PLUTONIC ASSOCIATIONS OF NORTH-EAST, BAHIA

*** Pierre Sabaté, ** Ian McReath, * Gaston Giuliani**

** ORSTOM, France and IGUFBA, Salvador, Brazil*
*** IGUFBA, Salvador, Brazil*

I. LARGE-SCALE GEOTECTONIC FEATURES OF BAHIA STATE

São Francisco Craton

Throughout Brazil, the effects of the Transamazônico (c. 2.0 ± 0.2 Ga) and Brasiliano (c. 900 – 500 Ma) cycles are widespread. In current Brazilian usage, the term "craton" is often applied to crustal blocks which became consolidated during the Proterozoic and were not subjected to deformation during the Brasiliano cycle.

The São Francisco craton (Almeida, 1967, 1977) is one of the larger cratonic units in Brazil (Fig. 1), and underlies or is exposed throughout most of Bahia State (Fig. 2). It is partly surrounded by fold-belts, although some of the limits are still imprecisely defined, especially to the north-west and north (Rio Preto and Riacho do Pontal belts, respectively: Mascarenhas and Sá, 1982). The western (Brasília) and south-eastern belts (Araçuaí) appear to have had a long late Proterozoic evolution, culminating in Brasiliano cycle folding and plutonism, while the northeastern belt has substantial Brasiliano supracrustals and granite intrusions.

Within the craton the subdivision of the rocks present has been attempted following a number of schemes. For the purposes of this guide, a much-simplified outline is summarized in Fig. 2 (Marinho and Sabaté, 1982). A few older Archean nuclei belonging to the Pré-Jequié or Guriense cycle (c. 3.2. Ga) are found, for exemple, in the granulitic Jequié complex, and in gneiss domes within the Contendas-Mirante volcano-sedimentary sequence. The Jequié cycle (c. 2.7 Ga) is widely imprinted. These high-grade Archean rocks are conventionally separated into complexes, based on criteria such as lithological composition and metamorphic grade, but contacts are often interdigitating or transitional, and correlations between areas separated by Archean or Lower Proterozoic fold belts composed of volcano-sedimentary or sedimentary rocks, often in low metamorphic grade, are difficult.

The high-grade rocks form the infrastructure for a number of volcano-sedimentary or sedimentary sequences whose ages are, in one way or another, doubtful. Some of the sequences have been compared to greenstone belts (Mascarenhas, 1979) and, by analogy with other world-wide occurrences, Archean or

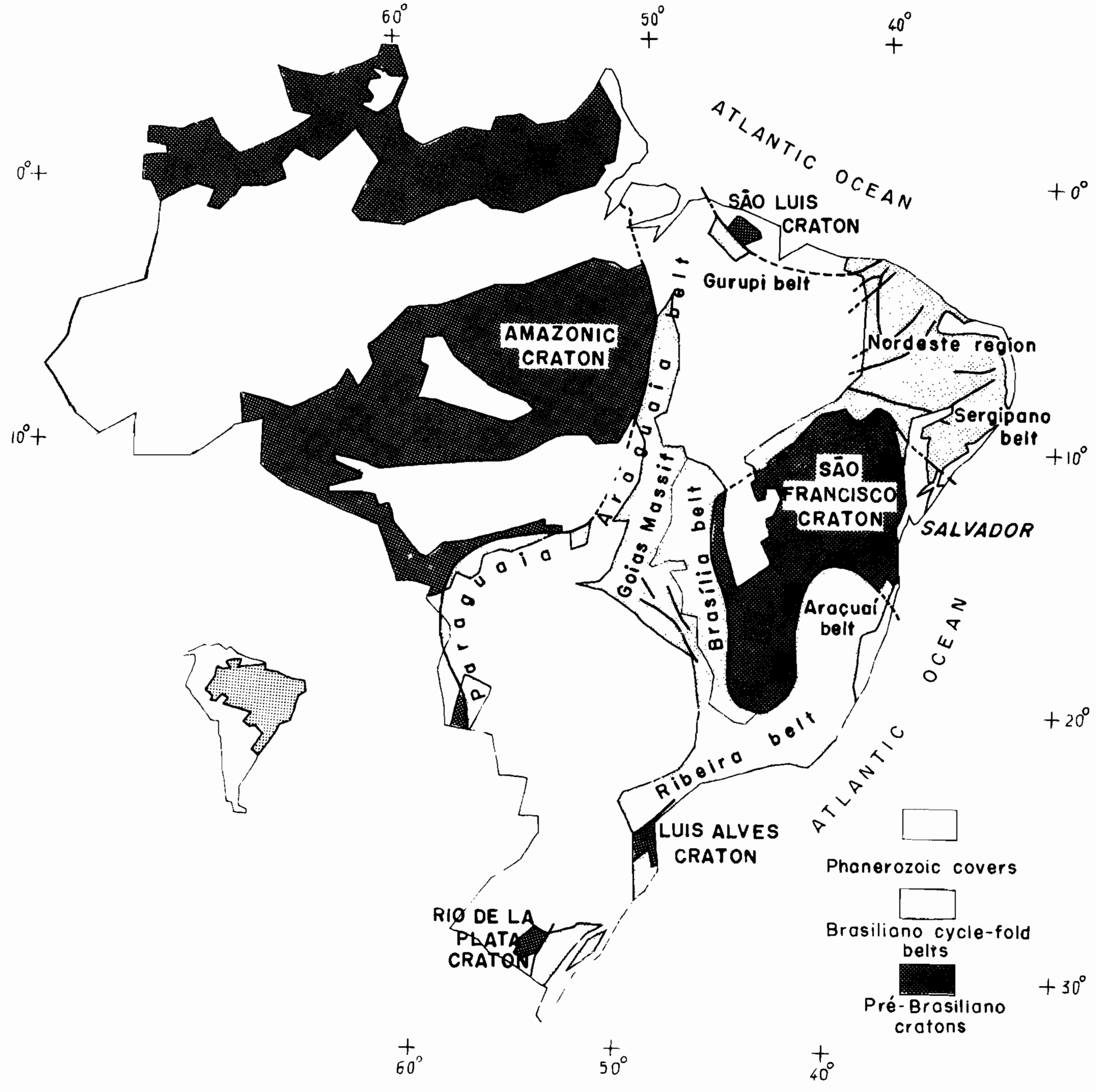

Figure 1.
Situation of the São Francisco Craton in the Brazilian shield.

Lower Proterozoic ages are usually assumed. On the other hand, radiometric dating by Rb/Sr whole rock isochrons has revealed up to now only Transamazônico minimum ages for the two better-studied cases of Serrinha and Contendas-Mirante (respectively Kishida and Riccio, 1980; Brito Neves *et al.*, 1980; and Marinho and Sabaté, 1982; Sabaté and Marinho, 1982). The Jacobina predominantly sedimentary sequence also has a Transamazônico minimum age.

In contrast, it seems likely that the deposition of the intracratonic Espinhaço volcano-sedimentary sequence commenced at a time corresponding to the end of the Transamazônico orogeny (c. 1.8 Ga) and may have continued over a relatively long time-span (see Sabaté *et al.*, this symposium). On the other hand, deformation and associated hydrothermal phenomena may well have ceased only during Brasiliano times. To the east of the exposed high-grade basement block of the Paramirim River basin, the Chapada Diamantina sequence, at least in its western portions, had a similar history.

In global terms, the Transamazônico cycle was extremely important for the evolution of the craton for, apart from the deformation of the supracrustal sequences already mentioned, migmatization and generation of anatectic granites was quite important in some basement locations, while syn- to late-tectonic granite intrusion played its part in the structuring of the volcano-sedimentary and sedimentary covers in their present forms. A belt extending from Juazeiro to Salvador, which then follows the coast in a southerly direction shows, quite abundantly, the imprints of this cycle.

Upper Proterozoic platform cover in the centre-north of the State, Jurassic-Crataceous sediments in the Tucano-Reconcavo basin in the East and the Urucuia in the west, and Cenozoic cover, widespread throughout the State from the coastal belt to the São Francisco River basin and proximities, complete the geological picture.

II. GEOLOGY OF THE SENHOR DO BONFIM – SERRINHA REGION

Introduction

The Senhor do Bonfim-Serrinha region is situated in the northeastern part of the State of Bahia and is limited by longitudes 39°00' – 40°30'W and latitudes 10°00' – 12°00'S (Fig. 2). It is included in the São Francisco structural province (Almeida *et al.*, 1981) and corresponds to the northern part of the oriental shied of Bahia (Inda and Barbosa, 1978).

In the crustal block, plutonic rocks varying in composition but with a general acid affinity, and mesozonal and catazonal formations predominate. Epimetamorphic terms are represented by series of sedimentary and volcano-sedimentary origin, some of which were interpreted as greenstone belts (Mascarenhas, 1976). The whole domain was consolidated at the end of the Transamazônico cycle, which closed around 1.7 to 1.8 Ga.

Various lines of study allow the separation of three domains within this tectonic block (Inda and Barbosa, 1978; Almeida, 1977, 1981):

– a northerly extension of the Jequié-Mutuípe zone, composed of granulitic and migmatitic rocks whose formation is related to two events, the Pre Jequié (c. 3.2 Ga) and the Jequié (2.7 Ga) cycles, but which were affected during the Transamazônico;

– the folded Contendas-Mirante-Jacobina and Serrinha-Uauá zones, whose age of deposition remains under discussion (Archean or lower Proterozoic?) but which have a Transamazônico isotopic imprint. A lower Proterozoic age is inferred for the deposition of the mainly sedimentary sequence of the intracratonic Jacobina basin, for exemple, by comparison with other identical intracratonic sequences throughout the world;

– the Salvador-Juazeiro (Curaçá) zone, the infrastructure of a Transamazônico mobile belt, with Archean components in granulite-charnockite facies, corresponding to those of the Jequié-Mutuipe zone, and migmatites and granites formed between 1.9 and 2.1 Ga.

Paraplatform covers, deposited and folded during the middle or upper Proterozoic are represented by the Sergipano folded system and the Una/Bambuí basin deposits. Unfolded Phanerozoic (Upper Jurassic-Lower Createaceous) occurs in the eastern part of the region, in the Tucano marginal basin. Tertiary and Quaternary cover, recognized in the western part of the area, completes the sedimentary formations.

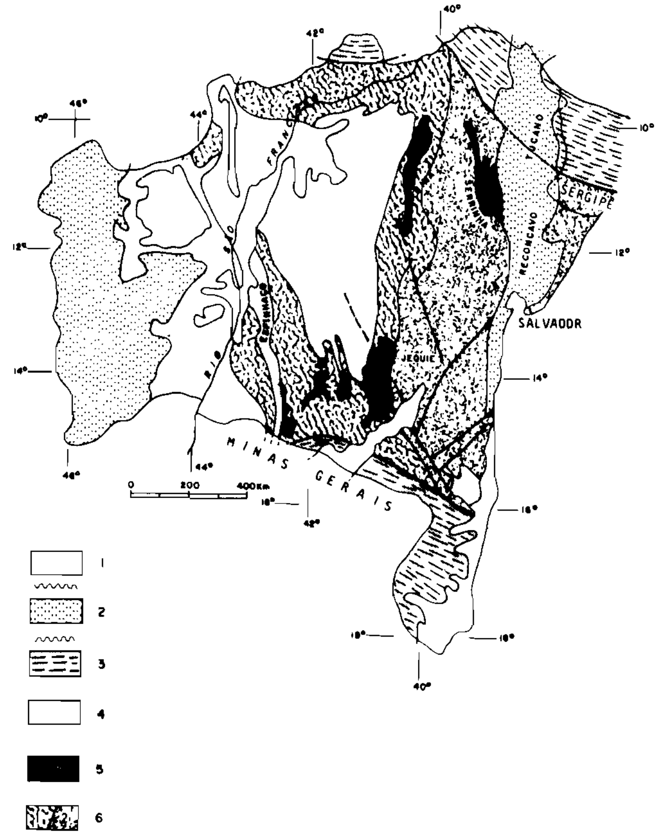

Figure 2.
Structural outline of Bahia state. Localization of Lower Proterozoic volcano-sedimentary sequences within the São Francisco Craton.
(1) Cenozoic cover; (2) Cretaceous Cover; (3) Upper Proterozoic fold belt; (4) Upper and Middle Proterozoic folded platform covers; (5) Lower Proterozoic volcano-sedimentary sequences; Jacobina, Serrinha, Itapicuru, Contendas Mirante (CM); (6) Archean basement gneiss-migmatitic locally rejuvenated during Transamazônico cycle (1) and granulites (2). Modified from Mascarenhas (1978) in Marinho and Sabaté, (1982).

The Archean Formations

The different geological divisions in the Senhor do Bonfim-Serrinha region (Fig. 3) represent an Archean high-grade metamorphic infrastructure formed by:

– to the west, the craton of Lençóis;

– to the east, the craton of Serrinha;

– in the centre, the Salvador-Curuçá mobile belt.

This latter contains some fragments of the old Gavião nucleus. Volcano-sedimentary belts of the upper Archean – Lower Proterozoic within the Serrinha craton are associated with the migmatitic, gneissic and granitic facies. They are represented by the Serrinha or Rio Itapicuru greenstone belt and the Capim belt.

The Lençóis craton

The Archean formation of the Lençóis craton described by Pedreira *et al.*, (1976) present different structures and lithologies which are mainly heterogeneous migmatites, gneisses and homogeneous migmatites. Within this formation, other facies corresponding to plutonic, volcanic or sedimentary components occur, distributed in narrow and variable belts of metabasites, metaultrabasites, amphibolites, calc-silicate rocks, marble, metacherts and quartzites. The chromitiferous serpentinite of Campo Formoso may be included in this group.

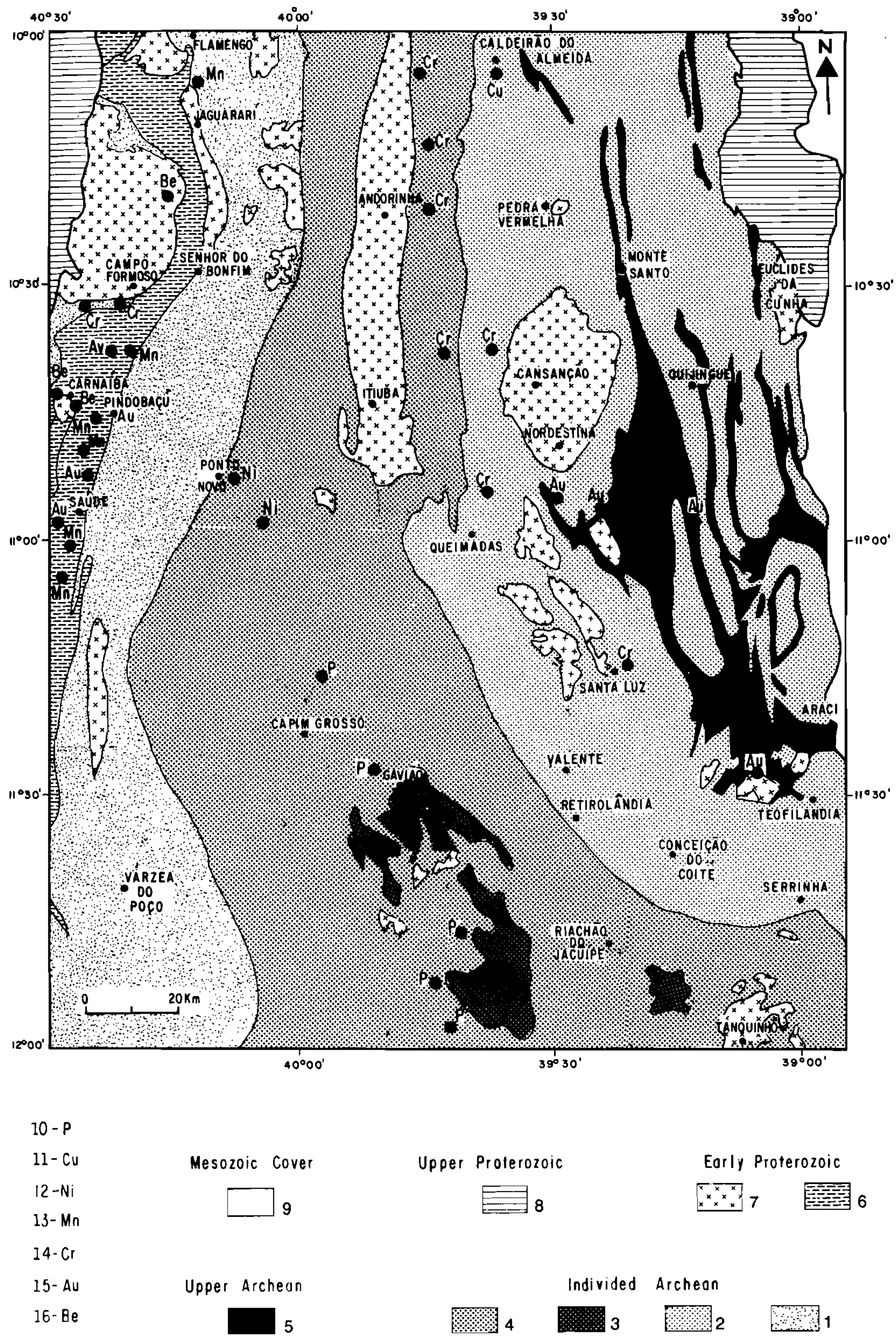

Figure 3.

Simplified geotectonic and geologic sketch map of the Senhor do Bonfim and Serrinha area with metallogenetic aspects. Data from "Projeto mapas metalogenéticos e de previsão de recursos minerais. Folhas Senhor do Bonfim e Serrinha, escala 1:250.000, DNPM, 1985.

(1) Craton of Lençóis; (2) Craton of Serrinha; (3) Fragments of the old Gavião Nucleus; (4) Salvador – Curaçá mobile belt; (5) Volcano-sedimentary belt of Capim complex and River Itapicuru greenstone belts; (6) volcano-sedimentary complex of Jacobina; (7) Transamazônico granitoids; (8) Sedimentary metamorphic belts, neogeosynclinal type of the folded Sergipano system and folded sedimentary cover of the Una-Bambui basin; (9) Unfolded sedimentary cover (upper Jurassic to Lower Cretaceous); Mineralization type: (10) Apatite and vermiculite; (11) Copper; (12) Nickel; (13) Manganese; (14) Chromium; (15) Gold; (16) Emerald and beryl.

Heterogeneous migmatites and gneisses

These correspond to banded rocks with a regional foliation trending N-S, with local variations related to migmatization in mobile zones. The banding is characterized by an isotropic neosome related to granite-pegmatite. The leucosome occurs in various forms as in typical migmatites. The neosomes are generally granitic with granoblastic textures.

Homogeneous migmatites

These result from advanced anatectic transformations. They have granitic to tonalitic compositions.

The chromitiferous serpentinite of Campo Formoso

This is a differentiated basic to ultrabasic complex which forms a long, narrow (25 x 0.5 Km) belt situated along the eastern margin of the Campo Formoso granite. The peridotite suffered a greenschist facies retrometamorphic effect, producing serpentinites, chlorite serpentinites and schists, talc schists, carbonated talc schists and amphibolites (Hedland *et al.*, 1974; Melfi *et al.*, 1979, 1980; Boukili, 1984; Calas *et al.*, 1984).

The chromite mineralization is developed in stratiform, disseminated or lump form. The stratiform type shows centimetric intercalations of serpentinite and chromite, while the disseminated type has chromite crystals dispersed throughout the whole rock. The lump type is associated with both stratiform and disseminated types represents the richest ore with grades varying between 30 and 45% Cr_2O_3. It can form massive layers with thickness between 1 and 3m. Reserves are estimated at 9,700,00 t diseminated and stratiform ores with 15-20% Cr_2O_3, and 950,000 t lump ore (Gonçalves *et al.*, 1978).

The Serrinha craton

This Archean craton (Seixas *et al.*, 1975), consolidated at the same time as the Lençóis craton, is composed of migmatite and gneiss (diatexites, metatexites and hornblende gneiss). The foliation trends N-S but shows some variations related to later intrusive and/or parautochthonous granites which develope circular and concentric structures, as in the Pedra Vermelha and Tanquinho areas (Fig. 3).

