Fe-Ti-V or Fe-Ti mineralizations. Others could be correlated, with some doubts, with the original simatic crust, according to the geochronological data.

Many continuous or discontinuous belts of metasedimentary rocks are recognized, and volcano-sedimentary sequences suspected, through the existence of associations such as amphibolite, metabasite, quartzite and/or metachert, calc-silicates and banded iron formations with magnetite/hematite, manganiferous formations and graphitic schists.

In the area of the Jequié complex and the Atlantic belt, petrochemical analysis show that there are important differences of behaviour, with on one hand, igneous tendences with a predominance of granitic components, and on the other, a metasedimentary tendency with a large basic component (Sighinolfi, 1970, 1971).

Enrichment of trace elements such as Rb, Y, Ba, REE, etc. in comparison with normal granites, and non depletion of others, such as Cr, V, etc., considered mobile during granulite facies metamorphism, lead Sighinolfi *et al.*, (1981) to consider that regional metamorphism occurred after the granulite metamorphism. Another possibility is that there must be doubts about the commonly used criteria for the distribution of heat-producing elements with depth (Sighinolfi *et al.*, 1981).

In the Curaçá river valley, a metamorphic sequence in high to medium grade was described (Barbosa *et al.*, 1964, 1970; Ladeira and Brockes Jr., 1969; Souza and Delgado, 1975) which, according to Lindenmayer (1981) "is composed of a gneissic basement of granodioritic to quartz-dioritic composition, with tonalitic components predominating, and gabbroic intercalations. This underlies a sequence composed of fine clastic sediments at the base and chemical sediments at the top, similar to those of Archean platform sequences as visualised by Sutton (1973) and Windley (1977). Within the supracrustals, subconcordant differentiated intrusions (hypersthenites-norites-gabbros-anorthosites, and norite-gabbro-anorthosite) and sills occur, which are mineralized with copper, and were formed by the fractional crystallization of a tholeiitic basalt magma".

Based on petrochemical data, Figueiredo (1980) concluded that the region of the Curaçá river valley is the lower part

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* In the specific case of the Jacobina Group (which should not be confused with the *Jacobina complex*), the features are similar to those of Witwatersrand, as shown by Sims (1977)

of a sequence which continues to the greenstone belt of Serrinha. This situation is similar to the model developed for the Botswana region of southern Africa by Key *et al.* (1976), who supported the hypothesis of the occurrence of thick meta-arkoses and magmato-sedimentary sequences at the base of the Vumba, Tati, Matsitama and Maitengwe greenstone belts.

On the other hand, taking into consideration the contact relations between the granite-greenstone terrains and those of high-grade, and the regional deformation and geochronological information available, Mascarenhas (1979) and Mascarenhas *et al.* (1982) assumed a vertical metamorphic gradation from granulite to greenschist facies.

Identical conclusions were achieved by Figueiredo (1980) for the northeastern region of Bahia.

GEOCHRONOLOGY Analysis of the geochronological data available for Bahia State (Távora *et al.*, 1967; Cordani *et al.*, 1969; Cordani and Iyer, 1979; Jardim de Sá *et al.*, 1976; Agreements SME/IG. USP-CPGeo, 1978 to 1982; and others) shows the existence of specific periods of absolute ages, as follows: >3,500 Ma (Lower Archean); 3,500 to 3,000 Ma (Middle Archean); 3,000 to 2,700 Ma (Upper Archean); 2,700 to 1,800 Ma (Lower Proterozoic); and 1,100 to 450 Ma (Upper Proterozoic to Lower Paleozoic).

As observed in Figs. 7, 8 and 9, the Rb/Sr isochrons, in general, can be criticized for the small number of data points. The isochrons obtained are, however, systematic and should therefore have the same significance as is given to isochron ages in general terms.

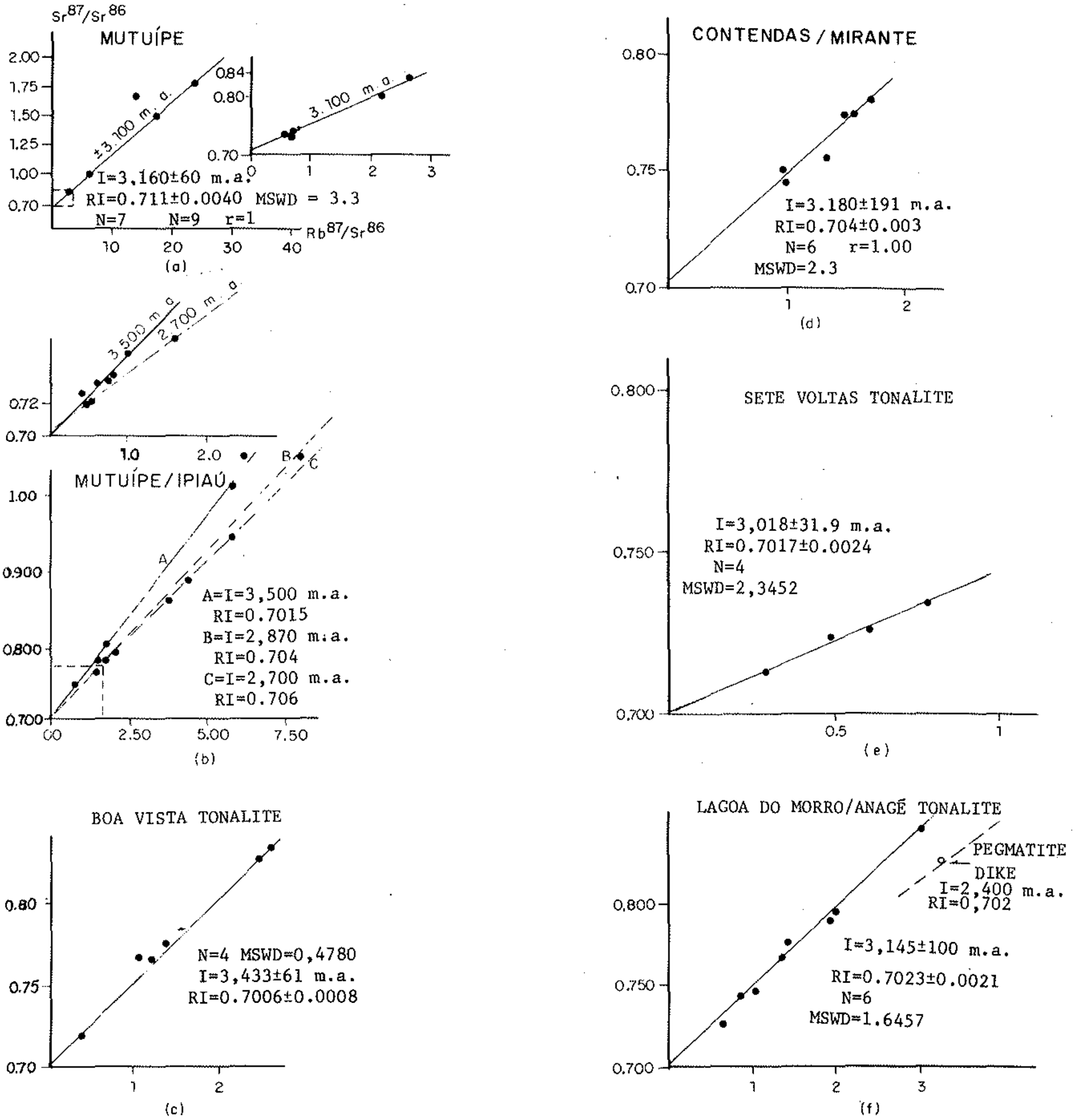


Figure 7A: — Rb/Sr isochronic reference ages for rocks of Early to Middle Archean