As in the Lençóis craton, various lithological types are superposed, forming belts of variable dimensions composed of ultramafics, amphibolites and calc-silicates. These intercalated formations allow the study of the regional folding style, which corresponds to isoclinal folds which are sometimes normal and symmetrical. The fold hinges of normal folds can be tight (SW of Monte Santo) or open (NE of Cansanção).

Chromitiferous serpentinites are also found in the Jacurici River valley, W of Cansanção and Pedra Vermelha. They occur in layered basic to ultrabasic sills, which have been metamorphosed, tectonized and are now concordant with the host granulitic rocks. These bodies with lengths from 500 to 1,500m and widths of from 20 to 800m, distributed in belts (Barbosa de Deus and Viana, 1982; Marinho, 1986).

Disseminated copper mineralization (chalcopyrite, bornite) is found in marbles associated with metacherts and metabasites in the area of Caldeirão do Almeida.

The Salvador-Curuçá mobile belt

Between the two cratonic segments, delimited by two fault systems (Gomes and Motta, 1980) is located the geotectonic unit represented by the mobile belt of Salvador-Curuçá. This belt was structured during the Jequié cycle and reactivated during the Transamazônico. Its essential constitution is formed by granulitic and charnockitic rocks and gneisses of amphibolite facies. Intercalations of metabasites, meta-ultrabasites, calc-silicates, marbles, quartzites, biotite gneisses and amphibolites are also encountered.

The whole segment presents a NW-SE folding in the southern part of the area, and a N-S direction in the northern part. Shearing and mylonitized zones with N-S and NE-SW directions are frequent.

Nickel mineralizations are found in serpentinite formations near Ponto Novo (Fig. 3). Apatite and vermiculite mineralizations are related to diopsidic calc-silicate rocks, carbonate rocks and syenitic pegmatites cross-cutting the granulites.

The Greenstone belt of the Rio Itapicuru (Serrinha) and the Capim complex: supracrustal formations

The greenstone belt of the River Itapicuru (Kihida, 1979; Kishida and Riccio, 1980) and the volcano-sedimentary formations of the Capim complex (Mascarenhas, 1976; Winge, 1984) are deposited in the Serrinha craton (Fig. 3). The age of these deposits is open to doubt. Conventionally, they are believed to be Archean or at least Lower Proterozoic. Radiometric dating, however, shows a strong imprint of the Transamazônic event (Brito Neves *et al.*, 1980) and unpublished and incomplete Rb/Sr and U/Pb (zircon) studies give no reason to believe that these complexes may have been deposited during the Archean (Teixeira, pers. comm.).

The River Itapicuru volcano-sedimentary sequence has a complex lithological composition including a basal mafic metavolcanic unit with chemical sediments and pelites. This is overlain by a less-continuous felsic metavolcanic unit with clastic sediments, and finally by a metaarkosic-metapelitic-graywacke unit with intercalations of metabasalt, marble, metacherts, amphibolite and iron formation. The two lower units are also recognized in the Capim complex.

The greenstone belt supracrustal rocks are deformed with a general direction NNW-SSE and show isoclinal and closed folds crosscut by longitudinal faults or shear zones. Jardim de Sá (1982) defined five phases of deformation in these rocks.

Gold – sulphide mineralization occurs in quartz-feldspathic breccia, quartz veins and silicified zones in the "Faixa Weber" zone, associated with a metagabbro sill. The origin of the host rocks for the mineralization is controversial. Montes Lopes (1982) believes that they are chemical metasediments within the basal mafic metavolcanic unit, while Teixeira (1984) considers them to be metaferrogabbro diferentiates within the basic sill.

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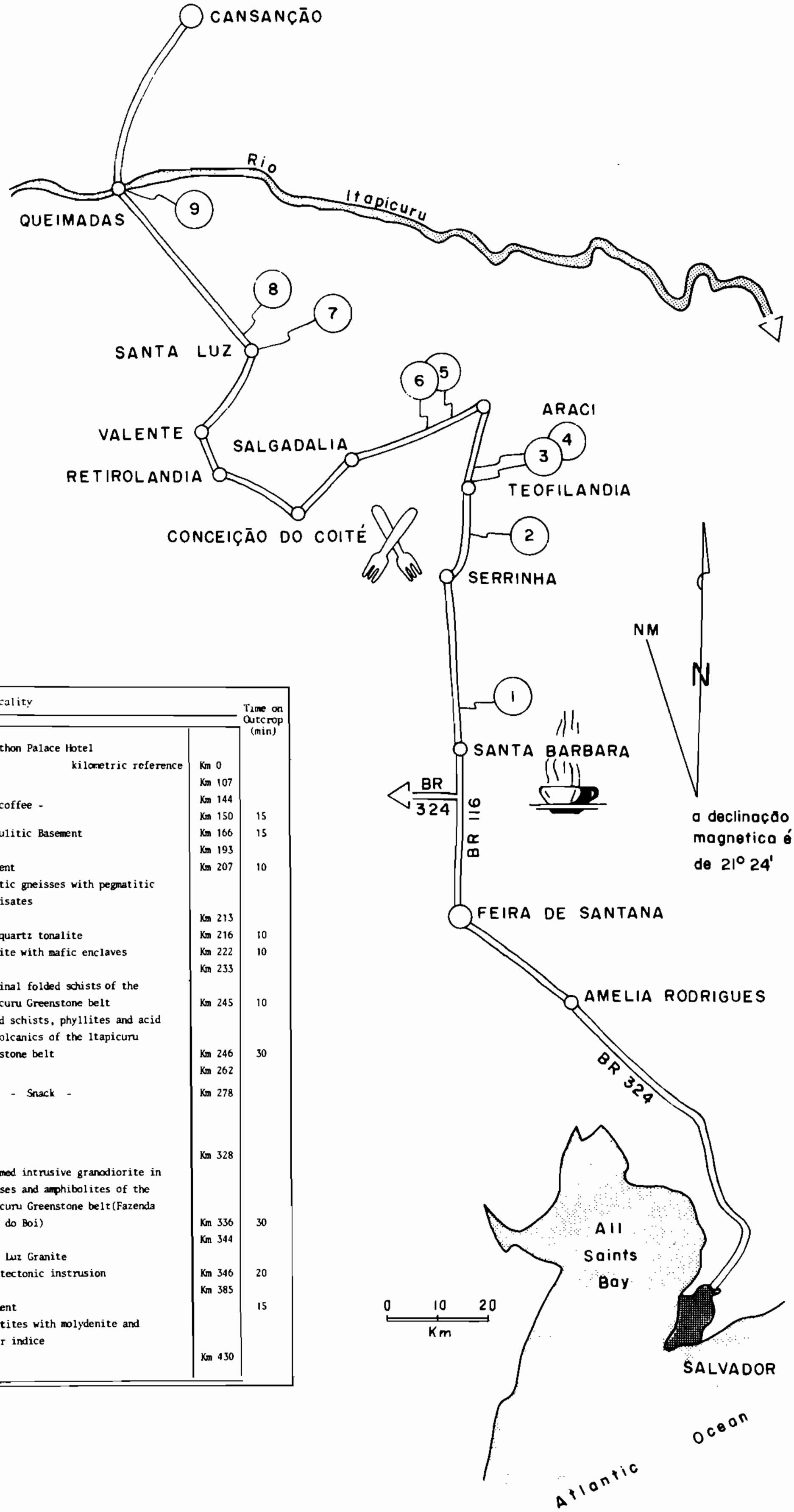


Time	Locality		Time on Outcrop (min)
06:00	SALVADOR - Bahia Othon Palace Hotel		
06:10	BR-324 road kilometric reference	Km 0	
	FEIRA DE SANTANA	Km 107	
08:00	SANTA BÁRBARA - coffee -	Km 144	
08:30		Km 150	15
08:50	**Outcrop 1** - Granulitic Basement	Km 166	15
09:15	SERRINHA	Km 193	
09:30	**Outcrop 2** - Basement migmatic gneisses with pegmatitic mobilisates	Km 207	10
09:40	TEOFILÂNDIA	Km 213	
09:45	**Outcrop 3** - Blue quartz tonalite	Km 216	10
10:10	**Outcrop 4** - Tonalite with mafic enclaves	Km 222	10
10:30	ARACI	Km 233	
10.50	**Outcrop 5** - Isoclinal folded schists of the Itapicuru Greenstone belt	Km 245	10
11:07	**Outcrop 6** - Folded schists, phyllites and acid metavolcanics of the Itapicuru Greenstone belt	Km 246	30
12:05	SALGADALIA	Km 262	
12:35 13.35	CONCEIÇÃO DO COITÉ - Snack -	Km 278	
	RETIROLÂNDIA		
	VALENTE		
14:20	SANTA LUZ	Km 328	
14:30	**Outcrop 7** - Deformed intrusive granodiorite in gneisses and amphibolites of the Itapicuru Greenstone belt (Fazenda Lagoa do Boi)	Km 336	30
15:15	SANTA LUZ	Km 344	
15:25	**Outcrop 8** - Santa Luz Granite Late tectonic instrusion	Km 346	20
16:25	QUEIMADAS	Km 385	
	Outcrop 9 - Basement Migmatites with molydenite and sulfur indice		15
17:00	CANSANÇÃO	Km 430	

GEOLOGICAL ITINERARY

FIRST DAY

Salvador – Cansanção

Plutonic bodies associated with the Serrinha greenstone belt

Salvador is localized on a fragment of Archean granulitic crust, separated from other similar areas by the sediments of the Recôncavo – Tucano basin.

The Mesozoic terranes of this basin are crossed between Simões Filho and Amélia Rodrigues on the federal highway BR-324. The characteristic scenery of the Recôncavo region is best seen during the first hour of the trip. Agricultural activity is based on palms, bananas and vast plantations of sugar cane, which have progressively taken the place of the tropical coastal forest, of which some better-preserved remnants are seen between Todos os Santos Bay and the road, and are easily recognisable by the density of the vegetal growth and the majestic appearance of the larger trees.

Good exposures of the sediments can be seen in the deep cuts which have been opened to allow the passage of the road. For example, at km 34 (after appoximately a half-hour of travel) fine-to coarse-grained arenites of the Cretaceous Maçacará Group (Or São Sebastião Formation) show bedding dipping to the west. In other parts of the region, these arenites form an important aquifer. As we progress toward the centre of the basin the bedding changes slowly to horizontal. On getting closer to the Feira de Santana plateau, at km 77 (approximately 1 hour) a long cut to the NE of the road shows east-dipping arenitic and conglomeratic members of the Petroleum Sequence, considered as the base of the Cretaceous in Bahia. During the ascent to the plateau, Jurassic shales and arenites are crossed. These mark the contact with the granulitic basement, which occurs in Amélia Rodrigues, but is covered by thin, horizontal, continental deposits of the Tertiary-Quaternary Barreiras Formation.

The Mesozoic sediments of the Recôncavo – Tucano rift reach more than 6km thickness in the northern part of the basin. Although generally poor in fossils, the Jurassic and Cretaceous ages were established using ostracods.

Between Amélia Rodrigues and Santa Barbara (Fig. 1.00), the terranes are composed of lithologically diversified groups which have probably had a complex structural history, but which have had the wisdom or malice of undergoing the uniformizing effects of the granulite facies. On maps, they are represented under the generic term Archean "charnockites" but include, as well as charnockites, hornblende granulites, leptites, enderbites, amphibolites, etc.

Some areas are migmatized. These rocks are correlated with the Jequié-Mutulpe granulite zone, with ages predominating at 2.7 Ga.

1st outcrop (Km 166)

A short stop will be made at a road-side outcrop, 6km to the north of Santa Bárbara, to illustrate the granulite terranes which compose the Archean basement.

The outcrop has an association of felsic and intermediate (enderbitic) rocks in granulite facies. Parageneses are perthitic microcline, plagioclase, hypersthene and quartz.

Biotite may appear in the felsic members. The textures are typically granulitic.

The granulitic foliation N150 is representative of the dominant regional direction.

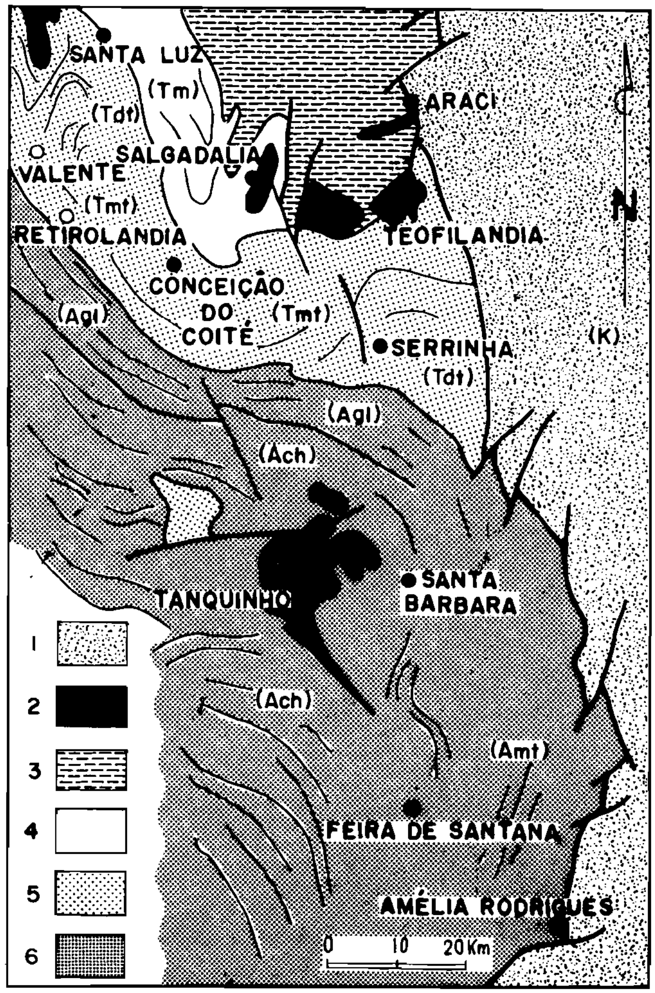


Figure 1.00

Simplified geological map of the crossed region between Amélia Rodrigues and Santa Luz

1. Mesozoic cover (K)
2. Transamazônico instrusions
3. Supracrustal formations of the River Itapicuru
4. Transamazônico gneisses and amphibolites (Tm)
5. Transamazônico migmatites: Metatexites (Tmt), Diatexites (Tdt)
6. Archean terrains: charnockites (Ach), Pyroxene granulite (Agl), Migmatites (Amt).

An amphibolitic lithotype is present in a vein which cuts the granulitic foliation and has an orientation which corresponds with that of the vein walls. This type could be related to the mafic magmatism which is recognized in the coastal granulitic belt and was responsible for a large number of intrusive bodies whose ages fall between 1.370 and 2.050 Ma (Cordani, 1973). They belong to an Hawaiian type tholeiitic suite (Bellieni *et al.*, 1986) whose significance, as far as the geotectonic evolution of the craton is concerned, is open to speculation.

Between the Ist stop and Serrinha, the route continues through charnockitic terranes attributed to the Archean, which then pass over to granulitic members (pyroxene-and pyroxene-hornblende-granulites associated with quartzites) which show the isotopic effects of the Transamazônico cycle without, however, showing signs of important mineralogical transformations.

At the city of Serrinha, the basal Transamazônico complex (Inda and Barbosa, 1978) commences. This includes microcline, coarse plagioclase-bearing and hornblende-gneisses, amphibolites and a migmatitic unit with metatexites and diatexites (fig. 1.00). A number of outcrops of this unit can be seen between Serrinha and Teofilândia. 11km to the north of Serrinha, a road-cut shows alternating gneisses and leptinites with small intercalated granitic sills and some discordant dykes.

2nd outcrop

3km further on, the outcrop to the west of the road has paragneisses with alternating coarse and fine-grained detrital rocks, and thin horizons of quartzitic metarenites. The gneisses are invaded by abundant pegmatitic mobilizates which are mostly interstratified but locally discordant. The overall foliation N125 dips progressively from 40° to 60° to the north.

Few radiometric data are available for these formations, which are attributed to the Transamazônico cycle (Brito Neves *et al.*, 1980; Bartels *et al.*, 1977).

Within these migmatitic formations, diatexites form true massifs which have a topographical expression such as the hills around Serrinha, for example.

Closer to Teofilândia, the road cuts have outcrops of altered granite partly affected by the deformations which also acted on the gneisses and migmatites.

3rd and 4th outcrops

North from Teofilândia, the route enters a large plutonic body responsible for the rounded topographic relief, with a width of more than 10km, which replaces the more accidented morphology further to the north, modelled over the supracrustal rocks of the Serrinha greenstone belt.

Recent road works have covered many outcrops of this body, but it is still possible to see some of the typical facies of the intrusion, for example, at 2.5 and 8km to the north of Teofilândia, where stops will be made.

The outcrops are well-preserved blocks, composed of a medium-grained tonalite which has a few large phenocrystals of rosy microcline. The matrix is composed of quartz, sericitized and saussuritized plagioclase, microcline, green hornblende, slightly chloritized biotite, pistacite, zoisite, sphene, zircon, ilmenite and apatite.

Restricted transformations are seen. The magmatic texture is preserved with a planar preferred orientation of the ferromagnesian minerals which, in this central part of the body, is sub-horizontal.

The quartz has a characteristic blue colour. The significance of this fact is at present unknown, but, in the absence of a detailed study, an interpretation can be proposed in the light of the observations of Green *et al.*, (1979).

They attributed the blue color of quartz in alpine metamorphics to the superposition of a low grade metamorphism (greenschist) upon high grade equilibrium permitting the formations of rutile inclusions in the quartz lattice.

The blocks near the church at 8km past Teofilândia are of a somewhat lighter coloured facies which contains rounded mafic enclaves formed by fine grained gabbroic rocks rich in biotite and amphibole, sometimes containing K-feldspar phenocrysts. Mineral transformations (chloritization, epidotization) are more promnent in these rocks.

In this part of the massif, the enclaves do not show much deformation. In the south-western part of the massif, they are more numerous and elongated.

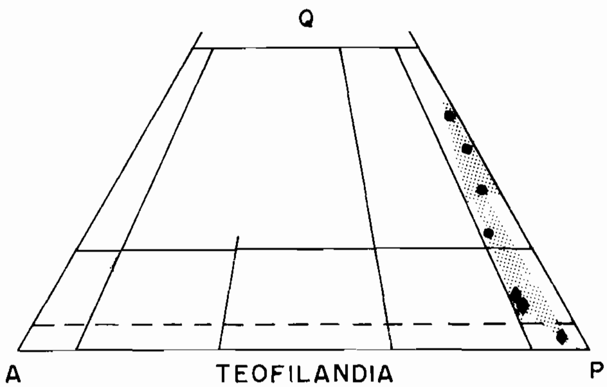


Figure 3.00
Modal distribution of the Teofilândia tonalites (circle) and related enclaves (diamond shape) in the QAP diagram.

There are facies variations in the tonalite. For example, in the northern part of the body, ferromagnesian-poor members are practically trondhjemites. These light green rocks are rich in idiomorphic plagioclase, and have a cumulate aspect. Overall, modal compositions show a typical tonalitic differentiation on a QAP diagram (fig. 3.00). Chemical compositions are as follows (table 3.10).

Table 3.10
Chemical range of the Teofilândia tonalites. (analyses: Department of Geochemistry UFBA, Salvador).

	TONALITES			ENCLAVES		
	INTERVALS		MEAN	INTERVALS		MEAN
SiO_2	67,12 a	64,70	66,70	68,26 a	52,36	60,31
Al_2O_3	15,23	13,70	14,66	16,10	13,67	14,49
Fe_2O_3	2,73	1,10	2,05	6,11	2,62	4,59
FeO	2,37	1,08	2,05	4,89	2,30	3,27
MnO	0,05	0,04	0,05	0,22	0,06	0,12
MgO	1,26	1,11	1,25	5,65	1,60	3,13
CaO	2,80	2,27	2,60	7,15	2,85	4,39
Na_2O	4,38	3,86	4,08	3,57	3,15	3,42
K_2O	2,66	2,34	2,54	2,40	1,16	1,78
P_2O_5	0,18	0,13	0,15	0,30	0,19	0,25

5th outcrop

In Arací, we take the dirt road which leads to Salgadália. This route offers the opportunity to see a profile through the southern part of the Serrinha greenstone belt (fig. 5.00) where essentially sedimentary members of the supracrustal sequence crop out.

12 Km past Arací, there is a good exposure of the schists of this sequence. The outcrop shows folded structures, amongst which should be noted:

– a P_1 phase of isoclinal folds with NW-SE trending, subvertical axial plane.

In this phase, folds of decimetric to metric amplitude and wavelength were developed, whose axes have a weak plunge (15 to 20°). The deformation developed a penetrative S_1 schistosity which transposes S_0, still recognizable in places.

– In this same outcrop, it is possible to see a phase F_3 of centimetric to decimetric kink-bands which affects S_1 and has verticalized fold axes. A sinistral shear along N 105, marked by drag folds which affect S_0 and S_1 accompanies the kink deformation, which does not develope a penetrative schistosity.

– the schistosity S_1 developed under the conditions of crystallization of chlorite and sericite and locally, muscovite and biotite.

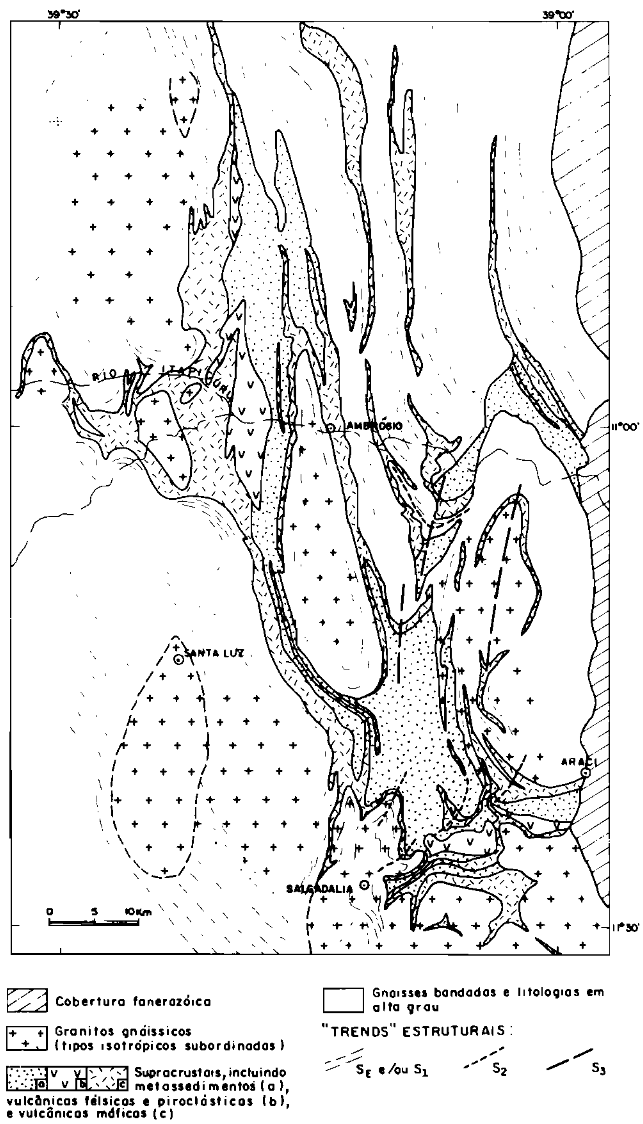


Figure 5.00
Geological sketch and structural situation of the Itapicuru greenstone belt after Kishida (1979) in Jardim de Sá (1982)

6th outcrop

One km further ahead a road cut presents remarkable exposure which allows the addition of much structural information.

In these schists, intercalations of felsic volcanics (metadacite) are found in metapelites and metarenites.

The whole shows an open anticlinal dissymmetric P_2 fold affecting $S_0 + S_1$ (undifferentiated) and which developes parasitic folds. At the eastern extremity of the cut, the style becomes modified, passing to tighter homoaxial folds of kink type. A penetrative S_2 foliation, subvertical with strike NW-SE developes crenulations, and shows recrystallization of chlorite and sericite.

Most parasitic fold are conjugate with F_2, but some do not conform with the F_2 patterns and may be related to the homoaxial F_1 phase.

Jardim de Sá (1982) found evidence for five fold phases in the area. The phases P_2 and P_3 correspond to his F_3 and F_5. He argues for additional phases on the basis of observed interference patterns. Relationships between the phases may be resumed as follows:

(i) between F_1 (=P_1) and F_2

– B lineations cut each other

no mesoscopic interference patterns are seen because of the isoclinal geometry of F_1 and subsequent flattening by F_3.

– an intersection lineation L_2 is visible on S_0 (fig. 6.10).

– the S_2 foliation could be a crenulation cleavage or a schistosity.

– crystallization of garnet occurs pre-F_2 and of andaluzite, syn-F_2.

– the ring-shaped structure centered on Salgadália results from F_2 being superimposed on F_1 (fig. 5.00).

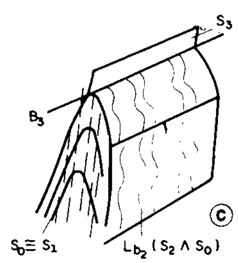


Figure 6.10
Interference figures between F_2 and F_3 (Jardim de Sá, 1982, fig. 2i)

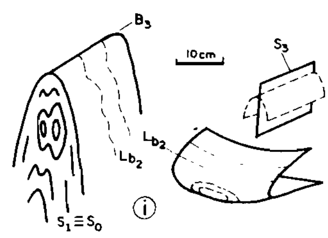


Figure 6.11
Interference figures between F_1 and F_2 (Jardim de Sá, 1982, fig. 2c)

(ii) between F_3 (= P_2) and F_1 (= P_1)

– the folding is co-axial

– an intersection lineation is produced by $S_3/(S_1 + S_0)$

– folding of veins boudinaged in F_1 occurs

(iii) between F_3 (= P_2) and F_2

– possible domes and mushrooms

– inclined to inverted style for F_2

– a refolded dome with axis B_2 curved due to heterogeneous deformation (fig. 6.11)

– a dome NW of Arací probably results from superposition of F_2 and F_3 (Fig. 5.00)

(iv) between F_4 and F_3 (= P_2)

– fracture cleavage S_4, little or undeveloped

– presence of B lineation (L_4)

– coaxial interference patterns with F_3

– dip variation of S_0 and S_1

On a regional scale, the expression of P_1 is constant, and is responsible for the inversion of the volcanic formations along the Rio Itapicuru section. In this, Davison (1986) indicates the presence of synclinal and anticlinal folds with vergence to the east, and wavelengths of around 20km. The syncline is occupied by metasediments and the anticline by the intrusive dome of Ambrósio. This author does not recognize the presence of isoclinal folds, and attributes the foliation parallel to the bedding S_0 to compaction during subsidence.

Fig. 6.20 present an hypothetical scheme of one of the present authors for discussion.

During the rest of the route towards Conceição do Coité, we return to the migmatite terranes of the basalt Transamazônico Complex, which continue until Santa Luz.

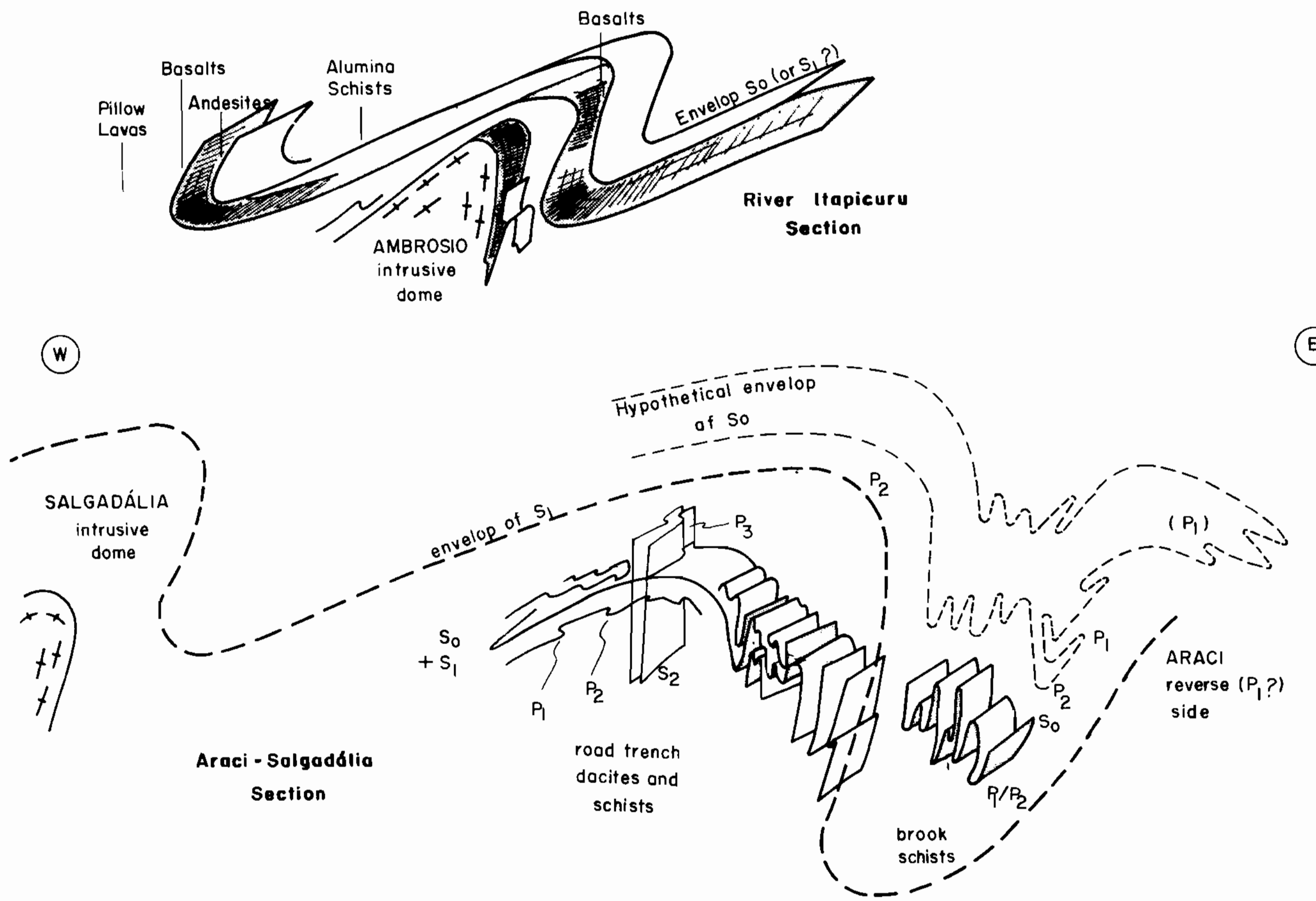


Figure 6.20
Interpretative rough sketch of the main structure of the Itapicuru greenstone belt formations.

7th outcrop

8km N of Santa Luz on the dirt road which leads to Celulose village on the margins of the Itapicuru River we are within the gneiss-migmatite unit of the basal complex. The outcrop chosen represents a granitoid member of this group, which forms a NW-SE elongated massif widening to the SW narrowing and finally disappearing to the NE. The morphological limits of the massif are concor‹ ›t with the overall direction of the gneissic foliation. Surrounding gneiss, amphibolite formations can be seen in the bordering valley, 500m to the north.

The principal points which can be seen in the granite are schematically shown in Fig. 7.00.

The Lagoa do Boi massif has two main facies:

– a medium-grained granitic facies, rich in feldspar phenocrysts in the centre of the body (SE of this outcrop)

– fine-grained granodioritic facies exposed at this outcrop, occupying the western border and the northern edge of the massif.

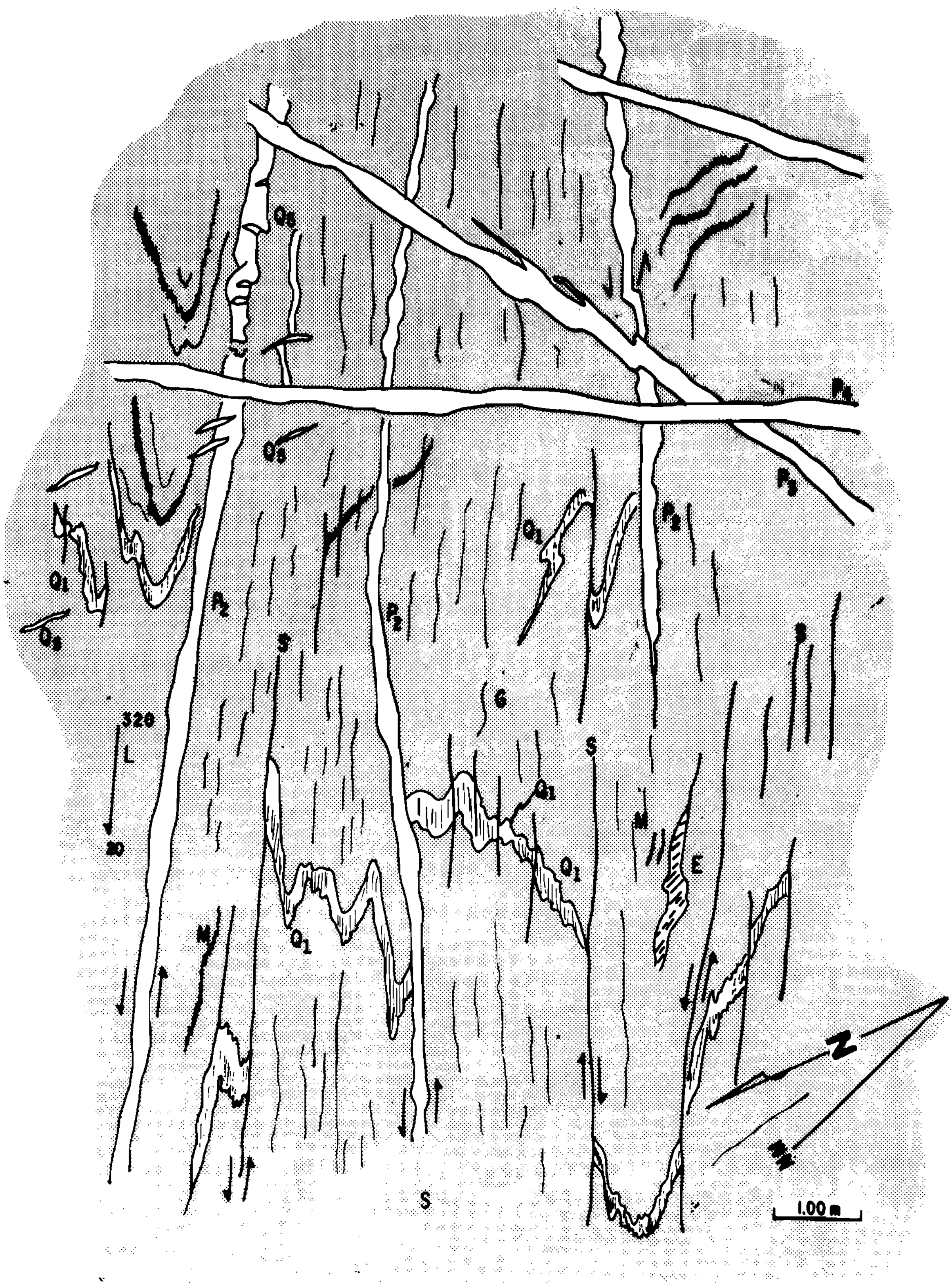


Figure 7.00

Simplified sketch of the principal exposure of the outcrop, showing the sucession of deformational and quartz/pegmatite penetration stages.
The scale is approximate, the real proportions are not respected for better visualization.

M – Magmatic biotite concentration
E – Enclave of biotite granite with deformed magmatic preferred orientation
L – Mineral lineation in the foliation plane S – Shears
Q_1 – Open tension fractures with folded and cleaved quartz
P_2 – Foliation concordant pegmatite with boundinage (Syn-shear)
P_3 – Late shearing pegmatites
P_4 – Post shearing pegmatite
Q_5 – Last tension gashes with black quartz

The body suffered continuous late to post magmatic shortening in response to a NE – SW compression which is reflected by a series of stages illustrated in Fig. 7.00, and which may be synthesized as follows:

– mise-en-place of the granodiorite; the NE – SW compression is probably already acting if we take into account the elongated form of the massif, forceably intruded within the host gneisses

– deformation of the magmatic orientation defined by supermicaceous concentrations, and by alternating quartz-feldspathic and biotitic layers or by preferred orientation of minerals within a granitic enclave. This deformation manifests itself in:

- folding of the magmatic layering
- stretching of the biotitic concentrations with the formation of schlieren
- rotation and stretching of the granitic enclave (fig. 7.10)
- probable initiation of the development of a foliation

The conditions were still sufficiently plastic to allow shear rotation of the enclave, but were sufficiently rigid to allow:

– formation of tension gashes, filled by quartz (Q_1)

– continuing compression the shortening being shown by folding of the quartz veins and the formation of an axial plane cleavage (fig. 7.11) as well as the probable accentuation of the foliation in the granodiorite

– close-spaced shearing along the foliation planes gives rise to

- accentuation of the transposition, formation of a mineral lineation
- development of alternate dextral and sinistral shears to compensate by extension the shortening caused by the compression. Globally, however, the shear is sinistral.
- fragmentation and laminar stretching of the enclave
- penetration of pegmatitic fluids along shear planes. The pegmatites crystallize and foliation concordant veins show signs of shear compression, such as the irregular boudinage and deformation of some crystals (fig. 7.11)

Figure 7.10
Enclave of granite with preferred orientation oblique to the foliation of the Lagoa do Boi Granodiorite (marked by the direction of the pencil).

Figure 7.11
Folded and cleaved quartz tension gashes affected by sinistral shear with pegmatitic filling in the foliated Lagoa do Boi Granodiorite.

The rheological conditions correspond to a ductile regime, but a certain plasticity persists, due perhaps to the presence of fluids and to less-than-complete crystallization of the granodiorite.

The direction of the compression changes towards E-W.

– continuation of the shearing as the crystallization of the granodiorite approaches completion. This manifests itself by the opening of tension gashes N60 to N80 with pegmatite filling (P_3). A certain ductility is still present, as shown by the slight sinistral movement which influences the form of the tension gash. (Fig.7.12).

– continuation of the shearing under rigid conditions, shown by.

- opening of new N30 tension fratures, invaded by pegmatitic fluids (P_4). Compression returns to NE-SW.
- opening of tension gashes filled by quartz, developed in granodiorite and pegmatites (fig. 7.13). Compression is NE-SW changing to N-S.

The sum of these observations shows that the deformation accompanied the final stages of crystallization of the granodiorite. On the other hand, the low angle mineral lineation, visible on erosion surfaces parallel to the foliation plane, formed as a result os the oriented crystallization of feldspar and quartz, and is identical to the mineral lineation formed during deformation and associated metamorphism of the host gneisses.

The orthogneissic granodiorite of Lagoa do Boi, therefore, marks through its collocation the principal tectonometamorphic event within the basal Transamazônico complex.

This massif is still undocumented from petrographic, geochemical or isotopic points of view. A migmatite NE of Santa Luz has yielded a biotite K/Ar age of 2,030± 100 Ma (Cordani et al., 1969).

Figure 7.12
Late shearing pegmatite the pencil marks the direction of the sinistral shear (superimposed on foliation). the sinistral movement on the lips of the pegmatitic vein is conjugated with the shear movement.

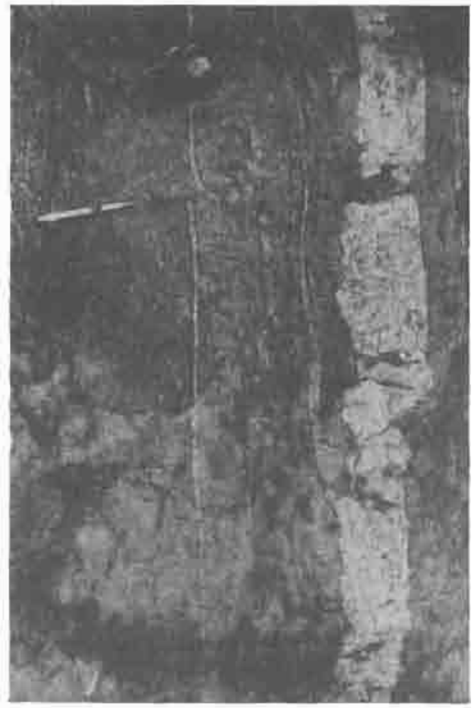


Figure 7.13
Last tension gashes with black quartz filling in the syn-shear boudinaged pegmatites, giving a new boudinage type, and in the granodiorite.