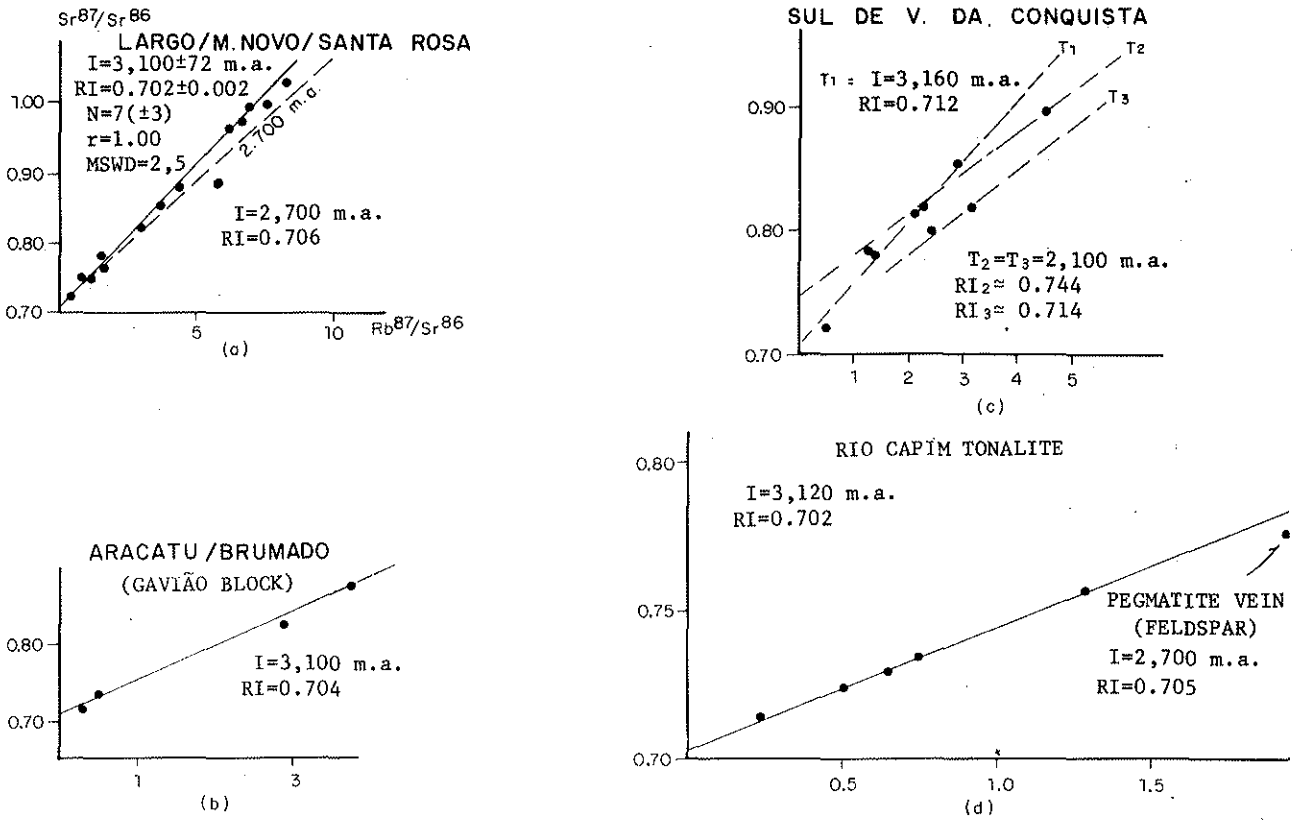


Figure 7B – Rb Sr isochronic reference ages for rocks of late to Middle Archean. Brito Neves et al., *1980: Fig. 11*Aa, d; *11*Ba,b, c. *SME/IG. USP-CPGeo, (1979/81); Fig. 11*A, b, c, e, f; *11*Bd

The values larger than 3,500 Ma are found in small, isolated nuclei of charnockitic and enderbitic compositions in high-grade metamorphic rocks of the *Jequié granulitic complex*, and, within the granite-greenstone terrains, in tonalitic-granodioritic bodies with the features of *mantled gneiss domes*, in the *Contendas-Mirante complex* (Fig. *7Aa, c*). These are the oldest rocks known in South America.

The possibility that rocks older than 3,500 Ma are present is seen in Fig. *7Aa*, where the result for a gabbro-norite falls well above the isochrone.

The values situated in the interval 3,500-3,000 Ma although representative of small nuclei, are rather widely distributed in the granite-greenstone terrains, as is seen from Figs. *7Ad, e* and *f*; *7Ba, b, c, d*). In the high-grade terrains, they were found as well in the region of Mutuípe (Brito Neves *et al.*, 1980) (Fig. *7Aa*) with a very high initial ratio ($R_0 = 0.711 \pm 0.00040$; MSWD = 3,3; N = 9).

Values in the interval 3,000-2,700 Ma occur over wider regions, well represented in the *Jequié complex* (the type area for the Jequié geotectonic cycle), and in the Brumado-Anajé region (Figs. *8A, B, C*).

Ages in the interval 2,700-1,800 Ma are distributed throughout the entire São Francisco province, thus showing the great influence of the Transamazônico geotectonic cycle in the State of Bahia.

Intermediate values of 2,500, 2,400, 2,300 Ma etc. lack a systematic distribution which would allow a specific phase or geotectonic cycle to be defined, and therefore these ages are believied to be the result of incomplete isotopic rehomogenization of the Rb/Sr system. On the other hand, the great concentration of values around 2,000 Ma (Figs. *9A, B*) shows this to be the age of the main phase of the Transamazônico cycle.

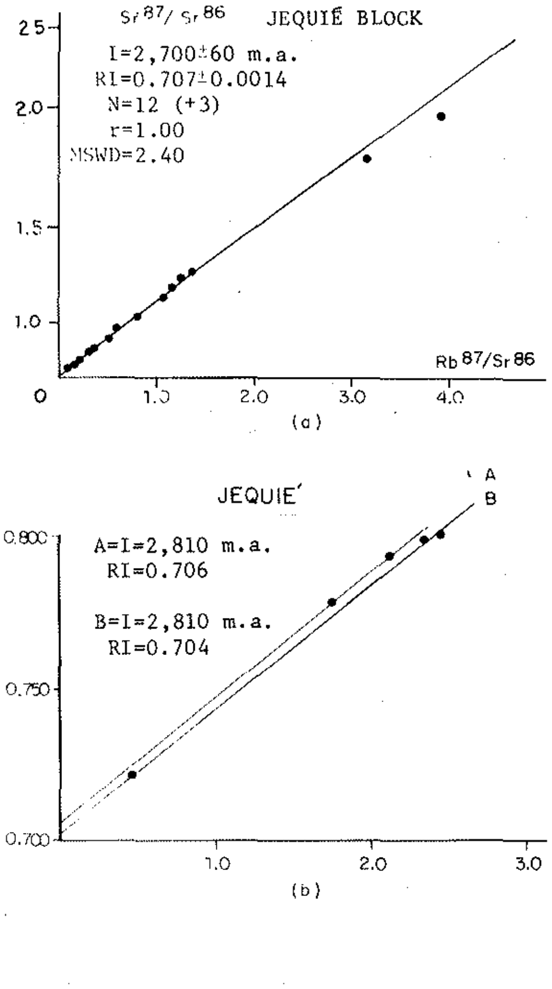


***Figure** 8A – (continuation)*

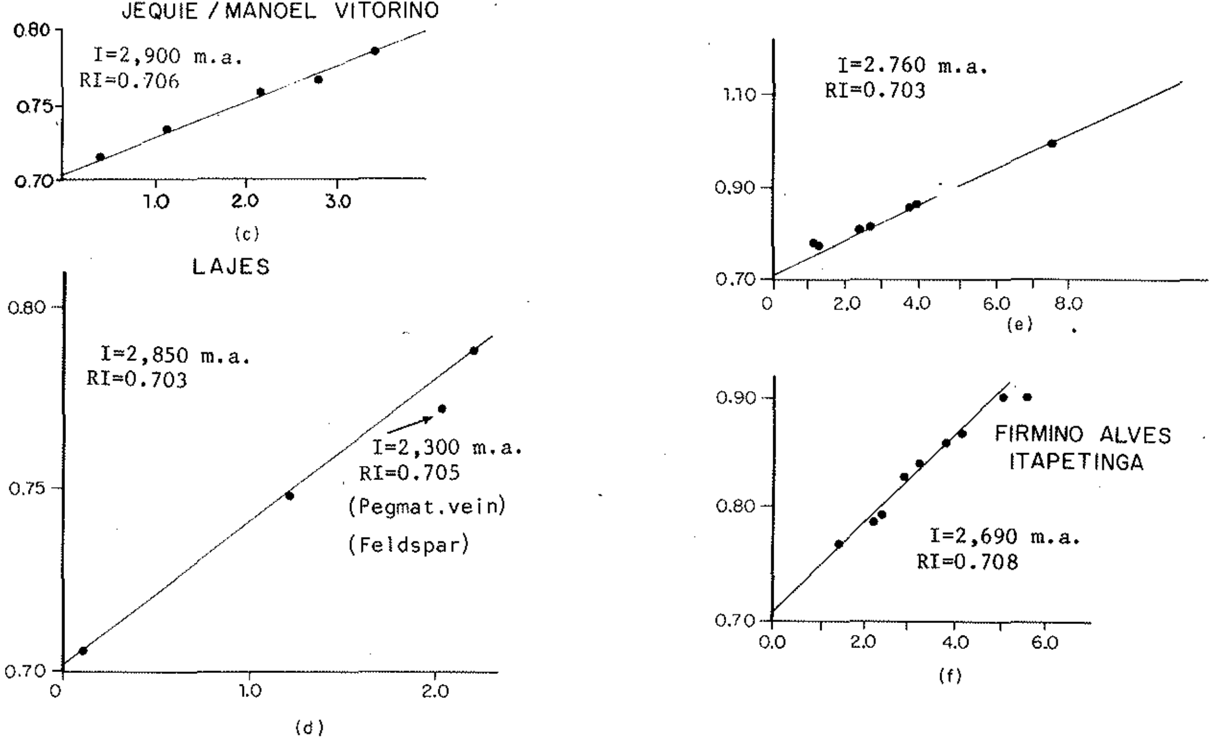


Figure 8A – *Rb/Sr isochronic reference ages for rocks of late Archean (Jequié Cycle). Brito Neves*, et al., *1980:* (a). *SME/IG. USP-CPGeo, 1980/82: 12*A (b, c, d, e, f)