8th outcrop

2 km NE of Santa Luz, standing out in relief with "crowns" of rounded blocks on the Morro do Lopes, the so-called "Santa Luz Granite" has a number of quarries. This is a small, NE-SE elongated body forcibly intrusive into migmatites and gneisses but which locally cuts these rocks (fig.8.00).

It is composed of quartz, microcline, sericitized and somewhat saussuritized oligoclase, biotite often cloritized, zircon and opaque minerals. Small quantities of muscovite may be present. Modal determinations (fig.8.10) emphasise the homogeneity of compositions within the QAP triangle. At the outcrop, however, there are slight facies variations marked by a subtle but spectacular magmatic banding (Fig.8.20). The difference between the two rock types present is minimal, the darker type containing slightly more biotite (c.5%, as opposed to c.3.5%) in the lighter type), and perhaps rather more plagioclase and less microcline. Locally, the differentiated levels are fragmented within the light granite, giving rise to a line of enclaves.

The magmatic orientation with N50-70 strike and low (35 – 40°) northerly dip is grossly perpendicular to the regional foliation, which emphasises the post-tectonic character of the granite in relation to the regional deformation of the gneissmigmatites.

A subtle sub-vertical N35 fabric is observed, which probably corresponds to small sinistral shears observed further to the north. Some late vertical joints also contribute to break the structural monotony of the granite. These joints are filled by silica and chlorite. They are distributed "en échelon" with submeridional direction.

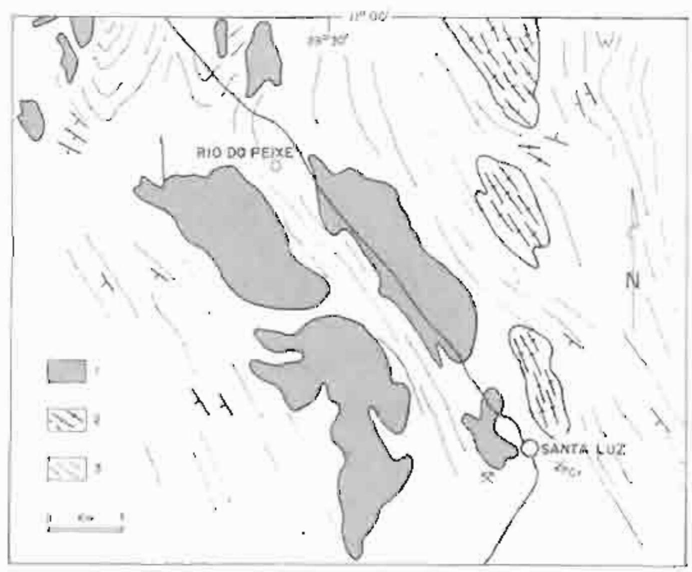


Figure 8.00
Sketch map of the Santa Luz instrusion and analogous bodies.

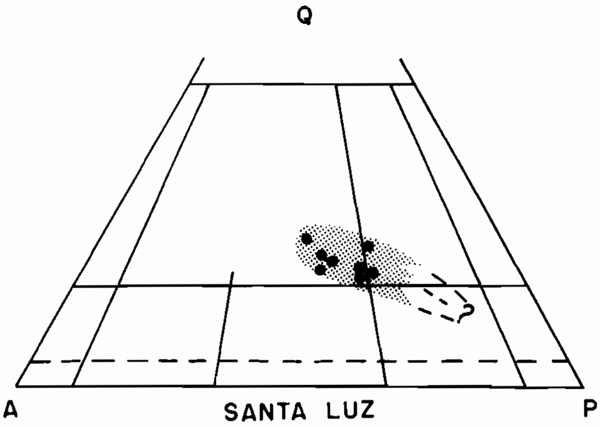


Figure 8.10
Modal distribution in the QAP diagram of the some Santa Luz granite samples. The darker facies near the granodiorite camp.

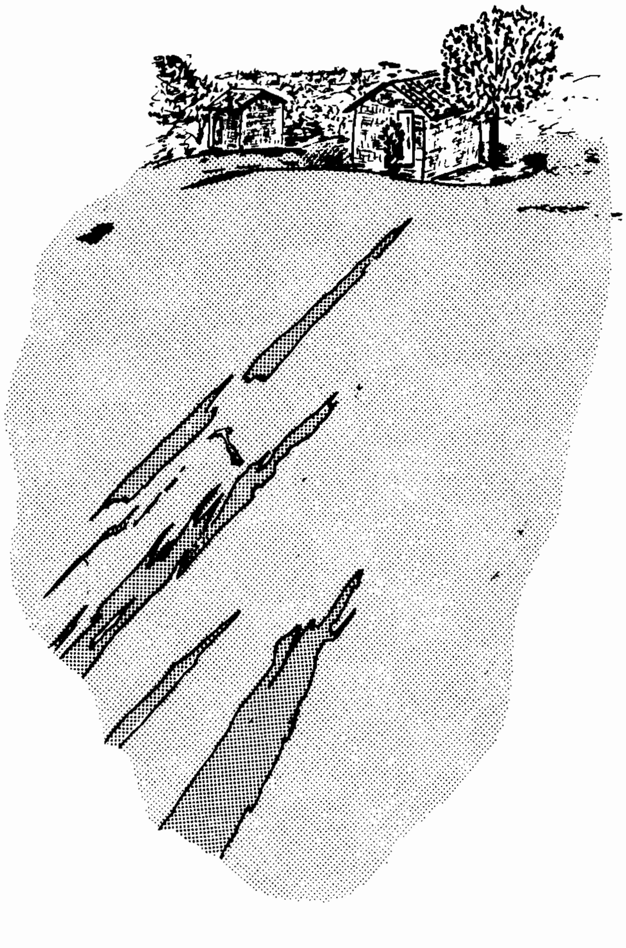


Figure 8.20
Outcrop features of the distribution of the darker facies in the light colored Santa Luz granite.

Some enclaves of orthogneiss, macroscopically similar to the Lagoa do Boi grandiorite have been encountered.

Chemically, the compositions of twelve samples from diverse localities within small granitic bodies similar to that at Santa Luz have given the following results:

	LIGHT COLOR TYPE		DARKER COLOR TYPE	
	INTERVALS	MEAN	INTERVALS	MEAN
SiO_2	78,02 a 69,32	70,31	71,64 a 68,48	69,95
Al_2O_3	14,74 a 13,70	14,18	14,22 a 13,32	13,59
Fe_2O_3	0,53 a 0,11	0,39	1,20 a 0,48	0,87
Fe O	1,65 a 0,25	1,14	2,01 a 1,65	1,79
Mn O	0,03 a 0,02	0,02	2,03 a 0,02	0,02
Mg O	0,36 a 0,12	0,24	0,30 a 0,22	0,25
Ca_2O	1,61 a 0,70	1,19	1,33 a 0,84	1,09
Na_2O	5,15 a 3,19	3,51	3,90 a 8,52	3,27
K_2O	4,90 a 2,18	4,32	5,40 a 4,20	4,80
P_2O_5	0,09 a 0,04	0,07	0,12 a 0,05	0,07

Table 8.30
Chemical range of the Santa Luz late tectonic granite. (analysis: Department of Geochemistry UFBA, Salvador).

The Santa Luz granite was dated by the K/Ar method in biotite at 1,800±60 Ma (Cordani et al., 1969).

Outcrop 9

A number of small Santa Luz type intrusions form the prominent reliefs within the plain, underlain by migmatites, between Santa Luz and Queimadas. An outcrop of migmatite inaccessible at the northern exit from the latter city to the east of road, 300 m before the bridge over the River Itapicuru.

The migmatite has a strongly dipping (c 75ºW), N-S to N15 foliation, with concordant granitic mobilizates rich in pink feldspar. The coarse, pegmatoid texture of the mobilizates contrasts strongly with the fine grain and regular orientation of the gneissic parts of the migmatite. The mobilizates also form irregular discordant veins or fill open sigmoid fractures related to the sinistral N135 shear which occur in the area. The veins generally contain magnetite.

A fine-grained, light rose coloured granite with cordierite spots invades the migmatites.

The concordant mobilizates have disseminated molybdenite mineralization. This mineral is also encountered in the biotite concentrations which surround the mobilizates. A fissuration which cuts the mobilizates and accompanies the supermicaceous borders is chloritized and contains sulphides (chalcopyrite). Muscovite appears locally in the vicinity of the sulphide-bearing planes.

The mean composition of the migmatites was obtained from seven analyses:

	MIGMATITES INTERVALS	MIGMATITES MEAN	MOBILISATE (1 SAMPLE)
SiO_2	73,62 a 67,80	70,36	68,98
Al_2O_3	15,38 a 12,20	14,71	15,24
Fe_2O_3	1,91 a 0,07	0,92	1,68
Fe O	1,36 a 0,11	0,58	0,26
Mn O	0,03 a 0,01	0,02	0,01
Mg O	0,47 a 0,04	0,19	0,11
Ca O	1,40 a 0,62	0,89	0,62
Na_2O	4,70 a 3,10	3,70	3,27
K_2 O	7,30 a 3,22	4,61	7,30
P_2O_5	0,15 a 0,02	0,07	0,11

Table 9.00

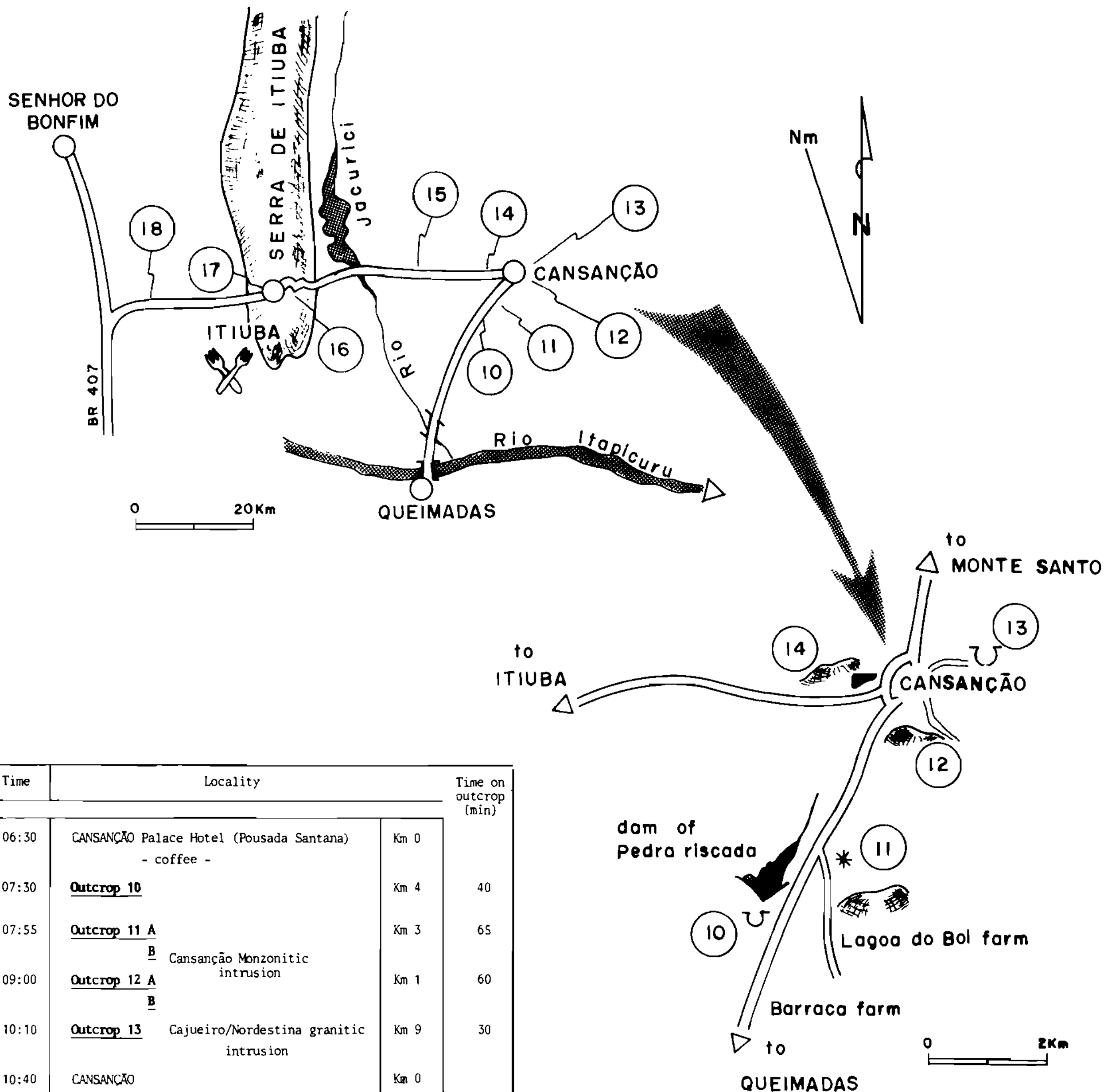
Chemical range of the migmatites of Queimadas, (analysis: Department of Geochemistry UFBA, Salvador).

The composition of the molybdenite-bearing mobilizates merits discussion.

This migmatite formation is followed practically all the way to Cansanção. A good outcrop can be seen at the roadside 18 km NE of Queimadas. Here, the migmatitic gneiss is grey, and has a N140 foliation with a banding resulting from the injection of coarse-grained to pegmatoid essentially white granite with rare patches of rose-coloured feldspar.

The whole is deformed by folds with low-angle axes (10 – 30°) with direction N175, and axial planes N86 – 34SE defined by a foliation. Here, biotitic concentrations are not present at the borders of the granitic mobilizates, but molydenite is present.

28.01.87



Time	Locality		Time on outcrop (min)
06:30	CANSANÇÃO Palace Hotel (Pousada Santana) - coffee -	Km 0	
07:30	**Outcrop 10**	Km 4	40
07:55	**Outcrop 11 A** **B** Cansanção Monzonitic intrusion	Km 3	65
09:00	**Outcrop 12 A** **B**	Km 1	60
10:10	**Outcrop 13** Cajueiro/Nordestina granitic intrusion	Km 9	30
10:40	CANSANÇÃO	Km 0	
11:00	**Outcrop 14** Cansanção intrusion	Km 2	25
11:45	**Outcrop 15** Basement Migmatitic gneiss, leptynites and amphibolite	Km 21	10
12:15	**Outcrop 16** Itiuba Sienitic intrusion	Km 40	10
12:40 13:40	ITIUBA - Snack -	Km 45	
13:45	**Outcrop 17** Itiuba Sienitic intrusion		45
15:00	**Outcrop 18** Archean migmatitic basement	Km 70	20
16:00	SENHOR DO BONFIM	Km 108	

SECOND DAY

Cansanção – Senhor do Bonfim
Plutonic bodies of Cansanção, Cajueiro, Itiúba and Their host rocks.

A large part of this day will be dedicated to the examination of a single small but excellently exposed plutonic unit in order to reconstruct the geometry and intrusion dynamics through structural petrological methods.

The Cansanção massif, on which is situated the city of the same name, is a circumscribed intrusive body of oblong shape whose larger dimension along a NNE-SSW axis is about 8 km, and whose width does not exceed 3 km. It cuts the larger intrusion of Cajueiro – Nordestina to the east, and intrudes migmatitic gneiss terranes (similar to those seen near Queimadas) to the west. It belongs to a group of three petrographically similar bodies (DNPM/CPRM, 1975).

Three principal facies are encountered in the Cansanção body:

– a monzodiorite or quartz-monzodiorite, rich in amphibole which defines a pronounced preferred orientation. This bluish facies with an incipient rosy base conferred by the presence of microcline occupies the SW and W margins of the body. The quartz content is about 3 – 5%.

– a hornblende-bearing monzonite, of generally lighter colour which depends on the amphibole content, varying between 5 and 15%. This facies occupies the larger part of the body. The quartz content is low at around 1%.

– a quartz monzonite occurs in the NE part of the body, but its cartographic expression remains undefined. Of pale pink colour, it is generally associated with swarms of enclaves. The quartz content is between 9 and 17%. Locally, monzogranitic terms with 20 – 25% quartz, and late syenitic or quartz-syenitic "infiltrations" which surround the enclaves, are found.

The body is also cut by veins and dykes of granitic aplopegmatites which may contain tourmaline, copper sulphides and their green alteration products.

An important characteristic of the body is the presence of chimneys containing mafic of great diversity. Some have a clear cumulate character. Compositions vary from 100% mafic minerals to monzodiorites, with various intermediate hybrids.

The mafic rocks form enclaves with more consistent characteristics, forming levels of lens-shaped enclaves in the magmatic edifice.

Qualitatively, the mineralogical composition is relatively homogeneous, with quartz, microcline, plagioclase (essentially, oligoclase), clinopyroxene, hornblende and biotite. Accessory minerals are allanite, sphene, apatite, rare zircon and some unidentified opaque minerals.

Alteration to chlorite and epidote is extremely limited except for some mafic enclaves in which pistacite can be important.

Quantitatively, there are considerable variations amongst the lithologies present, especially with relation to the mafic/felsic ratio and probably also with respect to the nature of the mafic minerals present. Semi – quantitative modal compositions were estimated for this guide, and in spite of the dispersion which results from the imprecise measurements, a crudely monzonitic trend can be seen (Fig. 10.00).

Geochemically, the acidic-basic association with an abundance of hybrid terms should provide an interesting model of evolution. The first geochemical data available are γ-ray spectrometric results for U and Th taken directly on the outcrops. The results obtained (60 – 80 p.p.m. U; 30 – 70 p.p.m.Th) show high values which might have indicated a promising target were it not for the fact that the structural petrological arguments diminish our hopes by demonstrating the erosion level which has been reached.

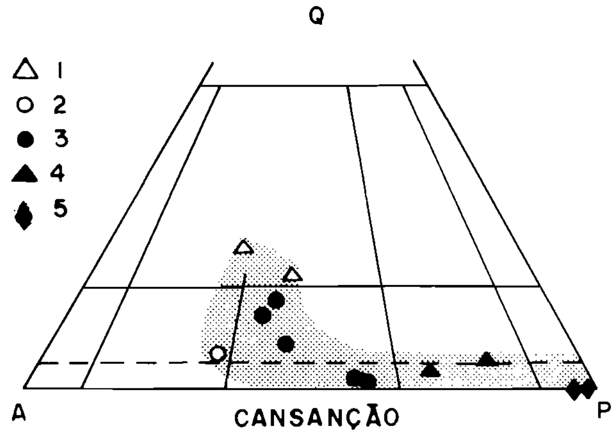


Figure 10.00
Estimated modal distribution in the QAP diagram of some samples of the Cansanção monzonitic intrusion.

(1) Aplopegmatites
(2) Late syenitic melt
(3) Monzonitic rocks
(4) Monzodioritic rocks
(5) Enclaves

10th outcrop

Situated at 4km SW of Cansanção near the recently constructed traffic police post on the BA 120 route to Queimadas, the outcrop consists of large rounded blocks which have been worked in an artesanal quarry.

The good exposure shows an amphibole-rich monzodiorite where a sub-horizontal planar preferential magmatic orientation corresponds to the attitude of some layers of felsic differentiates.

Through the presence of mafic and intermediate enclaves it is possible to deduce the polarity through the differences which exist between flat (biotite), acicular (hornblende) and ellipsoid (enclaves) markers. The difference of obliquity observed, which is an indicator of the rotational magmatic deformation, allows the sense of movement to be determined (Fernandez, 1982, 1984; Fernandez et al., 1983).

Fig.10.10 shows schematically the relationships between the markers from the different points of view which are possible around the outcrop. The sense of flow, appears on the monoclinic symmetry plane as the angle between the enclave and the linear or planar markers, which shows the sense of rotation. The magmatic flow is sub-horizontal towards WSW. Magmatic shapes traced by the felsic differentiates are those expected for the deduced flow (fig.10.20).

In this outcrop, a vertical fabric marked by a feldspathic or biotitic permeation (fig.10.20) which may have resulted from late-stage percolation of residual magmatic fluids with higher P_{H_2O} before final solidification of the body.

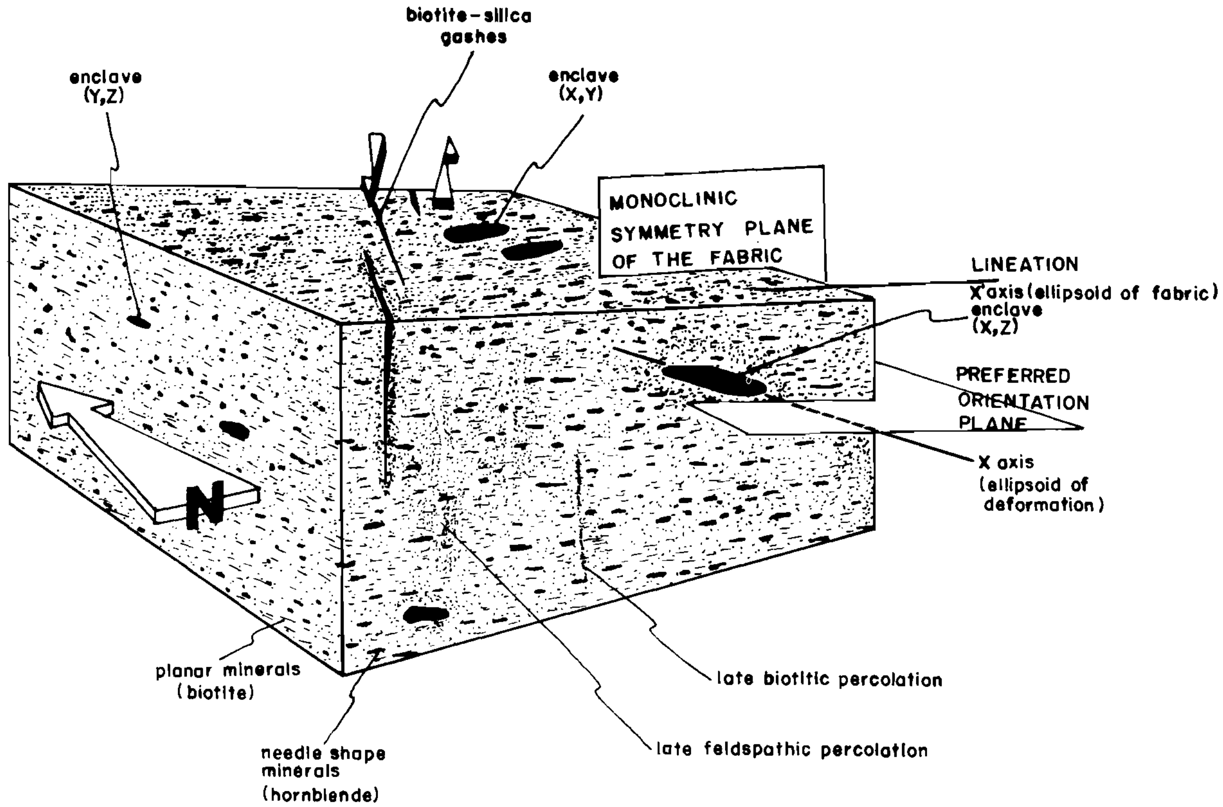


Figure 10.10
Sketch diagram block showing the three – dimensional relationship of petro-structural markers.

The presence of vertical NS fissures with silicification and hydrothermal biotite infilling marks the continuation of the phenomena of percolation after the solidification of the body. The penetration of the fluids occurred along "en echelon" tension fractures controlled by a probable dextral NE-SW shear. It is possible to imagine that the percolation in the absence of fissures was controlled within the incompletely solidified rock by potential fractures which preceded the effective fracturing.

11th outcrop

Returning 1 km in the direction of Cansanção, we take the track which leads to the farms Lagoa do Boi and Barroca.

A) After about 50m we encounter an outcrop composed of a lenticular body of cumulate gabbro formed of centimetric crystals of amphiboles cemented by a syenitic residuum (fig.11.00). A few m. further on, the monzonite appears once again.

B) Continuing for 0.5km to the south, near Lagoa do Boi farm a large slab stands out to the east. This formed of monzonite with a wide "corredor" containing a swarm of flattened enclaves (fig.11.10). The examination of the arrangement of the enclaves in relation to the flattening plane is interesting (fig.11.20).

The x-axis of the deformation ellipsoid of the enclaves is near to the line defining the intersection of the flattening plane (planar preferential orientation) and the (x,y) plane forms a dihedral angle indicating a mixed rotation of the enclaves (fig.11.21).

The direction of magmatic flow can be discussed in the light of these observations.

12th outcrop

Returning to Cansanção, we take the exit leading to Cacimba and Cajueiro. Near the houses there is access to a group of slabs with spectacular exposure. Two of these will be visited.

A) Shortly after the last houses of the city, the outcrop shows within the light-coloured monzonitic host, a long chimney of enclaves which widens in the central part where the enclaves attain metric size, and which has a N100 – 115 orientation.

Various types of enclave are seen, including double types. Size and shape are variable. Some are angular while others are rounded or elongated.

Grain size varies, from coarse in the cumulates or in the case of phenocrysts in the finer-grained matrices, to homogeneously extremely fine.

Compositions range from mafic to different monzodioritic types which are apparently intermediate hybrids between the mafic and felsic terms of the body. The chimney is composed by a quartz-bearing syenite which hosts the enclaves.

In the central part of the chimney, the greater elongation of the enclaves (x) is essentially vertical. The (x,y) plane dips 60 – 75° to the north. The mineral lineations observed on some planes parallel to the plane of preferential orientation have a strong plunge to the NE, analogous to the x-axis of the elongated enclaves.

Within the fabric with overall planar orientation N110 – 75N, a late fabric is seen which was probably produced during the late crystallization stages when the viscosity was sufficiently high to allow shearing, but the quantity of liquid present in the mush was still high enough to allow magmatic deformation without ductile behaviour. The publications of Fernandez (op.cit.) situate this type of rheological behaviour in the range of 70% crystallization.

Figure 10.20
Expression of the magmatic deformation (dynamic in conformity with the sense of flow).
The vertical feldspathic and biotitic fabric corresponds to the late stage percolation. The sub-horizontal fabric corresponds to the preferred magmatic orientation.

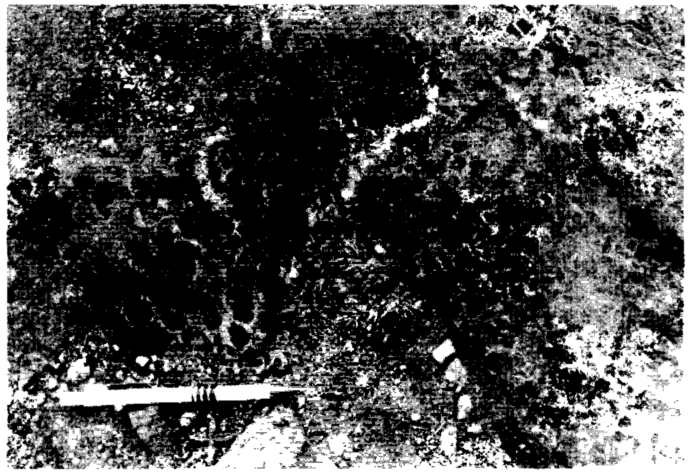


Figure 11.00
Cumulate hornblende crystals in a syenitic felsic residual melt. Gabbroic lens of the Cansanção monzonitic instrusion.

Figure 11.10
Chimney of elongated enclaves, Cansanção monzonitic intrusion.

This behaviour shows itself by the presence of small corredors of shear with decimetric length and centimetric width) with a constant horizontal sinistral component along N20 – 25. These are specially well seen at the borders of the chimney, and appear to be damped in the centre within the host syenite. The enclaves, already consolidated, do not suffer this deformation associated to the late crystallization stages of the body.

B) About 200m further to the SE on the right bank of the stream-bed which cuts the track leading to Cajueiro, another slab shows once again an enclave swarm which forms a band along N120. The preferred planar orientation is N80 with subvertical dip.

Remarkable mixing forms between mafic and monzonitic types can be seen (Fig. 12.00 and 12.01). These may be discussed in terms of magma mixing, and can be compared to the experimental results of Kouchi and Sunagawa (1982, 1985).

It is also interesting to note the rheological behaviour of the different components of the mixture: enclaves of different viscosities are involved by a mobile felsic liquid within the still-plastic monzodioritic material which, however, already possesses a preferred orientation, disturbed by the mobilization (fig.12.02).

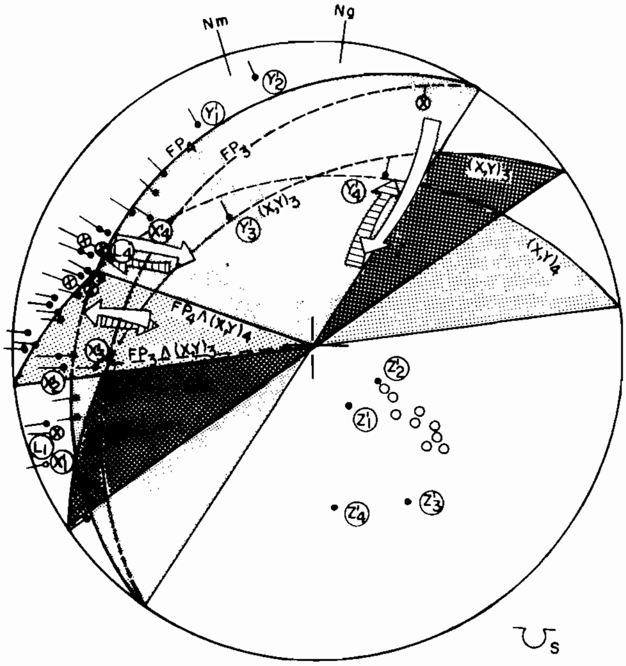


Figure 11.20
Stereographic equal area projection of elongated enclaves in the Lagoa do Boi farm, Cansanção monzonitic intrusion.
The apparent x-axis of deformation ellipsoid is plotted and some apparent axes are indicated.
Xn, Xy represent axis of the same well exposed enclave, (X, Y)n is the corresponding plane. Two of them are drawn with cyclic projection $(X, Y)_3$ and $(X, Y)_4$ as to compare with the respective flattening plane FP_3 and FP_4 as to compare with the respective flattening plane FP_3 and FP_4 (planar preferred orientation, the pole of which are represented by open circles). Calculated Z axis for the samples 1, 2, 3 and 4 are plotted.
Mineral (biotite or hornblende) lineations are indicated by crossed circles.

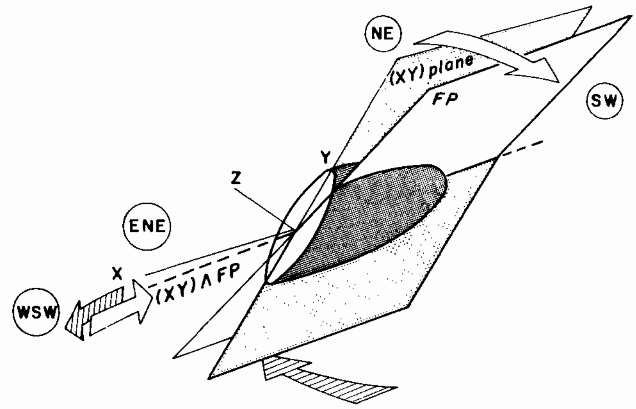


Figure 11.21
Schematic representation of enclaves ellipsoid characteristic compared to flattening plane (FP). The relative position of (X,Y)/FP intersection axis to X ellipsoid axis is variable.

13th OUTCROP

Returning to Cansanção, we take the track which runs around the south of the football field and leads to a quarry, about 1km to the NE after a suburb called Tapera. The quarry is in the massif of Cajueiro. (Maps show the village of Nordestina in the centre-southern part of the massif, but local people call the village Cajueiro and often do not know what "Nordestina" is).

The Cajueiro massif is a body of 40 x 30km (aprox.) composed of an homogeneous granodiorite in the centre and east part of the massif. It seems to pass progressively, to the west, SW and South parts, to the diatexites of the host rocks.

The rock is grey, fine-to medium-grained, with a tendency towards an isotropic texture in the centre, and clearly oriented at the northern, western and southern borders.

The composition varies from granodiorite to granite with quartz (10-20%), microcline (30-50%), oligoclase (50-30%) and biotite. Accessory minerals are zircon, sphene, apatite and magnetite. Garnet or muscovite can be present. Chlorite, epidote and sericite are secondary minerals.

Amongst the structural observations which can be made on the outcrop, two are very interesting:

1) on the southeastern climbing of the quarry there is a subvertical corredor of mafic enclaves with a NNW-SSE direction parallel to the magmatic fabric of the granite. The enclaves are stretched with a sub-vertical x-axis and a NS sub-horizontal y-axis. The shortening which prevailed during instrusion of the body is therefore ENE-WSW.

Some tension joints, filled by aplite, dislocate the corredor. The enclaves are affected as well by aplite-filled tension fractures with sub-horizontal dip which mark the maintenance of ENE-WSW compression after solidification of the corredor.

At the centre-top of the quarry, small folded granitic dykes are seen (fig. 13.00).

The magmatic fabric of the dykes is conserved subparallel to the contacts with the host rocks and weakly reflecting the axial plane fabric very strongly developed in the host granite.

This implies a blockage of the (ENE-WSW) shortening with opening of NE-SW dykes, consecutive folding of the dykes accompanied by shortening of the host granite in which is developed a N120-140 deformation interfering with the magmatic fabric and causing rotation.

14th OUTCROP

About 1km after the road junction at the western exit from Cansanção in the direction of Itiúba, a large outcrop to the north shows the association of different petrographic terms of the Cansanção massif.

Monzonites, mafics and various granitic dykes and aplopegmatites mark the border of the body.

The enclaves (fig. 14.00 for example) allow one to evaluate the symmetry of deformation and the magmatic flow direction.

The small dextral N20-40 shears whose role is subtle in the center of the body, are here much better developed and locally dominate in the fabric of the monzonite.

With all the structural information collected from the outcrops of this body, it is possible to attempt a geometrical reconstruction of the body. Continuing in the direction of Itiúba, cuts to the north of the road show a band of very altered mafic rocks which appear to surround the body in this NW part.

Figure 12.00
Swarm of enclaves. Expression of mechanical mixing and hybridization Cansanção monzonitic intrusion.

Figure 12.01
Magmatic mixing – mechanical phenomenon – Cansanção monzonitic intrusion.

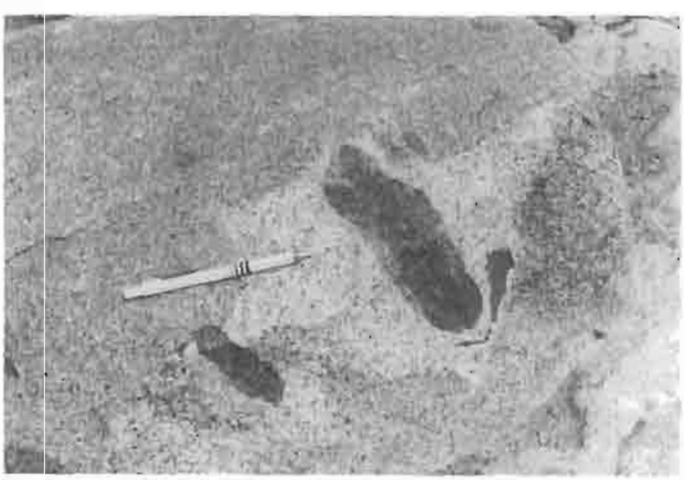


Figure 12.02
Rheologic reaction of the different types of materials during mobilization of enclaves with syenitic melt in the monzonitic mush.
Cansanção monzonitic intrusion.

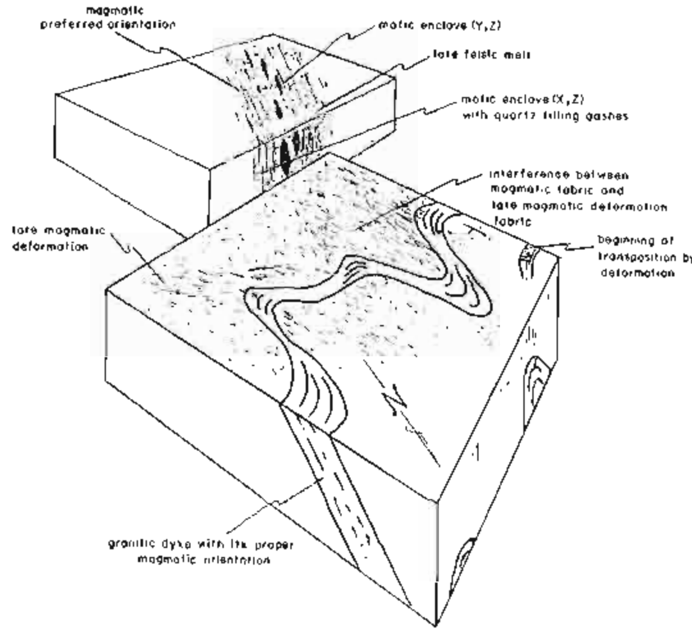


Figure 13.00
Sketch diagram block showing the folded granite dyke in the Cajueiro granite. The foliation resulting of the deformation is superposed to the preferred magmatic orientation.

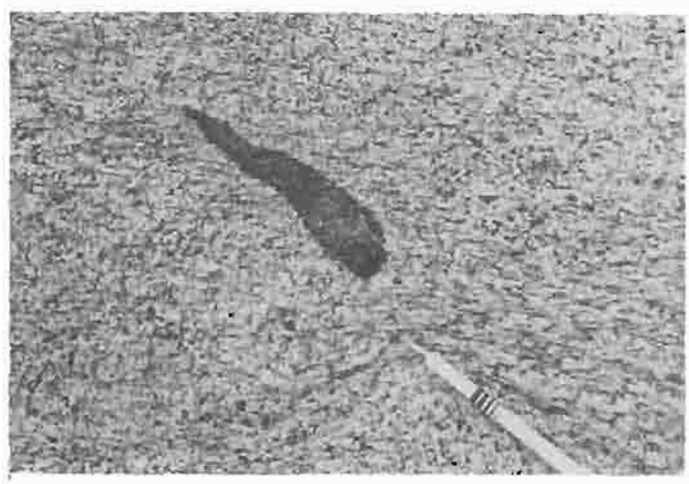


Figure 14.00
Angular relation between the ellipsoid of deformation (enclave) and the ellipsoid of fabric (sheet and needle minerals) whose best fabric axis is sub-parallel with the sliding plane) as a polarity criterium (anti-clockwise rotation). The sense of movement is indicated by the pencil. Cansanção monzonitic massif.

15th OUTCROP

Along the road to Itiúba, few outcrops are easily accessible.

12km past Cansanção, gneiss-migmatites similar to those seen on the first day between Queimadas and Cansanção are encountered.

At 19km, the road cut exposes an association of leucocratic leptinites with pink granite injections.

At 20km, we will make a short stop where the road cut shows an association of leptinitic gneisses and folded amphibolites.

The well-developed folded structure affects S_0 (+ S_1 ?).

The N10 axes are sub-horizontal, a schistosity (S_2 ?) is forming and fold-flank shears, locally laminated, are developed which emphasise the western vergence of the dynamics.

Granitic mobilizates are envolved in the folding and late pegmatoid veins cut the whole.

A discussion on the sum of structural observations made until now, and of the spacial-temporal significance of the intrusions would be useful here.

16th OUTCROP

The majestic hills which fill the horizon form the Serra de Itiúba, which we enter at km 35.

Structures and textures present have been interpreted as the results of regional metamorphism, and the 1.8–2.2 Ga ages found (Figueiredo, 1976; Bartels *et al.*, 1977; Pedreira *et al.*, 1978; Brito Neves, 1980; Mascarenhas *et al.*, 1984) are considered as reflecting this event. A model emplacement age of 2.7 Ga has been calculated (Figueiredo, *op. cit.*). In the Poço de Fora area at the extreme north of the batholith, Leube (1972) found ages of 1.0 Ga which may reflect reactivation.

Work in progress on the southern part of the batholith (Conceição, unpublished) demonstrates that the principal rock types present are leuco- to mesocratic oversaturated syenites. Overall, a distinction can be made between magmatic and tectonic facies. The magmatic facies, with little modification of primary textures, are observed in the central parts of the pluton. Intermediate and ultramafic enclaves are abundant. Bands of amphibole and clinopyroxene, often rich in apatite, magnetite and sphene, are widely distributed. Syenitic and alkali-feldspar granite pegmatite dykes are also present. The tectonic facies, composed of mylonitic and ultramylonitic gneisses, occur at the borders of the body and in close association with the faults which cross-cut the body.