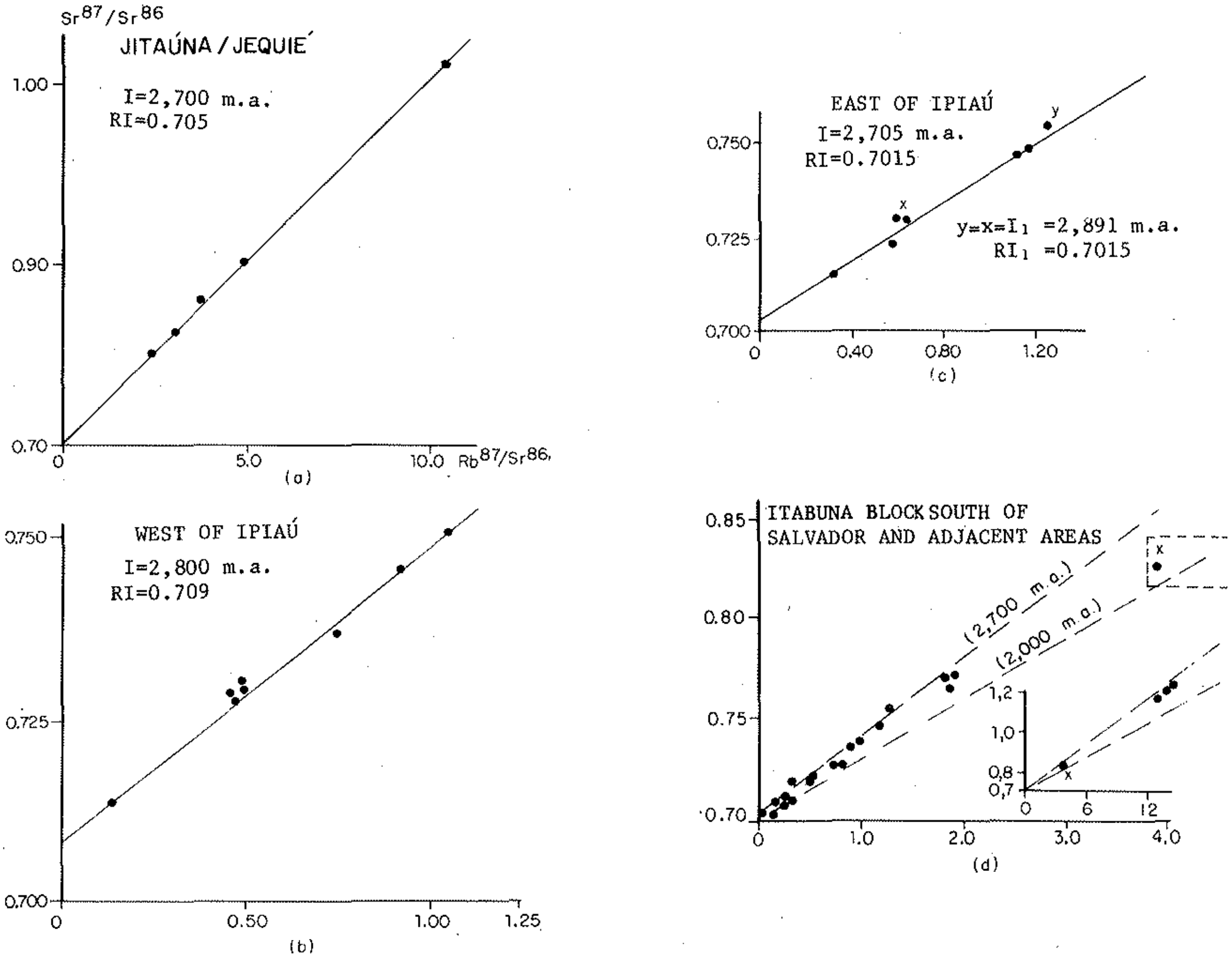


***Figure 8B* — (*continuation*)**

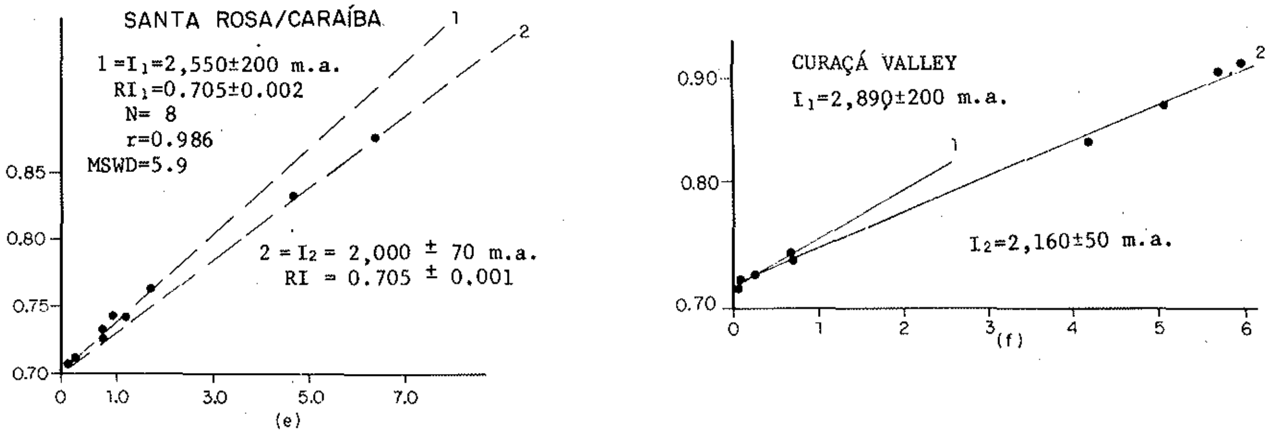


*Figure 8B — Rb Sr isochronic reference ages for rocks of late Archean (Jequié Cycle). SME/IG-USP – CPGeo, 1981/82: 12*B (a, b, c; *Brito Neves* et al., *1980: 12*B (d, e); *Lindenmayer, 1981: 12*B (f); *Brito Neves* et al., *1980: 12*C (a, b, c, e); *SME/IG-USP – CPGeo, 1980 81: 12*C (d); *Brito Neves*, et al., *1979: 12*C (f); *Cordani* et al., *1980: 12*C (g)

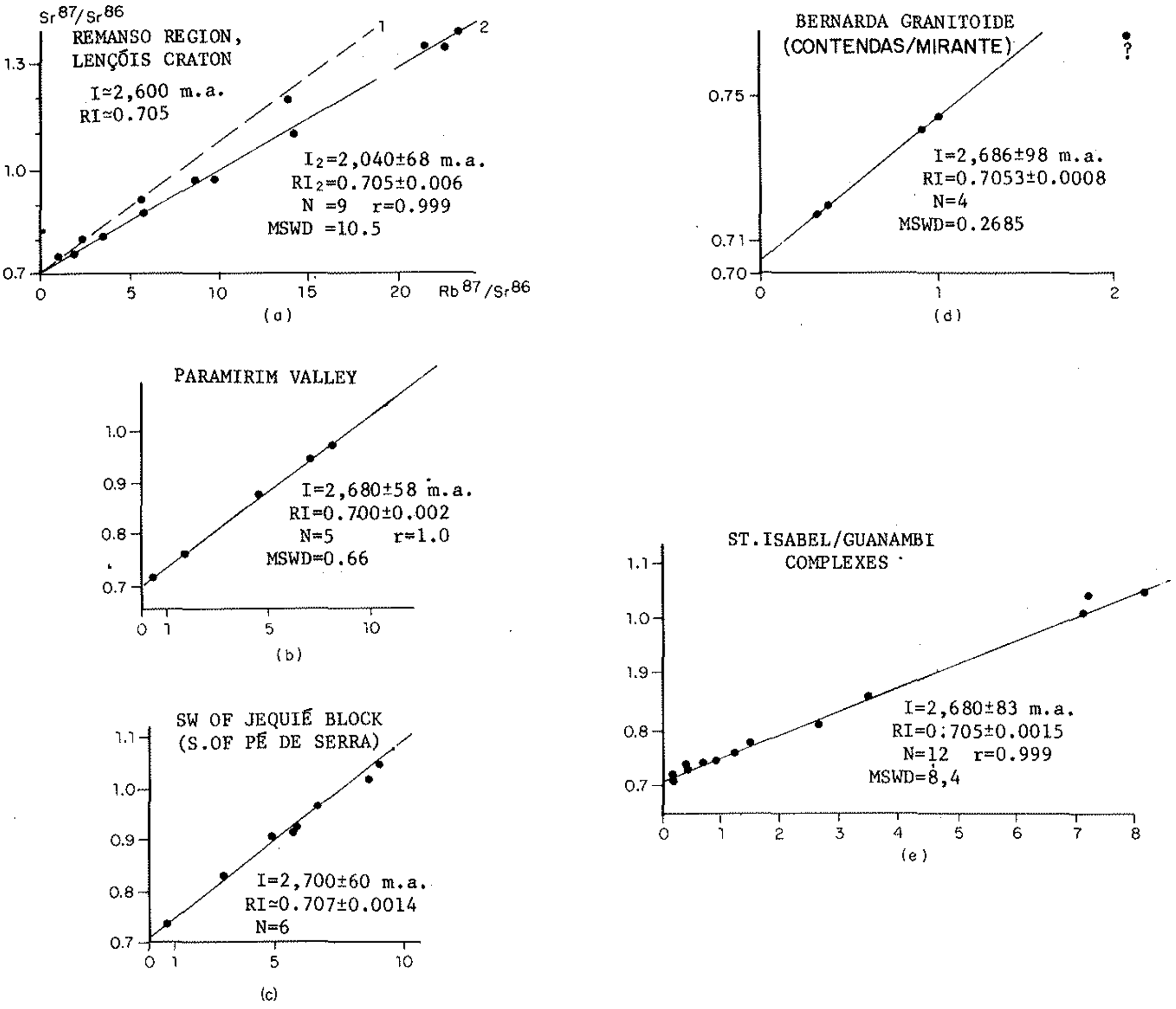


Figure 8C — Rb Sr isochronic reference ages for rocks of late Archean (Jequié Cycle)