At the western border, near the city of Itiúba, a granite dyke generation was intruded simultaneously with the deformation under NW-SE compression. On the other hand, the northern part of the Pedra Solta granite lacks signs of this deformation, nor does it have the deformations which are seen in the granulite terrain to the west.

There is some doubt, therefore, as to what extent the gneissic fabrics reported in other areas of the body are due to phenomena related to emplacement on the one hand, and later tectonic effects on the other.

Chemically, the syenites are miaskitic, and chemical variations observed correspond well with the mineralogical variation. The rocks are notable for very high Sr and Ba contents (Figueiredo, 1976, 1981). REE patterns show very strong enrichment of LREE relative to HREE and lack Eu anomalies, characteristics which are similar to Archean syenites believed to result from partial melting of a mixed garnet peridotite-eclogite mantle source (Figueiredo, 1981; Arth and Hanson, 1975).

According to Conceição and Sabaté (1986) the modal analyses of 50 samples show a variation of the quartz content between 0 and 25 vol.%, with a strong relationship between the contents of this mineral and the others, especially outside the quartz content range 1-13 vol.%, alkali feldspar forms 50-85 vol.% of the rock but diminishes in the quartz rich members. Plagioclase is restricted to constant values of less than vol. 5% but reaches 40 vol.% where the quartz content exceeds 18 vol.%. Clinopyroxene, hornblende and apatite are drastically reduced from 30, 40 and 1-9 vol.%, respectively, in quartz-poor facies to nearly zero in the quartz-rich facies. Sphene contents oscillate between 0 and 8 vol.% in quartz poor rocks, but decrease systematically in the quartz-rich rocks.

The syenitic batholith possesses an unusual geometrical form and rare facies distribution for an alkaline massif. In spite of the presence of mesocratic horizons, petrographic variation in the QAP diagram is limited and restricted to the satured domain. The rocks are little transformed and/or deformed, magmatic features being preserved intact.

A short stop will be made about half-way through the Serra to observe the geometrical features of the morphological lines.

17th OUTCROP

In Itiúba city a large rock pavement offers an outcrop in which various petrographic terms are seen, together with their structural relationships.

The fabric observed is of magmatic origin with a dominant N50º direction, with a strong NW dip in opposition with undulating mafic horizons composed of hornblende and clinopyroxene which are, apparently, cumulates. These "float" in the syenite and mark the sub-horizontal sedimentation by a viscosity barrier effect (= floor), associated with a strong stress regime which determines the vertical preferred orientation (= ascension).

The presence of mafic minerals oriented obliquely to the syenite fabric and that of the cumulates can be seen. These are probably late amphiboles from the last liquids which percolated through shears and fractures.

The outcrop is heavily infiltrated by veins and dykes, some of which possess their own fabrics showing, by their obliquity in relation to the borders, a sinistral shear during intrusion.

A porphyritic late granite cuts the syenite which is somewhat assimilated, as shown by the narrow hybrid zone where amphibole from the syenite "floats" in the granite (which lacks ferromagnesian minerals in the centre of the dyke) the feldspar phenocrystals have an irregular rounded form, produced by refusion corrosion. This idea could be justified by the equilibrium temperature between syenite and granite. The thermal difference between the respective solidi and the amount of heat transmitted by the hotter syenitic mass would favour the initiation of hybridization and r-equilibration of the phenocrystals through their peripheric refusion.

18th OUTCROP

After the Serra de Itiúba the E-W section crosses the migmatitic and granitic terranes of the Salvador-Curaçá belt. Few easily accessible outcrops are available since the cenozoic cover is widespread, at km 24, 5km before the BR-407 (Salvador-Senhor do Bonfim) road junction, an outcrop to the north of the road shows some aspects of the migmatites of this belt.

The migmatite is strongly folded with a well-developed N-S foliation. The folds, evidence for E-W shortening, are accompanied by subvertical NS to N40 shears.

Coarse-grained levels with augen developed by deformed feldspar phenocrysts are present.

Veins of rose-coloured, coarse-grained granite, sub-concordant with the foliation, are not strongly deformed. If injection was contemporaneous with the deformation which controlled the direction of the veins, their crystallisation probably occurred late in relation to the action of the stress.

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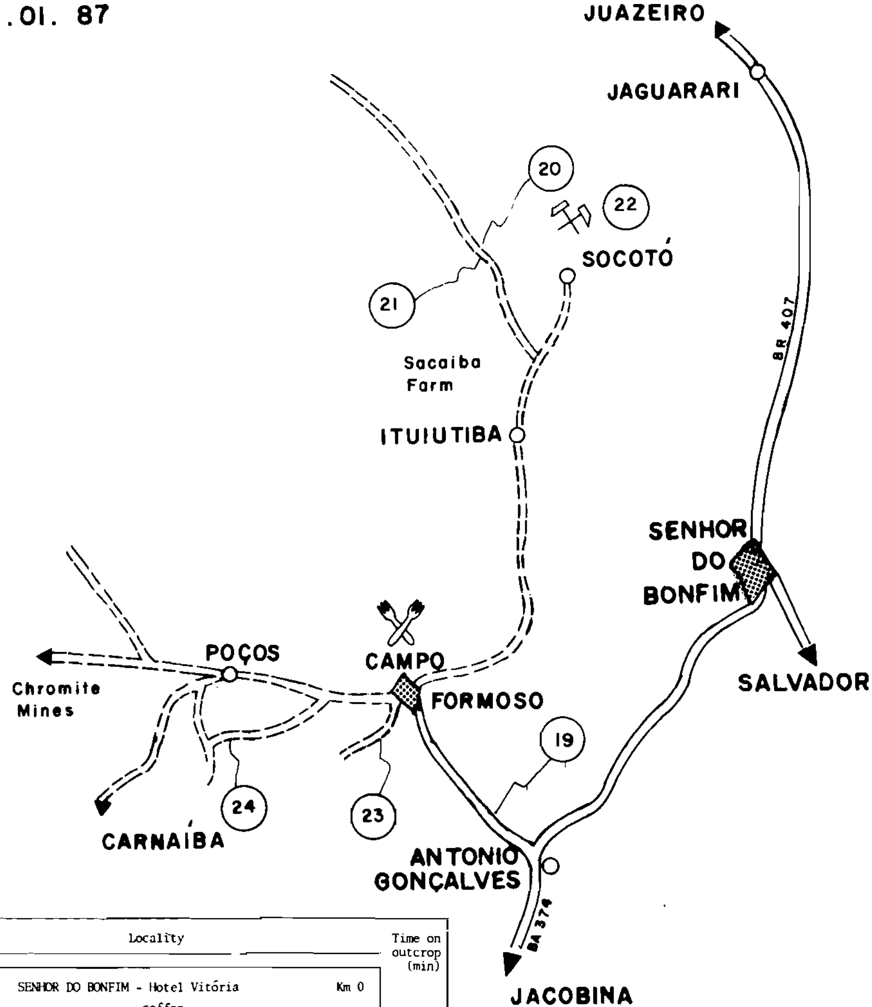


Time	Locality		Time on outcrop (min)
07:30	SENHOR DO BONFIM - Hotel Vitória - coffee -	Km 0	
07:48	ANTONIO GONCALVES	Km 17	
07:50	<u>Outcrop 19</u> Folded formations of the Serra de Jacobina	Km 19	20
08:20	CAMPO FORMOSO	Km 26	
	ITUIUTIBA	Km 16	
08:50	Sacaibá Farm cross road	Km 19	
09:00	<u>Outcrop 20</u> Granitic facies of Campo Formoso	Km 25	30
09:35	<u>Outcrop 21</u>	Km 24,5	15
10:00	Sacaibá Farm cross road	Km 19	
10:10	SOCOTÓ Refreshment		
10:20	<u>Outcrop 22</u> Socotó prospecting pits	Km 28	100
12:40	CAMPO FORMOSO - snack -	Km 0	
13:40			
13:50	<u>Outcrop 23</u> Orthogneissified Campo Formoso Granite	Km 4	30
14:30	CAMPO FORMOSO	Km 0	
14.45	<u>Outcrop 24</u> Muscovitisied Campo Formoso Granite	Km 5	45
15:45	Panorama on the relations Campo Formoso Granite, quartzite formation and ultramafics with chromite mine		5
16:30	CAMPO FORMOSO Visit of the Lapidary School of Campo Formoso SENHOR DO BONFIM		Ad.lib.

THIRD DAY

Senhor do Bonfim – Campo Formoso – Senhor do Bonfim Granitic Massif of Campo Formoso in the Serra de Jacobina formations, emerald prospecting pits of Socotó

On the third and fourth days the aims of this excursion are to show the leucogranitic instrusions of Campo Formoso and Carnaiba in their lithologic and structural context and to show the structural and petrographic characteristics of the Socotó and Carnaiba emerald prospecting pits (*).

An overview of the method of extraction and separation of gems is given. More details of the geology and the Be, Wo, mineralization type found in these prospecting pits are presented in the contribution by L. Rudowski *et al.*, (this Symposium).

Some notes on *historic evolution and emerald production of the prospecting pits:*

The whole production of emerald in Brazil until 1980 was obtained from the Carnaiba prospecting pits. The mineralization was discovered in 1964-1965 and the production between 1970 and 1980 was 204 tons of negociated emerald with a productivity factor of 2.17kg/m^3 (Moreira and Santana, 1982).

An appreciable volume of molydenite was recovered (see table 19.00). The discovery in 1981, of the famous Santa Terezinha de Goiás emerald field (Goiás State) and in 1983 of the Socotó field (Bahia State) caused an important migration of prospectors and a decrease of Carnaiba production. At present, around 600 prospectors are working in this district.

In January 1983, a propector from Carnaiba, José Cavalcante was hunting armadillos in the region of Campo Formoso and he found green beryl associated to phlogopitite rocks, similar to the Carnaiba field: The Socotó prospecting pit was discovered. At the present, the Socotó district mobilizes 900 prospectors and the production in 1986 is estimated to be 2688kg of emerald and green beryl (see table). A new emerald occurrence was discovered last December in Carnaiba de Cima.

The emerald, molybdenite, scheelite mineralizations from Carnaiba and Socotó.

The emerald and green beryl mineralization is contained in phlogopitites resulting from metasomatic transformation developed in ultrabasic rocks from aplopegmatitc and/or plagioclasic veins. Locally, intercalated tremolitic and talcose formations are encountered sometimes with disseminated scheelite mineralization.

Three types of serpentinites occurrences are observed:

– as imbricated structures in the Archean gneissic basement at Socotó (fig. 20.00). In this case, the deformation of the phlogopitites and veins is important and is shown by boudinage, shear zones, etc...

– as roof-pendants in the Carnaiba granite forming the prospecting fields of Bode, Lagarta and Gavião (Fig. 25.00, 25.01). The phlogopitites present in this case typical metasomatic zonations without important deformation.

– as country rock terranes in the Carnaiba granite field with the prospecting pits of Trecho Novo, Trecho Velho, Braulia, Formiga and Marota (fig. 25.00).

(*) Called garimpos in Brazilian. The prospectors are named Garimpeiros.

YEAR	CARNAIBA EMERALD AND GREEN BERYL (Kg)		CARNAIBA MOLYBDENITE (Kg)
1970	102770.4		-
1971	9520.7		1600
1972	15138.2		3700
1973	69120.0		1400
1974	14711.7		-
1975	35558.1		10200
1976	45578.1		4900
1977	18652.3		5400
1978	8652.3		6400
1979	15302.4		41400
1980	14503.4		29500
1981	8842.1		12500
1982	7467.4		3200
	CARNAIBA	SOCOTÓ	
1983	8989.6	4481.7	8200
1984	3459.6	2181.7	1186
1985	1432.2	2697.0	1190
(*) 1986	1018.7	2688.7	4330

Table 19.00
Negociated emerald and molybdenite production (in kg) from 1970 to 1986 (* november) of Carnaiba and Socotó prospecting. (*In* Anuário da Mineração – SME/BAHIA 1980-81, and *In* "Projeto Gemas" – DNPM/CPRM 1986).

19th OUTCROP

From Senhor do Bonfim, we take the road to Antonio Gonçalves. Just before this city, we turn west along the road which crosses the Serra de Jacobina leading to Campo Formoso. The road runs through a valley developed along an important fault.

From the road junction we encounter the formations of the Jacobina metamorphic complex, represented here by the volcanoclastic sequence of the Jacobina Group (Griffon, 1967). This group has various sub-divisions (Leo *et al.*, 1964); Griffon, 1967; Mascarenhas, 1969) of which we cross the Água Branca Formation at the top of the Group, and the Cruz das Almas Formation, formed by ferruginous and or manganiferous red phyllites, white, green and grey quartzites either pure or micaceous, with rare conglomeratic horizons, intercalations of aluminous schists and associated mafic bodies. These are underlain by fine-grained white or green (fuchsitic) quartzites with manganiferous phyllite intercalations.

The stop 2km after the junction shows the volcanoclastic association between two quartzite crests. The tight folding style of the series can be seen (fig. 19.10) with their North vergency.

After this we cross thick packets of quartzite with probable tectonic repetition before reaching the Campo Formoso granite. The chromitiferous ultramafics which form the Jacobina Group/Granite interface (fig. 20.00), are not seen in this section.

20th OUTCROP

At Campo Formoso we take the dirt road which leads to Ituiutiba, Socotó and the northern part of the granite massif.

The first stop will be made on a slab almost on the northern

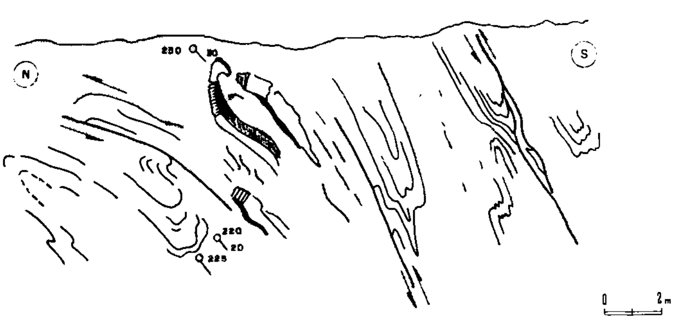


Figure 19.10
Isoclinal folding patterns of the volcanoclastic formations of the Jacobina Group near Campo Formoso. The vergency toward west is characterized.

border of the body at Gangorra Farm, 6km NW of Sacaibá Farm. The outcrop is situated on the western side of the road, 200m before a stream which cuts it to the north.

The outcrop shows different granitic facies of the Campo Formoso massif, as well as the associated aplopegmatite suite and the time relationships. The terms present are described by Rudowski *et al.,* (this symposium).

The main facies are:

– granite $\gamma 1$, medium -to coarse-grained, white coloured, leucocratic, characterized by abundant large crystals of muscovite. The composition is quartz, microcline, albite, oligoclase (An 35), muscovite, biotite and accessories: apatite, allanite and opaques.

– granite γ_{2a}, fine-grained with biotite dominant.

– granite γ_{2b}, porphyritic with two micas, which forms the main facies in the massif.

– granite γ_3, in veins, containing muscovite and garnet.

– a group of aplopegmatite veins with quartz, K-feldspar, muscovite, garnet, sometimes tourmaline and plagioclase and locally, beryl and molybdenite.

21St OUTCROP

Returning 500m S, an outcrop is seen in the valley to the east, at about 150m from the road passing two houses of rural labourers.

This outcrop shows a layered granite facies cut by an holoeucocratic granite in which we can see ghost structures of the layered granite "diluted" in the very fine grained matrix, in which pegmatoid pockets "float".

These two facies are cut by the porphyritic granite $\gamma 2b$ in which magmatic structures are seen (fig. 21.00).

22nd OUTCROP

Returning to Sacaibá Farm we take the road leading northeast to Socotó where we visit the prospecting pits of "Trecho Velho": geological features, metasomatic zones, aspects of the prospector pits working, method of extraction and separation of gems and possible descent in pits.

The emerald area of Socotó is developed in serpentinites which appear as imbricated structures in the Archean gneissic basement (fig. 2). The ultrabasic formations, oriented N150 – 180° are dipping 50 to 80° to the northeast, they are lens-shaped and present an extension of 2.5 kilometers and a width of 0.5 kilometer. The phlogopitite metasomatic zones are oriented mainly N150° E and result from the interaction of fluids, related to the deposition of plagioclasic veins, with the serpentinites. The figure 25.10 shows a reconstitution of the varied dispositions of the metasomatic zoning and related mineralizations. The emerald is well developed either in the plagioclase veins or in the coarse phlogopitite zone. Molybdenite is disseminated and scheelite is located in boundinaged formations.

Posterior hydrothermal veins crosscut the metasomatic system (quartz veins and fluorite veinlets).

The shafts present a maximum depth of 50 meters and the drifts follow the mineralized structures which are up to 30 meters long; they can be narrow with irregular forms and sometimes develope huge room cavities. The mines are supported by shaft lining, wood forming and wood boxes called "caixas" with a section of 1 to $2m^2$. The exploitation is undertaken using rudimentary tools and explosives. The recovered material is removed to the surface in rubber pails by manual or electric winches.

Infiltrated water is taken out by shaft pumps or using the rubber pails. The prospectors go down the shaft employing a winch system with a rubber tyre strap called "cavalo".

The emerald phlogopitic rock is broken and washed mainly by women and children. Emerald commercialization takes place in Campo Formoso town, well known in Bahia State, for it lapidary school.

The security and development of the prospecting pits (as for the Carnaiba field) is controlled by the D. N. P. M. (National Department of Mineral Production) in relation with the CRPM (Company of Ore Resource Exploration, Chief Geologist of these emerald prospects: Pedro Couto).

23rd OUTCROP

Returning to Campo Formoso we take the southwestern exit along a road which follows the southern border of the granite at the foot of the hills. After 4km we can see large rounded slabs on the southern slope.

These outcrops are formed by a strongly gneissified two-mica granite which contains quartzite enclaves from the roof.

The deformation results from a flattening which causes rotation of the crystals and continues with a ductile deformation, notably of quartz, in the solid state. Muscovite is present and deformed along the preferred orientation.

Besides the preferred N80–74S orientation, a second apparent foliation N60 is caused by continued rotation of the feldspar crystals in relation to sheet minerals, which is the expression of the dextral shear which accompanied the flattening.

The resulting lineation is N95 sub-horizontal, NS tension fractures correspond to the direction of the force which caused the shear.

It is interesting to note the presence of coarse and fine-grained facies, where phenocrystals of the former penetrate into the latter.

Small pegmatite veins are affected by the formation.

The small NS shears in which tourmaline is present postdate the other deformations. The last NS fractures, developed under a rigid regime, contain muscovite.

24th OUTCROP

Returning to Campo Formoso, before arriving in the city, we take the road to the west in the direction of Poços. We leave this road after 5km by a track which runs south. 3km further on, we encounter an interesting large outcrop. The process of muscovitization will be discussed.