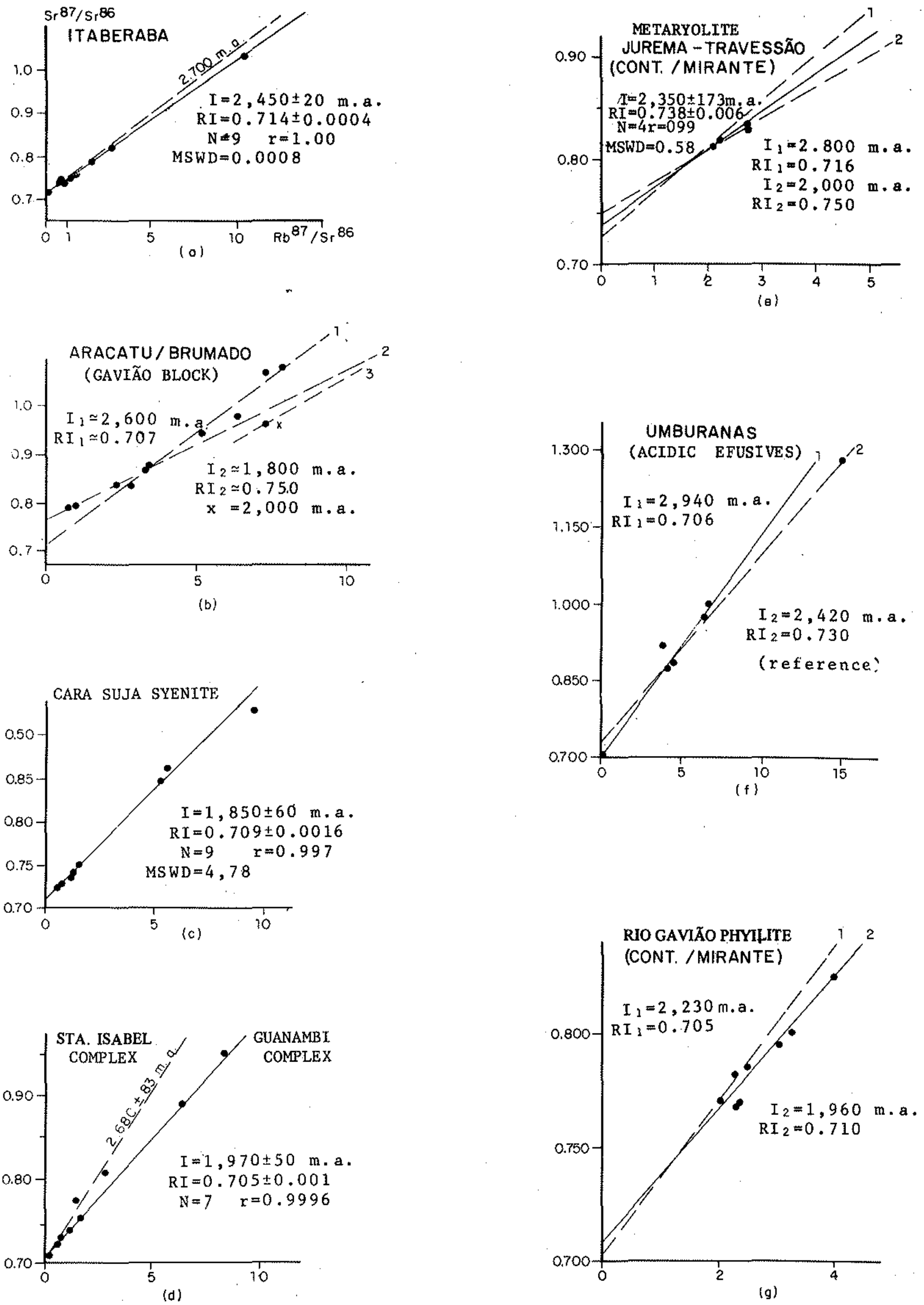


Figure 9A – Rb/Sr isochronic reference ages for rocks of early Proterozoic Brito Neves et al., *1980:* (a, b, c, d, e, f); *SME IG. USP – CPGeo 1980:* (g)

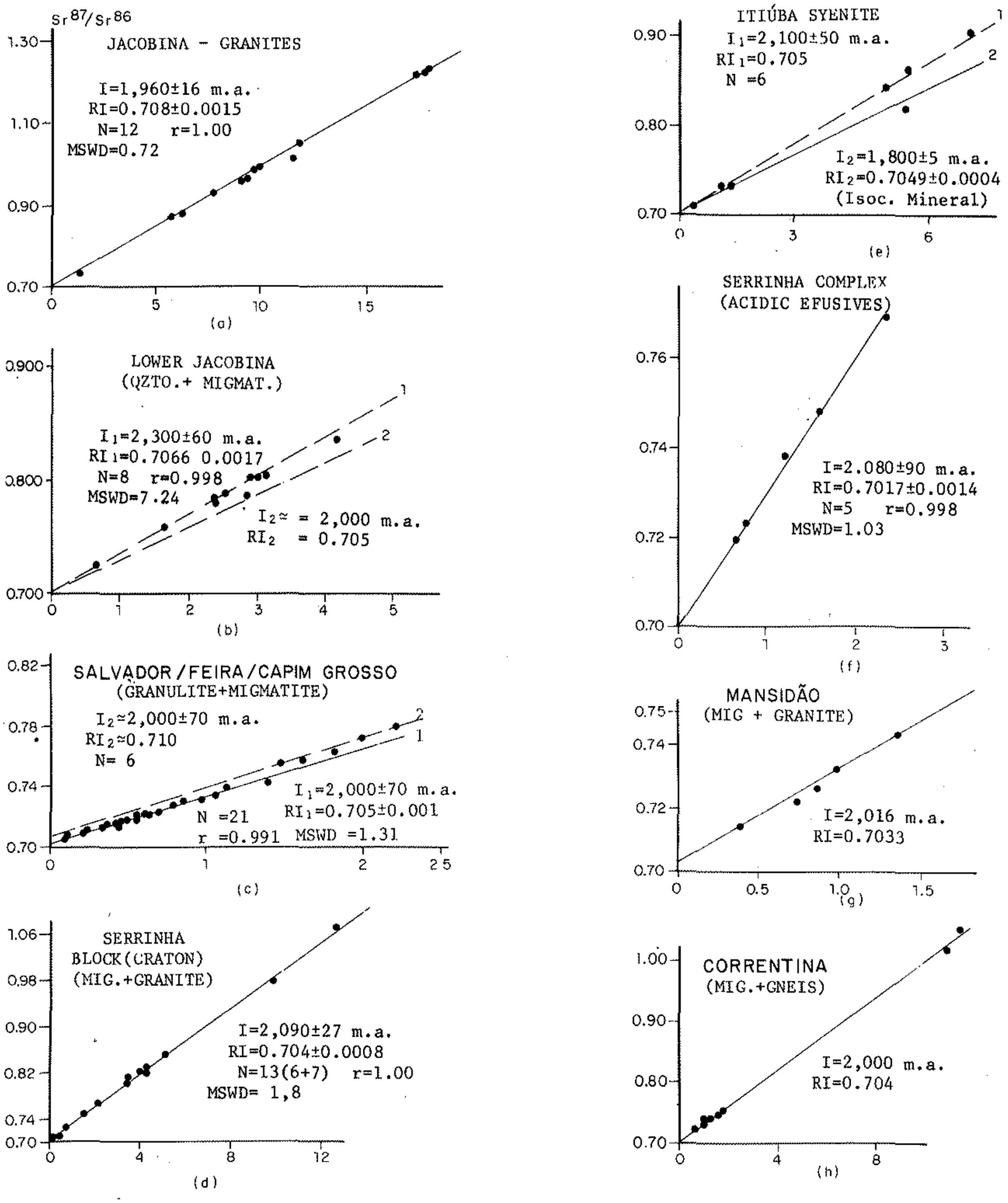


Figure 9B — Rb/Sr isochronic reference ages for rocks of Early Proterozoic Brito Nèves et al., *1980:* (a, b, c, d, e, f); *SME/IG USP – CPGeo, 1981:* (g, h)

This cycle, through its wide-spread occurrence, causes serious difficulties in the separation, in time and space, of the geological processes which acted until the end of the Lower Proterozoic. It is not possible to separate the particular events which must have occurred since the Archean, and it is therefore impossible to avoid speculation.

In Fig. 10, a synthesis of the geochronological data representative of the Archean to Lower Proterozoic in Bahia is presented. In this, it can be seen that the location of the older nuclei does not follow a pattern of decreasing ages, which would result from evolution by accretion, and it is therefore more realistic to consider the oldest areas simply as having been preserved from the continuing deformation in, and additions to, an already extensive crust.