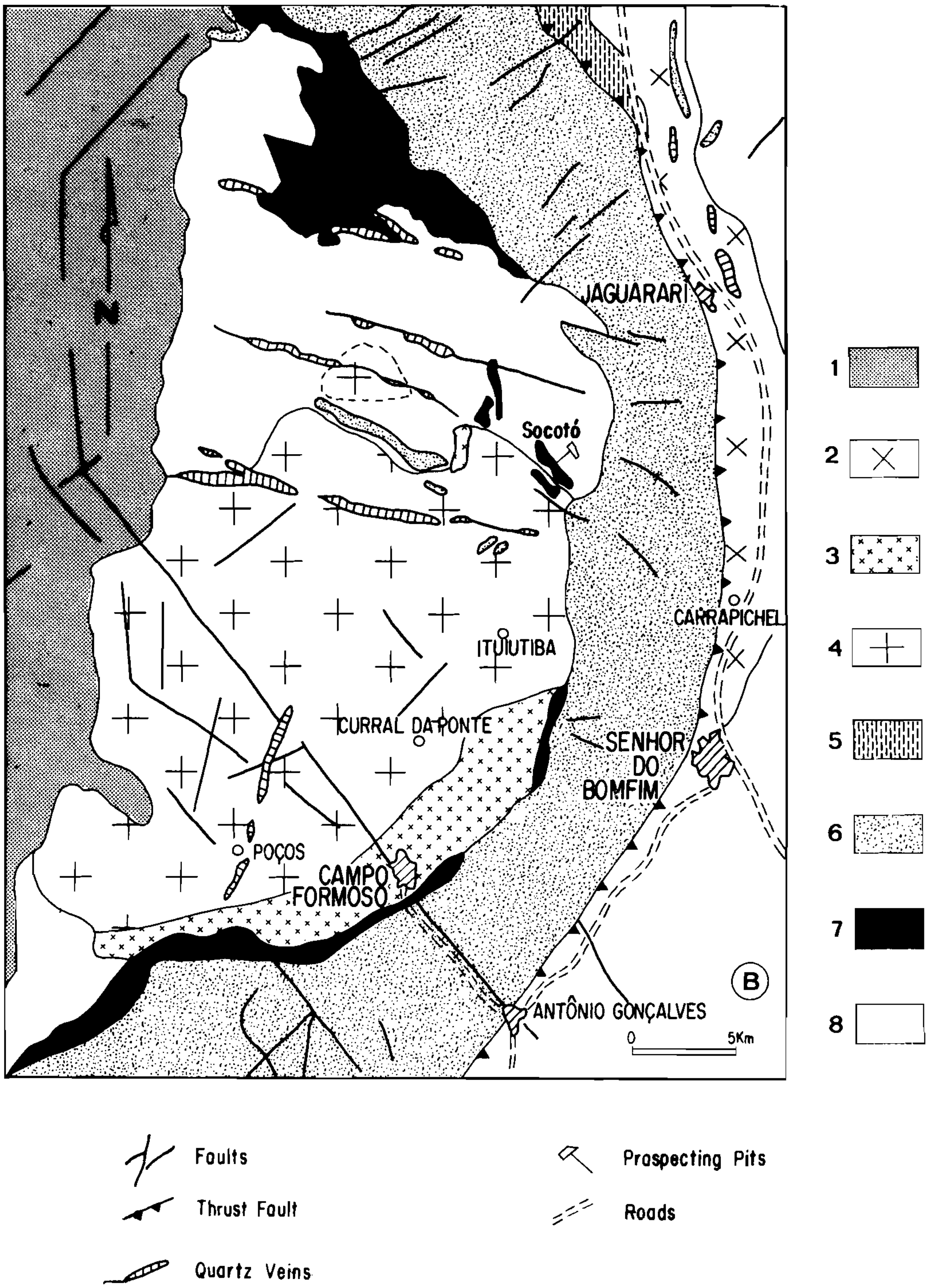


Figure 20.00
Geological map of the Campo Formoso granitic intrusion and its structural context.

(1) Upper Proterozoic cover
(2) Jaguarari granite
(3) Two mica Campo Formoso granite
(4) Porphyritic two mica Campo Formoso granite
(5) Phyllites and chlorite schists
(6) Quartzites and volcanoclastic formations
(7) Serpentinites
(8) Archean gneiss and migmatites

(After Rudowski *et al.*, (this Symposium), modified from Couto *et al.*, 1978)

The outcrop shows the association of coarse granite with zoned automorphic phenocrystals, alternating with corredors of finer-grained, muscovite-poor granite.

Small groups of muscovite crystals accompany the magmatic fabric defined by the phenocrystals and the alternation of facies.

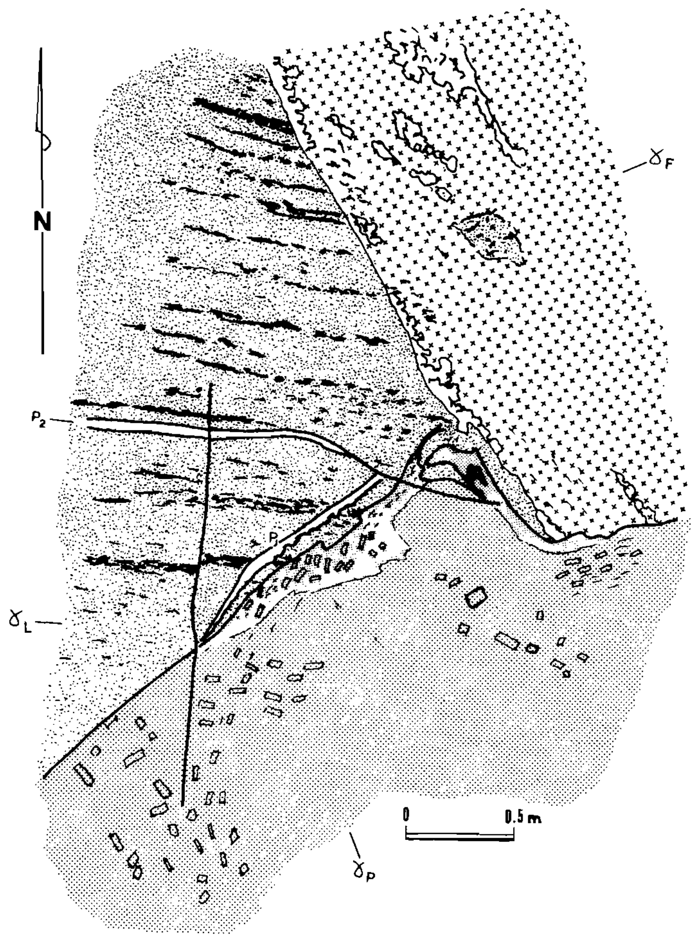


Figure 21.00
Outcrop relation of the three granite facies of the Campo Formoso massif.

- γ L – Layering granite
- γ F – Fine grained, aplitic granite with pegmatoid pockets and diluted features of the γ L granite
- P_1 – Pegmatite vein
- γ P – Porphyritic two mica granite. The K-feldspar phenocrystals define magmatic preferred orientation
- P_2 – Late aplopegmatite

A fine-grained granite cuts the fabric. This lacks muscovite, but a later transverse pegmatite contains this mineral, which may be thought to have resulted from late muscovitization affecting granites and pegmatites. The discussion can be developed around this point.

Our present view is that the muscovite belongs to the early magmatic phase, but the crystallisation and mobilization continued with the passage of late fluids, such as those which filled the late sinistral shears.

A N20 pegmatite vein system is dislocated by syn-magmatic sinistral shear.

Summarizing the observations at the four granitic outcrops, the chronology of formation of the Campo Formoso massif may be synthesized as follows:

1) γ 0 – biotite-bearing layered granite
2) γ 1 – coarse muscovite-bearing granite peripheric facies
3) γ 2a – (1) muscovite poor, fine-grained granite, synchronic with γ_1
   γ 2a – (2) same fine-grained post-γ 1 granite with pegmatite pockets
   γ 2a – (3) same, only aplitic after degassing of fluids)
4) γ 2b – porphyritic (main granitic facies)
5) γ 2c – fine-grained granite (Gongorra Farm) cutting porphyritic granite
6) γ 3 – veins

The chronologic position of γ 0 is incertain. It is only clearly anterior to γ 2a-(2). From this outcrop we continue to the west on the road leading from Poços to the chromite mines of FERBASA.

Modal analyses for the granites are shown in Fig. 24.00.

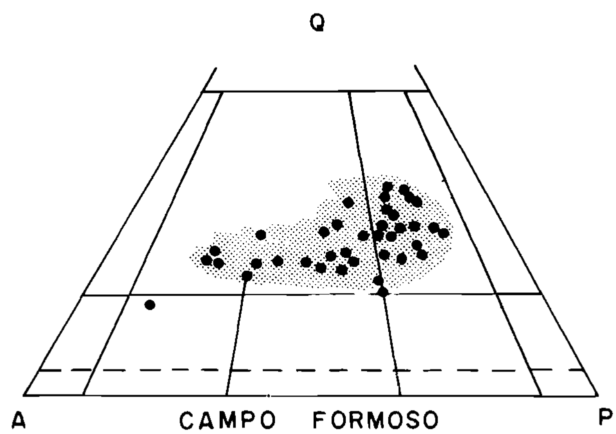


Figure 24.00
Modal distribution, in the QAP diagram, of some Campo Formoso samples. (analyst R. Boneli Conceição); the plotted data in the granodiorite field are essentially from Oliveira *et al.*, (1974).

At the limits of the massif, one view-point takes in all the morpho-geological elements.

To the south, the Serra de Jacobina, at whose base the open pit chromite mines in 45/50°S dipping serpentinites which mark the top of the muscovite-bearing granite. To the west, the granite is covered by the coarse-grained detrital sediments of the Bebedouro Formation and Carbonates of the Salitre Formation (Unå Group) of the Upper Proterozoic. To the SW, the granite gives way to basement gneisses.

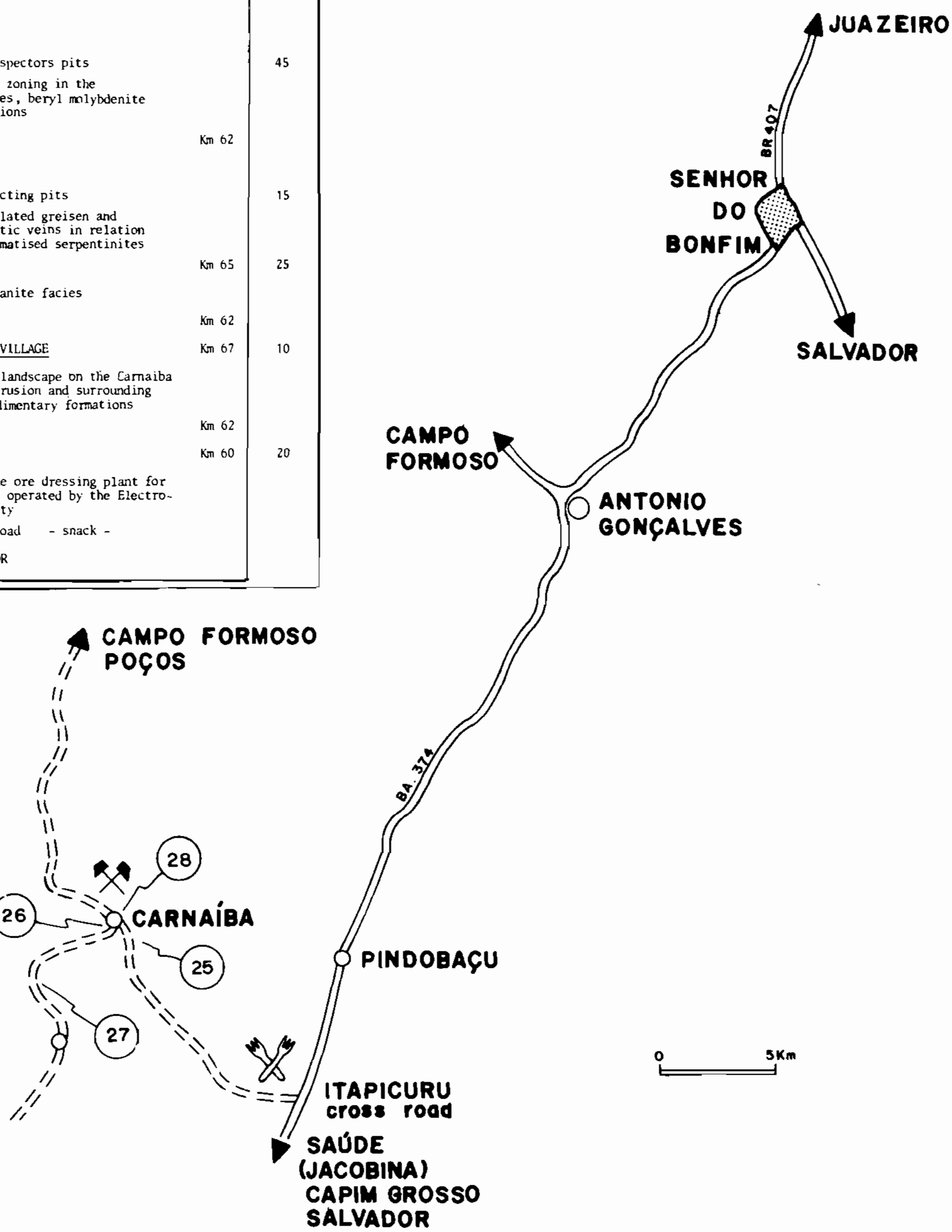
At the side of the road, a few transported blocks give a sample of the chromitiferous serpentinite.

On the return to Campo Formoso, a visit to the Lapidary School is planned.

This school is patronized by the Mines and Energy Secretariat of Bahia State and the Municipality of Campo Formoso. Afterwards, we will see the commercialization of emeralds in Campo Formoso Square.

30.01.87

Time	Locality		Time on outcrop (min)
07:30	SENHOR DO BONFIM - (Hotel Vitória)	Km 0	
	- coffee -		
08:10	PINDOBAÇU	Km 40	
08:20	ITAPICURU cross road	Km 48	
	(transfert to land cars)		
09:00	Formiga Propectors pits	Km 61	
09:15	<u>Outcrop 25</u>		
	Braulia prospectors pits		45
	metasomatic zoning in the serpentinites, beryl molybdenite mineralizations		
	CARNAIBA	Km 62	
10:05	<u>Outcrop 26</u>		
	Bode prospecting pits		15
	granite, related greisen and aplopegmatitic veins in relation with metasomatised serpentinites		
10:35	<u>Outcrop 27</u>	Km 65	25
	Carnaiba granite facies		
11.15	CARNAIBA	Km 62	
11:25	<u>CARNAIBA DE CIMA VILLAGE</u>	Km 67	10
	Geological landscape on the Carnaiba granite intrusion and surrounding volcano-sedimentary formations		
11:45	CARNAIBA	Km 62	
11:50	<u>MAROTA</u>	Km 60	20
	Visit to the ore dressing plant for molybdenite operated by the Electro-metal Society		
13:10	ITAPICURU cross road - snack -		
14:10	Return to SALVADOR		



FOURTH DAY

SENHOR DO BONFIM – CARNAIBA – SALVADOR

Granitic massif of Carnaiba and emerald prospecting pits of Braulia and Bode.

The Carnaiba pluton forms a small intrusive occurring in an antiform structure within Serra de Jacobina (fig. 25.00). The main granitic facies is a mesocratic porphyritic two mica granite, similar to the Campo Formoso porphyritic facies. Aplopegmatitic joins are well expressed and show beryl and sulphide mineralizations.

The Carnaiba prospecting pits are developed either in roof pendants in the Carnaiba granite or in country rocks terranes (fig. 25.00 and 25.01). The emerald bearing zones are similar to these of Socotó but related to the emplacement of aplopegmatitic joins and/or plagioclasic veins. An important molybdenite mineralization is encountered either as dissemination or as molybdenite bearing-quartz veins, especially in the Marota (80% of the molybdenite production from Carnaiba) and Trecho Novo prospecting pits, (fig. 25.00).

After crossing the essentially quartzitic formation of the Serra de Jacobina along the exotic Itapicuru valley we enter in the different but equally exotic landscape of the Carnaiba emerald "garimpos".

25th OUTCROP

Braulia prospecting pit.

Study of a typical and complete metasomatic zonation developed at the contact of a plagioclase vein within serpentinites – aspects of the molybdenite and scheelite mineralizations.

The quarry of Braulia (fig. 25.01) permits the observation of two types of mineralized structures:

(1) metasomatic structures:

– a representative metasomatic zonation is developed in the serpentinites and related to a plagioclasic vein emplacement.

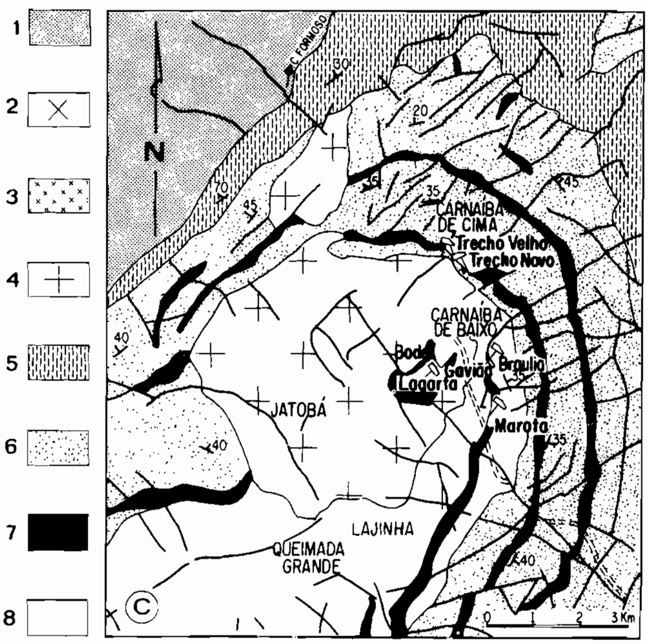


Figure 25.00
Geological map of Carnaíba granitic intrusion and its structural context. The legend is the same as in fig. 20.00.
After Rudowski *et al.*, (this Symposium), modified from Santana *et al.*, (1980).

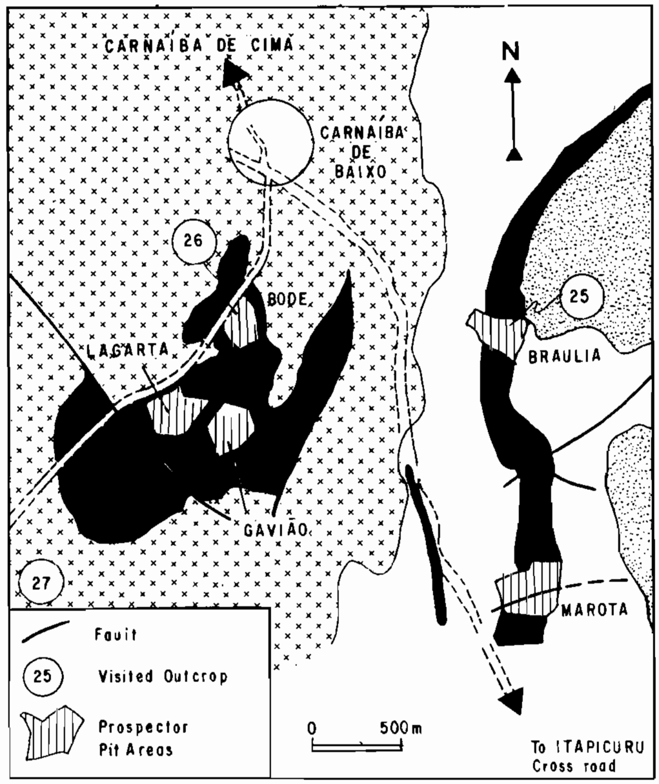


Figure 25.01
Simplified geological map of the prospecting pits of Carnaíba de Baixo; gneiss (white), serpentinites (black), quartzites (dotted), granite (cross).

From internal to external zones, we can distinguish the following (Fig. 25.10):

- a brown coarse phlogopitic zone presenting crystals of biotite (0.2 to 3cm) with local apatite concentrations. Chromite is present only in the outer part of this zone (microscopic thin section results).
- a light brown, fine grained phlogopitic zone associated with chromite.
- a phlogopitic zone with talc, chromite and magnetite.
- a talc-chromite-magnetite-serpentinite zone with some phlogopite which disappear in the external part of this zone.

– a narrow metasomatic zone composed of a biotite and tremolite association is locally observed. Scheelite mineralization occurs in these more calcic zones that probably result from the metamorphic transformation of basic intercalations in the serpentinites.

(2) quartz vein structures: molybdenite-beryl quartz veins crosscut a metasomatic zone, producing a muscovitisation in the phlogopitites.

26th OUTCROP

Bode prospecting pit.

In this area (fig. 25.01), the serpentinites appear as roof pendants in the granite and they are crosscut by aplopegmatitic joins.

At the contact of a composite aplopegmatitic (oriented N30° E and dipping 60° to south) with serpentinites, a metasomatic zonation is observed. It presents imbricated zones with sharp rectilinear limits. We can identify from internal to external zones:

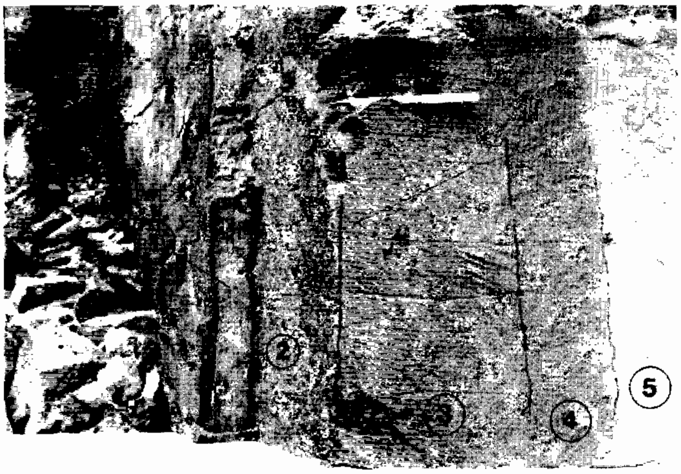


Figure 25.10
Metasomatic zones from a plagioclase vein in the serpentinites. Bode prospecting pit: (1) plagioclase vein; (2) coarse phlogopitite; (3) fine phlogopitite; (4) composite talc-phlogopitite; (5) serpentinite.