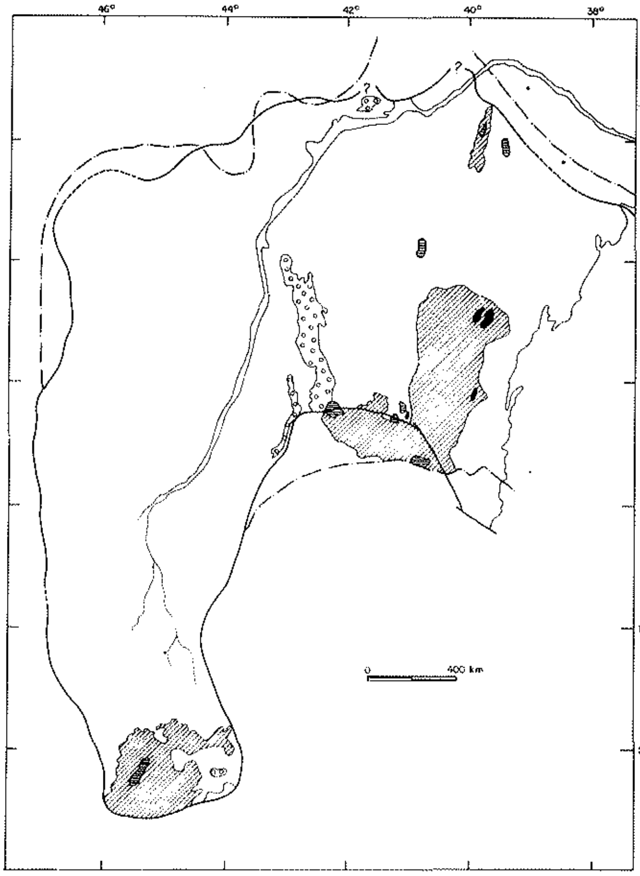


Figure 10 – Actual representation of Archean regions, nuclei and fragments in the São Francisco province, from Rb/Sr isochronic data ● *>3,5 b.y.;* ▤ *≅3,0 b.y.;* ▨ *3,0 to 2,7 b.y.;* ⁘ *2,7 to 2,5 b.y.;* ☐ *Phanerozoic and Early to Middle Proterozoic covers, and Pre-Espinhaço assemblage stabilized during the Transamazônico Cycle. Province limits: -ᵃ-ᵇ?-ᶜ- tectonic:* a) *Covered;* b) *Uncertain;* c) *Probable.* – – – – *Gravimetric*

On the other hand, assuming (Brito Neves *et al.*, 1980) that changes of Rb/Sr ages only occur in open physical-chemical systems, which allow losses or gains of material, and taking into consideration the fact that the observed ages occur practically every 100 Ma (with ages 2,000 Ma, 2,100, 2,300, etc., to 3,500 Ma with intervals which represent the peaks of the geotectonic cycles) it is reasonable to accept that the crustal evolution was a continuous process in an extremely active crust.

GEOTECTONIC ELEMENTS The structural outline of Bahia shows that the regional foliation directions possess divergences, and sinuosities and curves, apparently defining local "barriers" which behave more rigidly during the deformations (Fig. 11). These more rigid areas were defined by Mascarenhas *et al.* (1976, 1979) as *proto-cratons*, and the various examples are Jequié, Aracatu, Medina, Serrinha and Gavião-Riachão do Jacuípe-Ipecaetá (Marinho, *in* Seixas *et al.*, 1975).

These protocratonic areas are interpreted as being Archean nuclei which, nevertheless, were not completely immune to mig-magmatic processes and polycyclic deformation, while retaining the older tectonic configuration. At present, they are termed the Serrinha, Remanso, Guanambi and Medina cratons. With the exception of the Medina craton, where the data are sparse, the gravimetric interpretations confirm the existence of these areas, where the sialic crust is thicker (Motta, *in* Mascarenhas *et al.*, 1982; Davino, 1980).

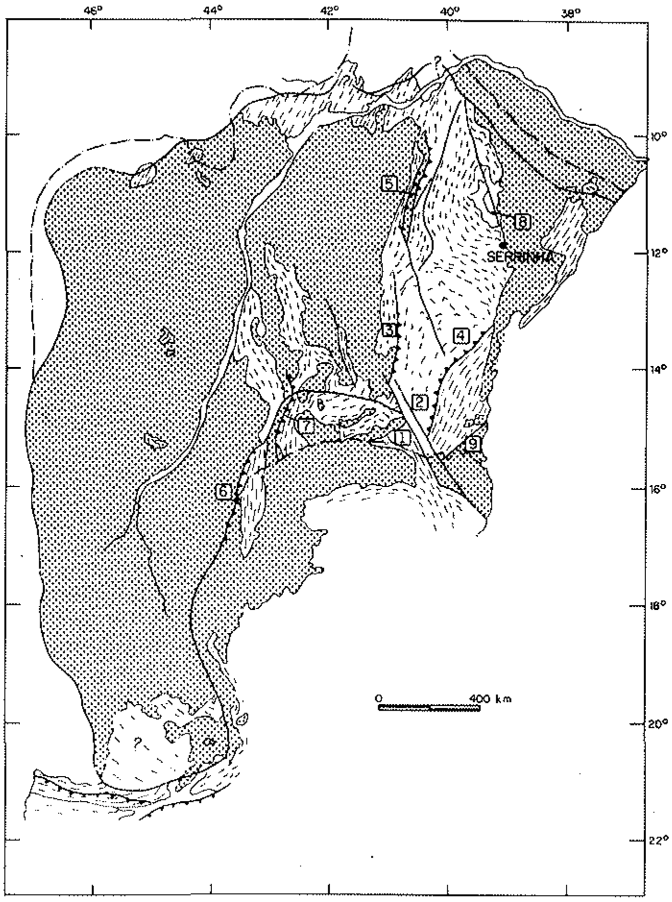


Figure 11 – Dominant foliation direction pattern in the São Francisco province, in gneiss, migmatites and granulitic rocks

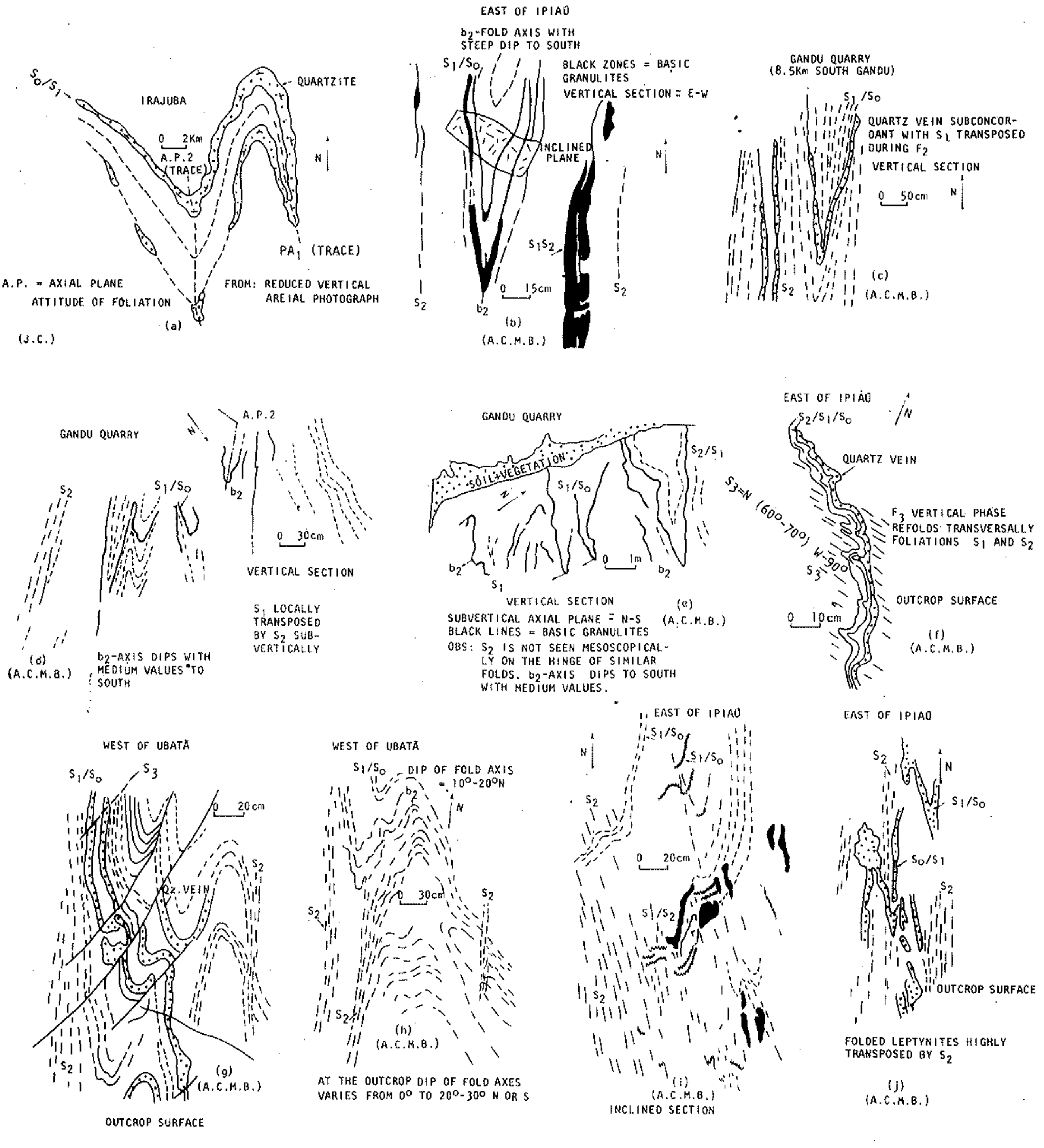
▒ *Covers*
▨ *Gneiss, migmatitic and granulitic rocks*
▲▲▲▲ *Thrust fault*
-——- *Strike-slip and/or oblique faults (Generally associates mylonitic zones):* **1** *– Planalto-Potiraguá fault;* **2** *– Poções-Itororó fault* (**1**, **2** *– Itapebi lineament);* **3** *– Maracás fault;* **4** *– Conquista plateau fault;* **5** *– Jacobina fault swarm;* **6** *– Itacambira fault;* **7** *– Caetité fault;* **8** *– Monte Santo mylonitic zone;* **9** *– Itabuna shear zone*
——-- *Geologic province limits*
– – – – *Gravimetric*

In the eastern part of the State, they appear to control, or were controlled by, the formation of structures of mobile-belt type, and this could also be true of the area represented by the Santa Isabel complex between Urandi-Guanambi, which separated the Remanso craton from that of Guanambi, although more detailed study is necessary.

According to Almeida (1979), both the Jequié and Serrinha cratons participated in the processes which led to the formation of the Coastal *mobile belt* at about 2,700 Ma, in which there occurs the majority of the high-grade metamorphic rocks of Bahia.

To Mascarenhas (1979), at about 2,700 Ma the Jequié craton was an extension of the Remanso craton, and the Coastal *mobile belt* skirted the Serrinha craton with its western (in the direction of the Curaçá river) and eastern (along the Atlantic coast, starting as Salvador) branches.

As was demonstrated by the geochronological data, Transamazônico *Rb/Sr* values are pratically inexistent in the



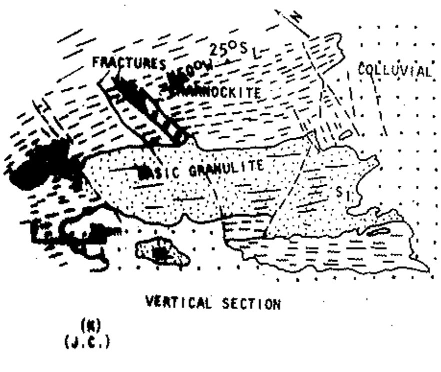


Figure 12 – Folding styles and deformations on high-grade rocks of Jequié Complex (J.C.) and Atlantic Coast Mobile belt (A.C.M.B.) (Drawing based on photographs of outcrops and on vertical aerial photographs); a) Interference pattern type 3 (Ramsay, 1967) of regional character (b, c, d, e) F_1/F_2 coaxial interference patterns on vertical to subvertical sections with various degrees of deformation intensity of S_0/S_1 f, g, h, i, j) fold configurations on horizontal surfaces of outcrop (f, g) F_3 vertical phase gives transversal deformation of $S_0/S_1/S_2$, locally with drag folds. k) vertical section on the Ipiaú archean fragment (3.5 b.y. see Fig. 7Ab) showing gently dipping cataclastic foliation not deformed by F_2/F_3 phases. Xenolith of basic granulite in acidic granulite. Obs: Every folding is of similar type

Jequié complex but the deformations which affected the Atlantic coastal region affected this complex as well. On the other hand, the coastal region, and all the central, western and northeastern areas were very strongly subjected to isotopic homogenization during the Transamazônico, and these processes seem to have been related to intense crustal reworking, granitization and migmatization events.

In the coastal region, and including all central-east Bahia, the Transamazônico geological activity remobilized part of the Coastal mobile belt and the pre-existing cratonic areas (Serrinha), forming the Atlantic Coast *mobile belt* (Mascarenhas, 1979*a*; Mascarenhas *et al.*, 1982) during which retrometamorphism of the granulites ("decharnockitization" according to Moutinho da Costa and Mascarenhas, 1982) occurred.

To this phase can be related the intense vertical transpositions found in the entire domain of the Atlantic Coast *mobile belt*, which also affected the Jequié complex. The styles of deformation are visualized in Fig. 12.

In this figure, an earlier folding phase is shown, the style of which is similar to a "*nappe de charriage*" which appears to be related to Archean events. In the context of the Archean and Lower Proterozoic regions of Bahia, this phase of recumbent folds or folding with horizontal axes, which produced the gneissic foliation S_1 and in which intrafolial folds with N-S axes folds are observed, is always present. This phase was followed by symmetrical or asymmetrical to isoclinal folds, locally with intense vertical transpositions, producing a type 3 interference pattern of Ramsay (1967) (Fig. 12*a*).

The intensities of the second folding and the vertical transpositions are locally variable, and may develop or not an S_2 foliation. This latter is a prominent structural element and is considered as correlated with the formation of the Atlantic Coastal *mobile belt*. It is, nevertheless, problematic whether the phase of intense transposition, which also caused the formation of mylonites, ultramylonites and blastomylonites as well as the S_2 foliation, occurred in synchrony with the normal folding or whether it was later.

On the other hand, the isoclinal character, which is observed locally (Fig. 12) could also be related to this phase of intense transposition.

The undulating nature of the fold axes, which can dip north or south, could be related to a wide-spread deformation, usually open but locally tight and orthogonal to the two earlier phases, which, in part, allowed the preservation of the supracrustal sequences in synform keels, according to Mascarenhas (1979).

Local evidence, both in the high-grade rocks and in the granite-greenstone terrains, stress the patterns of transverse deformation, the meaning, intensity and expression of which need further analysis.

To these geotectonic elements are related a number of aproximately N-S faults, and NW-SE fault systems which produce various geotectonic blocks, and brought the high-grade rocks to their present positions, as can be seen in Fig. 11. These faults served, as well, as controls for the intracratonic basins of the Middle and Upper Proterozoic.

GEOTECTONIC SKETCH The geotectonic model presented in Fig. 13 stands for the up to date geological knowledge since 1979, when first elaborated by Mascarenhas.

At present, the sketch includes the gravimetric data, as interpreted by Motta (in Mascarenhas *et al.*, 1982) and the geochronological information acquired mainly by the Programme of Geological Dating of Bahia State, undertaken by the Secretariat of Mines and Energy under an agreement with the Geochronological Research Center of São Paulo University.

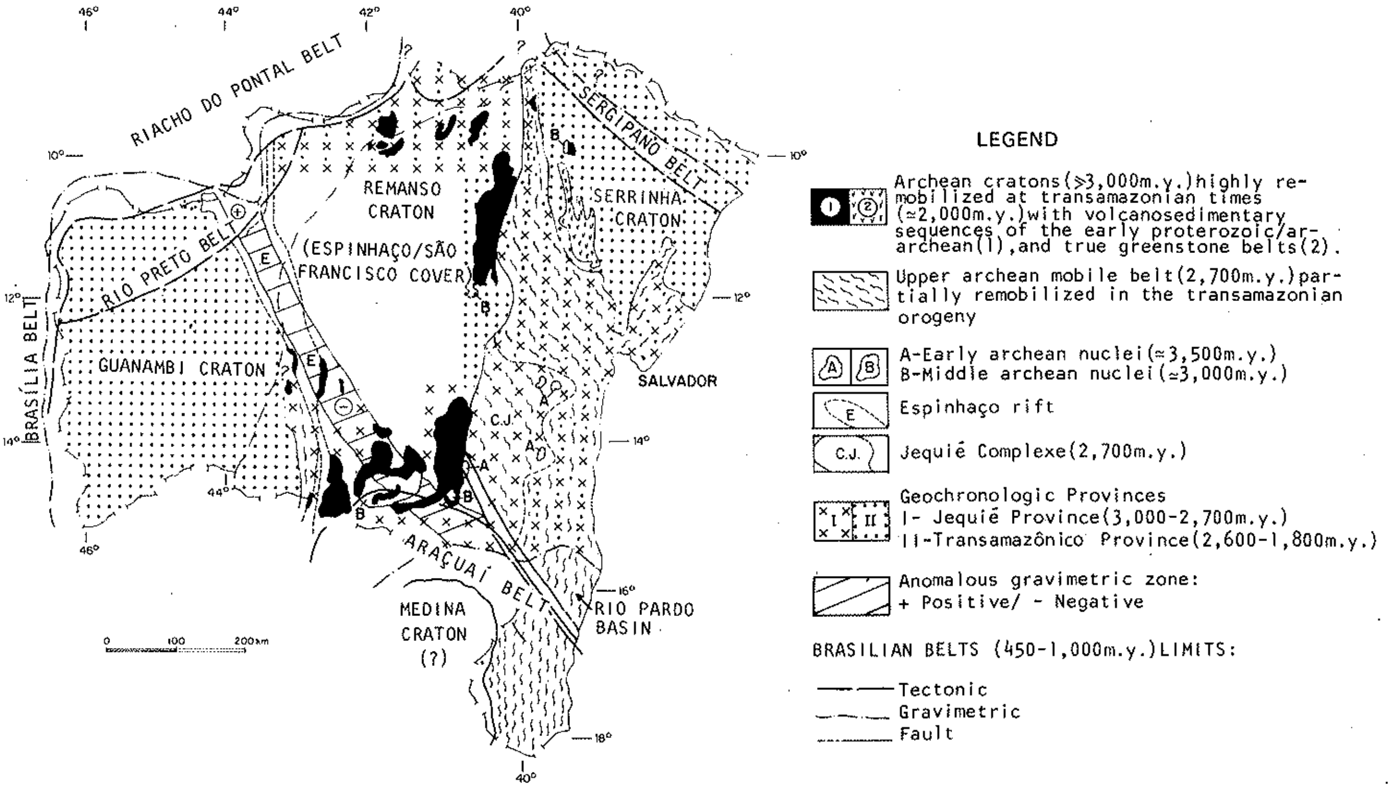


Figure 13 — Geotectonic model for the Archean and Proterozoic in Bahia State, with geochronologic provinces. Adapted from Mascarenhas, 1979

To the geological limits of the São Francisco craton were added the gravimetric limits, which agree reasonably well with the former.