- a coarse grained phlogopitite (15cm) with green beryl
- a fine grained phlogopitite (35cm)
- a chromite-talc-phlogopitite zone (50cm)
- the serpentinite formations

A small exploration shaft permits the observation of the following phenomena.

– the relation granite/aplopegmatitic join/phlogopitite. An aplopegmatite join is intercalated between the granite and the phlogopitite; the granite contact suffers a biotitic alteration probably related to the circulation of the fluid along the contact zone.

– the development of quartz veins producing a greisenization of the Carnaiba granite.

The synthesis of the metasomatic zoning and associated mineralizations is sketched on fig. 26.00.

27th OUTCROP

Continuing to the south along the track which leads to Jatobá, 1km further on we turn left on to the Marreta Farm road. 2km from the junction a running river 150m SE exposes a large outcrop in which are united the granitic facies of the Carnaiba massif.

We see:

– a group of folded gneiss-migmatite as angular blocks, fragmented, rotated and cut by granites, veins and aplopegmatite dykes.

– a granite, with layering defined by large biotite crystals and centimetric, idiomorphic whole feldspar with signs of rotation to a preferential EW orientation, cuts the migmatite. The layered granite has some analogies with that of Gongorra Farm in the Campo Formoso massif.

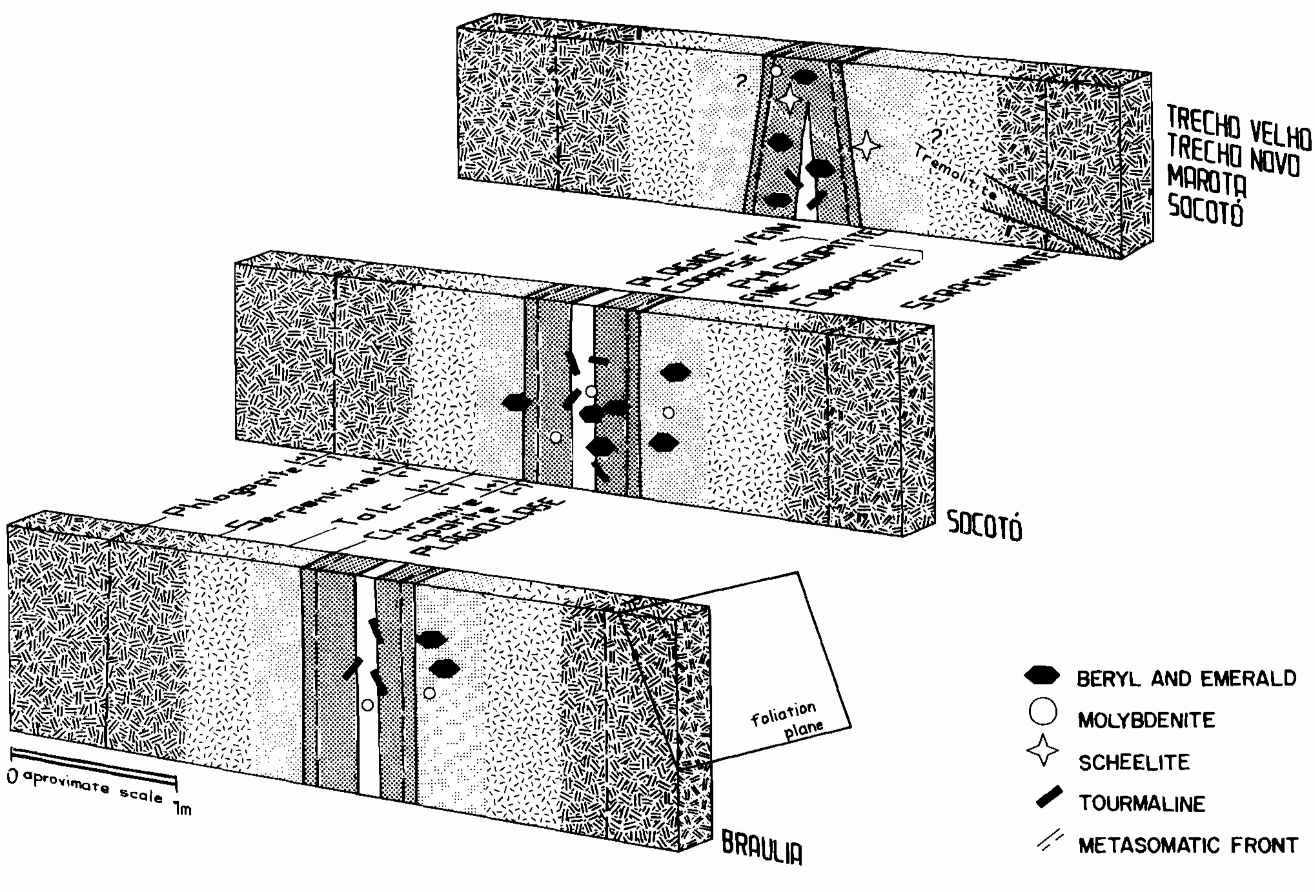


Figure 26.00
Synthetic reconstitution of the metasomatic zones, paragenesis and related mineralizations of the emerald district of Campo Formoso and Carnaíba.

– a fine-grained granite occupies most of the SE part of the outcrop, and sends dykes and veins into the migmatitic gneisses. This is the main facies of the Carnaiba massif.

– a suite of white to pink aplopegmatite dykes, aplites with pegmatitic borders or pink pegmatites invading the foliation of the migmatitic gneisses or beryl-containing pegmatites (the only ones with muscovite) which cut all others.

– two phases of tension fractures with sigmoid quartz infillings, one of which is cut by the fine grained granite, the other preceeding the beryl pegmatites.

Chronologically, we have:

1) Migmatites

2) Intrusion of to with large biotites and well-developed magmatic preferred orientation.

3) Injection of fine aplites with usually pegmatitic borders, cut by.

4) Quartz filled tension fractures oriented N75.

5) Intrusion of the fine-grained, muscovite-bearing Carnaiba granite, cutting the previous fractures, enclosing all previous rocks in a polymict roof pendant. This is cut by.

6) Quartz-filled tension fractures N25.

7) Intrusion of beryl-muscovite pegmatites.

Returning to Carnaiba de Baixo. We take the route to Carnaiba de Cima. We cross the village almost abandoned till last December.

During 1970 to 1980, the extensive exploitation of Trecho Velho and Trecho Novo prospecting pits (fig. 25.00), assured the development of the Carnaiba de Cima village, situated at 900 meters above sea level.

At the eastern extremity of the village a promontory offers a panoramic view of the Carnaiba massif.

The observation of the landscape permit us to have a representative view in the structural relationship between Carnaiba granite and its surroundings. The intrusive granite and the Archean gneissic basement form the Carnaiba depression, and they are surrounded by the volcano-sedimentary formations of Serra de Jacobina (Serra do Espinheiro to the west, Serra das Laranjeiras to the south and Serra da Pedra Furada to the east).

Coming back, the last stop will be made in the little agglomeration, near the Marota prospecting pits, where the Electrometal Society recently installed its ore dressing plant for molybde nite, to recover a strategic ore and to try to fix a part of the population.

The visit will be described by Dr. Paulo Tadeu, Project Manager.

After a meal break at the Itapicuru crossroads, the return journey to Salvador offers several hours for discussing the geotectonic evolution of this part of the São Francisco craton, the granitogenesis and metallogenesis.

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A part of this work became possible thanks to the patient teaching by Prof. Angel Fernandez of his remarkable methodological approach which opens a further dimensions in the study of granites. The work also benefitted from discussions, observations and comments of Profs. Jean Lameyre and Bernard Bonin and Dr. Patrick Le Fort, who were "guineau-pigs" during earlier rehearsals of this excursion.

A special mention is also due to Pedro Couto, who apart from sharing with much his wade attentiveness knowledge of the Serra de Jacobina and the emerald fields of Campo Formoso and Carnaiba, helped with many facilities during the field work in the area of the "garimpos".

REFERENCES

ALMEIDA, F.F.M. 1981 – O Craton do Paramirim e suas relações com o do São Francisco. In. Simpósio sobre o Craton do São Francisco e suas faixas marginais. Salvador, 1981. Pp1-10.

ALMEIDA, F.F.M. 1977 – O Craton de São Francisco. Revista Brasileira de Geociências, 7(4) p.349-364.

ALMEIDA, F.F.M. 1967 – Origem e evolução da Plataforma Brasileira – Div. Geol. Min. Dep. Nac-Prod., Bol 241.

BARBOSA DE DEUS, P. and VIANA, J. dos S., 1982 – Jacurici Valley chromite district. ISAP Abstracts and Excursions., 97-107.

BARTELS, R.L.; TORQUATO J.R. and OLIVEIRA M.A.F.T. 1977 – Geochronological Investigation in Granulitic Terrain Northeast of Feira de Santana, Bahia State. VIII. Simp. Geol. Nordeste, Soc. Bras. Geol., Núcleo Nordeste, Bol. esp., Resumos das Comunicações, 18-19.

BELLIENI, G.; PICCIRILLO, E.M.; OLIVEIRA, M.A.F.T; BRITO, C.M. 1986 – Enxame de diques máficos no Cinturão Atlântico ao Sul do Estado da Bahia. XXXIV Cong. Bras. Geol., Goiânia, Bol. nº 1, Resumos, 170.

BOUKILI, H. 1984 – Pétrologie, minéralogie et géochimie des alterations des roches ultrabasiques à chromite de Campo Formoso, Brésil. Thèse 3 ème Cycle, Strasbourg, 130p.

BRITO NEVES, B.B.; CORDANI, U.G. TORQUATO, J.R.F. 1980 – Evolução Geocronológica do Precambriano do Estado da Bahia – Secr. Minas Energia., Bahia; Coord. Prod. Min. textos básicos nº 3; 1-80

BRITO NEVES, B.B. 1977 – Vergência centrífuga residual no sistema de dobramento Sergipano. Revista Brasileira de Geociências, 7(2), 102-114.

CALAS G., MANCEAU A.; NOVIKOFF A. et BOUKILI H. 1984 – Comportement du chrome dans les minéraux d'altération du gisement de Campo Formoso (Bahia, Brésil) Bull. Mineral, 107, 755 – 766.

CONCEIÇÃO, H. and SABATÉ, P. 1986 – O batólito de Itiúba (Bahia): um corpo sienítico singular. 382 ren. anual Soc. Bras. Prog. Cien., resumos, F.3,, Geol: 758.

CORDANI, U.G. 1973 – Evolução Pré-cambriana da Faixa Costeira do Brasil, entre Salvador e Vitória. Tese Livre Doc., Inst. Geoc., Univ. São Paulo, (unpublished).

CORDANI, U.G.; ISOTTA, C.A.L. and ABREU, A.C.S. 1969 – Reconhecimento geocronológico do embasamento da região oriental do Estado da Bahia XXIII Cong. Bras. Geol., Salvador, Anais Soc. Bras. Geol., 1970; 159-164.

COUTO, P.A. and ALMEIDA, J.T. 1982 – Geologia e mineralizações na área do garimpo de Carnaíba. Bahia. In: Congresso Brasileiro de Geologia. V.3, 850-868.

COUTO, P.A. 1978 – Projeto Serra de Jacobina; Geologia e prospecção geoquímica. Relatório Final. Salvador. CPRM. 12v. Convênio DNPM/CPRM.

DNPM/CPRM 1975 – Projeto Bahia – Relatório, vol. 5, 67-75 (unpublished).

DIDIER, J.; DUTHOU, J.L. and LAMEYRE, J. 1982 – Mantle and crustal granites: Genetic classification of orogenic granites and the nature of their enclaves. Journal of Volcan, and Geoth. Res., 14: 125-132.

FERNANDEZ, A. 1984 – Etúde théorique et expérimentale du developpement de la fabrique dans les roches magmatiques. Application à l'analyse structurale des granitoídes. Thèse en Sciences, Univ. Clermont – Fd, France, 239p.

FERNANDEZ, A. 1982 – Signification des symétries de fabrique monoclinique dans les roches magmatiques. C.R. Acad. Sci., Paris, t. 294, ser. II: 995-998.

FERNANDEZ, A.; FEYBESSE, J.L. and MEZURE, J.F. 1983 – Theoretical and experimental study of fabric developed by different shaped markers in two dimensional simple shear. Bull. Soc. Geol., France, sér. 7, XXV, nº 3: 319-326.

FIGUEIREDO, M.C.H. 1976 – Geologia e geoquímica da região de Poço de Fora – Vale do Curaçá-Bahia. Tese de mestrado. Inst. Geoc. Univ. Fed. Bahia, 87.

GOMES, R.A.A.D. and MOTTA, A.C. 1980 – Projeto levantamento gravimétrico no Estado da Bahia. Relatório Final. Salvador, CPRM. 5 V Convênio DNPM/CPRM.

GONÇALVES, J.C.V. 1972 – Projeto Cromo. Relatório Final. Salvador, CPRM. V.1, Convênio DNPM/CPRM.

KOUCHI, A. and SUNAGAWA, I. 1985 – A model for mixing basaltic and dacitic magma as deduced from experimental data. Contr. Min. Petrol., 89: – 17-23.

KOUCHI, A. and SUNAGAWA, I. 1985 – Experimental study of mixing basaltic and dacitic magmas. Sei. report, Tohoku Univ., Japan, Ser. III, Vol. XV, nº 2: 163-175.

GRIFFON, J.C. 1967 – Estudo estrutural e genético da jazida de esmeralda de Carnaíba, Bahia. Anais da Academia Brasileira de Ciências. Rio de Janeiro, 39 (1); 153-161.

HEDLUND, D.C.; DE COUTO MOREIRA, J.F.; PINTO, A.C.F.; DA SILVA, J.C.C. et SOUZA, G.V.V. 1974 – Stratiform chromitite at Campo Formoso, Bahia, Brazil,. Research U.S. Geol. Survery, 2 nº 5, 551-562.

INDA, H.A.V. and BARBOSA, J.F. 1978 – Texto explicativo para o Mapa Geológico do Estado da Bahia. Escala 1:1000.000. Salvador, SME/CPM 122.

JARDIM DE SÁ, E.F. 1982 – Nota sobre o estilo estrutural e relações gnaisses vs. supracrustais no Greenstone Belt de Serrinha, Ba. Ciências da Terra, (2). 8 – 13.

KISHIDA, A. 1979 – Caracterização geológica e geoquímica das seqüências vulcano-sedimentares do médio Rio Itapicurú. Tese mestr., Inst. Geoc. Univ. Fed. Bahia, Salvador, 79.

KISHIDA, A. and RICCIO, L. 1980 – Chemostratigraphy of lava sequences from the Rio Itapicurú Greenstone Belt, Bahia State, Brazil. Precambrian Research, 11: 161-178.

KISHIDA, A. and RICCIO, L. 1979 – "Greenstone Belt" do Rio Itapicurú-(Ba). Estratigrafia química e algumas idéias sobre sua evolução geotectônica. In "Simpósio sobre o craton do São Francisco e suas faixas marginais, Salvador, 63-72.

LAMEYRE, J. and BOWDEN, P. 1982 – Plutonic rock types series: discrimination of various granitoid series and related rocks. Journal of volcanology and Geothermal Research, 14: 169-186.

LEO, G.W.; COX, D.P. and CARVALHO, J.P.P. 1964 – Geologia da parte sul da Serra de Jacobina, Bahia Brasil. Rio de Janeiro. DNPM/DGM, 84 Bahia/84p.

MACHADO, G.V.S.; SABATÉ, P. and McREATH, I. 1984 – Granitóides Transamazônicos da Bahia: tendências petrológicas e relações geotectônicas. XXXIII Cong. Bras. Geol., Rio de Janeiro, Resumos: 160.

MARINHO, M.M.; ROCHA, G.M.F.; DEUS, P.B. de and VIANA, J. dos S. 1986 – Geologia e potencial cromitífero do Vale do Jacurici, Bahia. XXXIV Cong. Bras. Geol,, Goiânia, Anais V.7.

MARINHO, M.M. and SABATÉ, P. 1982 – The Contendas-Mirante volcanosedimentary sequence and its granitic-migmatitic basement. Excursion Guide Internat. Symp. Archaean, Early Proterzoic, Geol. Evolution and Metallogenesis. Secr. Minas Energia, Bahia: 139-184.

MASCARENHAS, J. de F.; PEDREIRA, A.J.; MISI, A.; MOTTA, A.C. and SÁ, J.H. da S. 1984 – Província São Francisco em Almeida, F.F.M. de e HASUI, Y. (Coordinators) – O Precambriano do Brasil. Blucher, São Paulo, pp.46-122.

MASCARENHAS, J. de F. 1976 – Estruturas de tipo Greenstone Belt no leste da Bahia. A. XXVII Cong. Bras. Geol., Ouro Preto, 4: 25-50.

MASCARENHAS, J. de F. 1969 – Mapeamento geológico da parte norte da Serra de Jacobina, Bahia, Boletim da Sociedade Brasileira de Geologia, São Paulo, 18 (1), 1-22.

MELFI, A.J.; TRESCASES, J.J. et BARROS DE OLIVEIRA, S.M. 1979-80 – Les laterites nickelifères du Brèsil. Cahiers, ORSTOM, Sér. Geol., XI, nº 1, 15-42

MONTE LOPES, C.A. 1982 – Algumas características geológicas e geoquímicas das mineralizações de ouro na área de jazida da Fazenda Brasileiro, Bahia. Unpublished Master's Thesis, UFBA 99pp.

MOREIRA, M.D. and SANTANA, A.J. 1982 – O Garimpo de Carnaíba, geologia e perspectivas. Anais do XXXII Cong. Bras. Geol., Salvador,Bahia, v.3, 862-874.

OLIVEIRA, N.A., FROES, R.J.B., OLIVEIRA, T.T. 1974 – Granito de Campo Formoso, Bahia, An XXVIII Cong. Bras. Geol., Porto Alegre, 125-132.

PEDREIRA, A.J.; KISHIDA, A.; TORQUATO, J.R. e MASCARENHAS, J.F. 1978 – Inventário e reavaliação do conhecimento geológico da parte central do Craton do São Francisco. Soc. Bras. Geol., Núcleo da Bahia, Pub. Esp. nº 3: 67-136.

PEDREIRA, A.J. et al., 1976 – Carta geológica do Brasil ao milionésimo. Folha Salvador (SD.24). Brasília, DNPM 127.

SABATÉ, P. and MARINHO, M.M. (1982) – The Contendas-Mirante volcano-sedimentary sequence and its granitic-migmatitic basement. ISAP. Abstract excursions, Salvador, Bahia, 139-184.

SEIXAS, S.R.M., et al. 1975 – Projeto Bahia II. Geologia das folhas Itaberaba e Serrinha. Relatório Final. Salvador. CPRM. v. 1. Conv. DNPM/CPRM.

SME/CPM. 1976 – Projeto rochas básicas e ultrabásicas de Euclides da Cunha. Relatório final, vol. I (texto), 105-110 (unpublished).

TEIXEIRA, J.B. (1985) – Geologia e controles da mineralização aurífera na Fazenda Brasileiro, Serrinha, Bahia. Geol. Rec. Min. Estado da Bahia, Textos Básicos, v.6, 7-49.

TORQUATO, J.R.; OLIVEIRA, M.A.F. and BARTEL R.L. 1978 – Idade radiométrica do granito de Campo Formoso, Bahia. Uma idade mínima para o Grupo Jacobina. Rev. Bras. Geoc., 8: 171-179.

WINGE, M. (1984) – A seqüência vulcano-sedimentar do Grupo Capim, Bahia. Geol. Rec. Min. Estado da Bahia, Textos Básicos, v.5: 43-103.