A new gravimetric element, the anomalous Buritirama-Vitória da Conquista belt, was brought to light as a result of the interpretations of Davino (1980) and confirmed by Motta (*op. cit*). This anomalous belt reflects the presence of a crustal discontinuity, with prominent gravimetric highs to the extreme NW, and gravimetric lows to the SE, in the region to the east of Macaúbas and west of Paramirim.

This belt coincides with the limit between the Salvador and São Francisco cratons, as defined by Cordani (1973). At present, it seems to reflect the limit between the Guanambi and Remanso cratons, even though the possible Guanambi-Urandi *mobile belt*, defined in a preliminary fashion by Mascarenhas (1979), is situated to the east of the anomalous gravity belt.

If this belt represents Archean and/or Lower Proterozoic elements, activated during the Brasiliano; if it is simply an element formed at the end of the Precambrian by the collision of two paleoplates or during the evolutions of a *mobile belt* (Cordani, 1973, 1978); or if it was produced during the evolution of the Espinhaço Supergroup, as was suggested by Jardim de Sá *et al.* (1976), Moutinho da Costa and Silva (1980) and Moutinho da Costa and Inda (1982); or, if it evolved during the Brasiliano cycle as a result of jostling of crustal blocks (Torquato and Kishida, *in* Pedreira *et al.*, 1978) are suggestions for which it is not possible to establish any conclusive choice.

With reference to the *mobile belts*, at present doubts remain as to the preferred model of evolution, with two possibilities to be considered (Mascarenhas *et al.*, 1982):

a) the Jequié complex did not form during the Upper Archean as a consequence of structural processes resulting in the formation of *mobile belts*, but is only a highly-eroded continuation of the Remanso Craton;

b) the Jequié complex formed as part of a mobile belt at about 2,700 Ma, forming part of the Coastal *mobile belt* of Almeida (1979), and preserved from the processes of remobilization during the Transamazônico (2,000 Ma) which gave rise to the Atlantic Coastal *mobile belt* (Mascarenhas, 1979*a*).

Present doubts concern two items:

a) the age of the event which produced the penetrative foliations and vertical transpositions which affect extensively both the Jequié complex, and the Atlantic Coastal belt up to the Curaçá river valley. They could either belong to a final event within the Jequié cycle, or could have generated during the Transamazônico, in view of the following factors:

- They exist in both regions, but it is still not possible to define a specific Transamazônico deformative event, the characteristics of which are different from those which affected the Jequié complex.
- The geochronological interpretation for the area of the Atlantic coastal belt (Brito Neves *et al.*, 1980; Moutinho da Costa and Mascarenhas, 1982) assumes the presence of Archean rocks, remobilized during the Transamazônico, the remobilization being intrinsically related to granitizing processes, such as injection, migmatization, and metasomatism.

b) the Rb/Sr isochron ages may not have been affected by the deformational or metamorphic processes, if the physico-chemical system remained closed, *i.e.*, if there were no gains or losses of either Rb and/or Sr.

Under these circumstances, the geotectonic outline of Bahia State can be synthesized as follows:

a) with the sialic crust established during the Archean, the Jequié geotectonic cycle produced a new crustal sub-division by forming the Coastal, and possibly the Guanambi-Urandi *mobile belts*, giving rise to the Serrinha, Remanso, Guanambi and, perhaps, the Medina cratons;

b) these cratonic areas included sequences of greenstone-belt type, geosynclinal accumulations similar to greenstone belts, heavily granitized and migmatized, as well as basic-ultrabasic and gabbro-anorthositic complexes. The geosynclinal accumulations, with their products of paraplatform sedimentation, could have partly evolved during the Lower Proterozoic.

c) the Transamazônico geotectonic cycle, with a similar intensity to that of Jequié, remobilized the larger part of the crust in Bahia State, through deformation, granitization and migmatization. Locally the intensity was sufficient to rework the rocks of the Coastal *mobile belt* and the cratonic areas, establishing the Atlantic Coastal *mobile belt*.

There are insufficient criteria yet available to evaluate whether the Brasiliano marginal fold belts around the São Francisco craton were established in Archean or Lower Proterozoic *mobile belts*, although this idea was proposed by Mascarenhas (1979) on the basis of the polycyclicity concept of formation of *mobile belts* (Anhaeusser *et al.*, 1969; Kröner, 1977).

MINERALIZATION

Most of the mineral deposits in the State of Bahia occur within the Archean and Lower Proterozoic terrains. Many of these deposits are intimately connected with the origin and evolution of the host rocks.

The deposits of greater economic importance are those of gold, chromium, copper, magnesite, lead-zinc, talc, manganese, iron-titanium-vanadium and uranium. Smaller deposits of barite, asbestos, beryl (emerald), molybdenite and vermiculite are also found within the domains of the Archean and Lower Proterozoic terrains. The most important mineral deposits of the State of Bahia are related and localized in Table 1 and Fig. 14.

Gold

The largest deposits of this element are in the districts of the river Itapicuru and the Jacobina hills, the latter a traditional gold producer in the State, the working of which commenced in the mid-XVIIIth. century.

In the Itapicuru river region occurs the greenstone belt of the same name, where, during the last decade, the first signs of gold mineralization were discovered, leading to the finding of the gold-bearing body within the so called Faixa Weber. The main mineralizations are of stratabound type, contained in two principal levels, parallel and folded, and composed of chloritic schists and subordinate quartz-feldspathic breccia and irregular quartz-carbonate segregations (Teixeira, 1981). The most important host-rock for the mineralization, called the *magnetic schist*, is composed of chlorite, quartz, carbonates and plagioclase, with large quantities of magnetite and several accessory minerals, such as epidote, biotite, apatite, arsenopyrite, pyrite, ilmenite, pyrrhotite and gold. Of lesser importance, the gold occurs disseminated in quartz-carbonate masses, in pegmatite veins, in recrystallized chert beds, and in zones of silicification along fractures and faults (Teixeira, *op. cit.*). The economic ore bodies are always related to zones of breccias, mylonites and silicification within the mineralized portion. Apart from lithological and structural controls, the mineralization is stratigraphically controlled, since *magnetic schist* is limited to two levels, localized at the top and the bottom of a complex maf-

Table 1 – Major mineral deposits in the Archean and Lower-Proterozoic terrains of Bahia State

a) Mineral deposits in predominantly sedimentary complexes

Mineralization	**Host Rock**
Au	Magnetic chlorite schist of the Itapicuru greenstone belt
Pb, Zn (Ag)	Magnetite-bearing amphibolite of the Boquira complex
Mn (Fe)	Carbonatic metasediments of the Urandi-Licínio de Almeida complex
Mn	Phyllites of the Jacobina complex

b) Mineral deposits in volcano-sedimentary complexes

Mineralization	**Host Rock**
Au	Metaconglomerates and quartzites of the Jacobina Group
Magnesite, Talc	Metacarbonates of the serra das Éguas and Colomi groups

c) Mineral deposits in high grade metamorphic terrains

Mineralization	**Host Rock**
Fe-Ti-V	Gabbro-norite-anorthositic intrusions
Cu (Au)	Pyroxenite-gabbro-noritic intrusions
Cr	Peridotite-pyroxenite-gabbroic layered intrusions
Mn	Basic granulites with supergenic alteration

(Ag, Fe, Au): Minor quantities and by-products

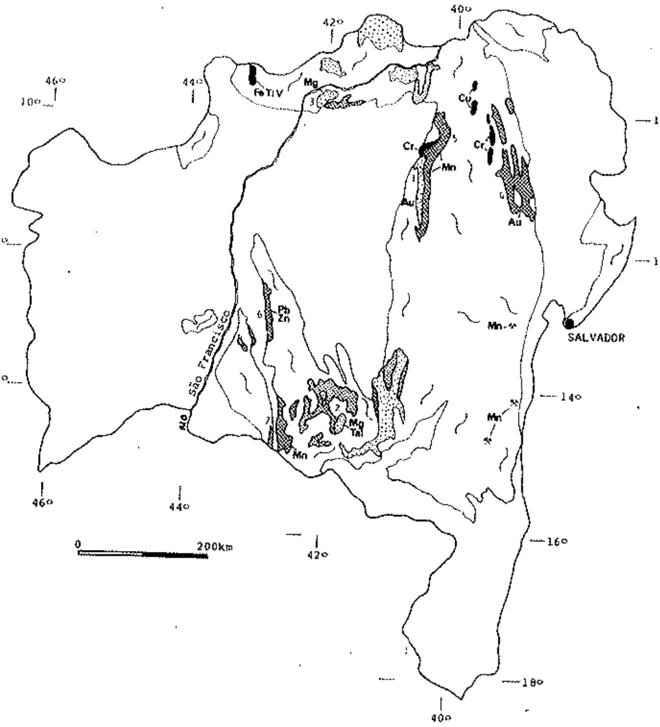


Figure 14 – Geologic sketch map showing the distributions of Archean and Lower-Proterozoic terrains and the major mineral deposits of Bahia State.

ic sequence, in contact with carbonaceous, pelitic and chemical sediments.

The Jacobina includes a sequence of metaconglomerates, metarenites and metapelites which were deposited in a Lower Proterozoic basin established in the granite-greenstone basement. At present, the sequence has a monoclinal structure. The lower part of the sequence is composed of conglomerates and quartzites which were deposited in a fluvial paleosystem, the current direction of which was east to west (Sims, 1977). The principal mineralizations are localized in this part, distributed in at least four levels. The gold occurs in the free form within the matrix of the conglomerates, usually accompanied by recrystallized pyrite and, in some levels, uranium minerals.

The primary mineralization appears to have been syngenetic, although subsequent remobilization and redistribution occurred as a result of metamorphic and supergene processes. Mineralizations within discordant quartz veins, along fracture surfaces and within mafic-ultramafic intrusions which cut the sequence are examples of the remobilization. Similar gold-bearing conglomerates are found in the Witwatersrand, South Africa, especially the Elsburg bodies.

Magnesite and talc In the centre-south of Bahia, principally in the region of the Serra das Éguas, one of the largest magnesite deposits in the world is found. It forms part of a folded sequence of metasediments, which include metacarbonates, metapelites, metarenites and iron formations in the lower part, passing gradually to calc-silicates and metabasites.

The magnesite deposits form beds and concordant lenses, with thicknesses of up to hundreds of meters, intimately associated with dolomitic marbles. The genesis of these has been discussed in terms of, either, direct precipitation of magnesite and calcium-magnesium carbonate under oceanic conditions, or as the result of progressive metasomatism of dolomites by magnesian hydrothermal solutions. In the latter case, the source of the magnesium would be formed through retrometamorphism of the basic volcanics which occur at the base of the sequence (Moraes *et al.*, 1980).

Several talc deposits are associated with the magnesite of Serra das Éguas, and many of them are economically viable. The origin of these bodies has been attributed to processes of retrometamorphism of magnesite, with addition of silica and water, or to hydrothermal alteration, steatization of ultrabasic rocks (Moraes *et al.*, *op. cit.*).

In the northern part of the state, in the municipality of Sento Sé, metasedimentary sequences of the Colomi Group, correlatable with those of Serra das Éguas occur, and also contain thick stratiform magnesite bodies. The ore is massive, with thin concordant lenses of chlorite-talc schists and fine talc veins filling fractures. In this region, the iron formations are quite prominent and in some places form lenses of compact hematite.

The stratiform character of the magnesite deposits, their great thickness and the nature of the associated rocks are strong arguments in favour of a purely sedimentary origin.

Lead and zinc The Boquira complex is an association of metamorphozed volcano-sedimentary rocks, and contains one of the most important lead-zinc deposits of Brazil. The host rock to the ore is a magnetite-bearing amphibolite, with carbonate and siliceous levels. The mineralization is vein-like and, above all, is concordant with the banding in the amphibolites. This banding strikes north-south, with steep dips, either to the west or to the east. The orebodies have a mean thickness of 1.5 to 2 m, and lengths of up to some hundreds of meters.

Two types of ore exist, oxidized and sulphide. The first is composed essentially of cerussite and lesser quantities of smithsonite, pyromorphite and anglesite. This ore has an irregular distribution, and can attain depths of up to 50 m. The sulphide ore is composed of galena, sphalerite, pyrite and small quantities of chalcopyrite. Apart from lead and zinc, the Boquira deposits bear the recovery of silver as a by-product.

The mineralization is stratiform, with a distinct lithological control, and is considered to be syngenetic, although regional metamorphism and tectonism have caused modifications (Espourteille and Fleischer, 1980). The source of the mineralization is still discussed, either in purely sedimentary terms, or in terms of a volcanogenic origin.

Copper The principal copper mineralizations in the State are found in the Curaçá river valley. Of these, the Caraíba Mine deposits are the most prominent, being the second largest in the country. The mineralized bodies are associated with mafic-ultramafic complexes with approximately lenticular shapes, folded and stretched in a north-south direction. Mineralized petrographic types include pyroxenites (hypersthenites), norites, gabbro-norites, gabbros and, more rarely, anorthosites. The mineralizations occur mainly as chalcopyrite, magnetite, pyrite, bornite, pyrrhotite and ilmenite. These minerals are usually disseminated, but can also occur as veinlets along foliation and fracture planes. Massive mineralizations are restricted to the pyroxenites and to fracture zones. The tectono-metamorphic processes which affected the rocks caused remobilizations and redistributions of the mineralization, and this may explain the great variation of copper content within the ore-bodies (Delgado *et al.*, 1975).

The origin of the mineralizations is attributed to magmatic differentiation within layered basic intrusions, through the formation of an immiscible sulphide liquid (Lindenmayer, 1980).

Iron-titanium-vanadium These mineralizations are associated with gabbro-norite-anorthosite bodies within gneiss-migmatite and granulite terrains. The largest reserves are in the Campo Alegre de Lourdes region, in the extreme north of Bahia (Fig. 14), distributed in eight deposits which *totalise* almost 100 million tons of ore with mean contents of Fe = 47.40%, Ti = 21.10% and V = 0.75%. The ores are composed of exsolved ilmenite-hematite grains and magnetite, with a gangue of feldspar and mica.

The host rocks are well-deformed and retrometamorphosed. In spite of the tectonic and metamorphic modifications, the mineralizations preserve textural and structural features which indicate an origin by magmatic segregation. These deposits present features intermediate between those of Allard Lake and of Sanford Lake (Soares *et al.*, 1977).

In the south and centre-south of Bahia, various iron-titanium-vanadium deposits are known, and are in the exploratory phase.

Manganese Some dozens of small and medium manganese deposits occur in Bahia State, concentrated mainly in the districts of Urandi-Licínio de Almeida (south-west), the Jacobina hills (centre-north) and in the south of the State (Fig. 14). In the first two districts, the manganese occurs within volcano-sedimentary associations in low to medium metamorphic grade. In the last district, the deposits are hosted by granulites. In all cases, surface enrichment by supergene processes has formed economic ore grades, in the form of manganese oxides, principally psilomelane and pyrolusite.

In the Urandi-Licínio de Almeida district, the manganese deposits are associated with a volcano-sedimentary sequence which contains hydrothermally-altered basic-ultrabasic rocks, calc-silicates, metapelites, metacarbonates, metacherts and iron formations.

The manganiferous rocks within the sequence are carbonatic,sometimes have high iron contents and are structurally concordant with the host rocks. A volcanogenic origin for the mineralization has been proposed (Moraes *et al.*, 1980) on the basis of the geological environment and the nature of the associated rocks, but a purely sedimentary origin should not be discarded.

In the Serra de Jacobina region, the manganese deposits are distributed along almost all the eastern side, contained in phyllites of the Jacobina volcano-sedimentary complex. The primary mineralization is believed to have been deposited as manganese oxides and hydroxides (Mascarenhas *et al.*, 1976, 1979). Nevertheless, the present-day ores are possibly of supergene origin.

The manganese deposits of the south of Bahia are related to supergene alteration of belts within the granulite complex. These belts are concordant with the regional structures, and sometimes extend for over 10km along a NNE-SSW general direction. In most cases, the host rocks are basic granulites, which led to an interpretation of the original rocks as marls, now metamorphosed in the granulite facies (Silva *et al.*, 1980). These metamorphic conditions must have modified considerably most of the original characteristics making the recognition of the primary mineralization very difficult. The present mineralization is within secondary enrichment crusts composed of manganese oxides, usually accompanied by isolated crystals and veinlets of graphite.

Chromium The State of Bahia possesses almost all the known chromium reserves of our country; they are centralized in the Campo Formoso and Jacurici river valley Districts, located in the northeast portion of the state (Fig. 14).

The Campo Formoso deposits are found in metamorphosed mafic-ultramafic rocks, nearly always changed into serpentinites and chloritites, which are exposed at the foot of the west flank of the Jacobina range, with an extension of about 15 km and mean width of 600 m. The ore occurs as disseminated and massive forms composed of chromitite layers with thicknesses ranging from centimetres to 2 m. These deposits are regarded as of stratiform type, and it is believed that the original mafic-ultramafic body was substantially larger than the present-day one, being largely eroded before the deposition of the Jacobina Complex (Thayer, 1970, unpublished). The ore reserves of this district are estimated to be over 30 million tons.

The chrome deposits of the Jacurici river valley are within mafic-ultramafic sills, which are emplaced in granulites, gneisses and migmatites and, in synform structures, they show the same deformation patterns of the enclosing rocks. The sills have ticknesses lesser than 300 m and very variable lengths, sometimes reaching a few kilometres, and in general, they are composed of peridotite-pyroxenite, gabbro-serpentinite and eventually chromitite layers.

Orebodies are quite thick (in general ranging from 5 to 8 m), as compared to the whole thickness of the host sills. At the Medrado/Ipueira Mines, the main chromitite body occurs at the base of the layer, consisting of orthopyroxene-olivine-spinel (Barbosa de Deus, 1982, unpublished). The chrome ore reserves in the Jacurici river valley are evaluated in the order of 11 million tons.

Other deposits The State of Bahia has the largest reserves of barite of our country, mostly occurring as veins inserted both in gneissic-migmatitic complex rocks and in volcano-sedimentary complexes. These deposits are belived to be a result of hydrothermal processes.

In the region of Carnaíba, in the west flank of the Jacobina range, granitic intrusions dating from the end of the Early Proterozoic (1,800 Ma) caused metamorphic-metasomatic effects, which, in the contact zones, give rise to beryl (emerald) and molybdenite mineralizations. Within the high grade terrains (gneisses, migmatites and granulites), mafic-ultramafic bodies often occur, showing sometimes evidence of strong hydrothermal alteration. Some of these bodies contain amianthus, vermiculite and talc economic deposits.

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