Chapter II

GEOLOGY OF THE JEQUIÉ-ITABUNA GRANULITIC BELT

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INTRODUCTION

The Archean and Early Proterozoic Jequié-Itabuna Granulitic Belt is one of the largest outcropping granulite provinces of the world. This region has been studied in detail for the last 15 years. Significant papers dealing with the subject are those by Sighinolfi (1970, 1971); Cordani (1973); Sighinolfi & Sakai (1977); Cordani & Iyer (1979); Sighinolfi et al. (1981); Costa & Mascarenhas (1982); Oliveira & Lima (1982); Oliveira et al. (1982); Iyer et al. (1984); Delhal & Demaife (1985) and Iyer et al. (1987). Since most of these papers have been limited to local areas and specific themes, it has been difficult to correlate them, thus, precluding a wider view of the geotectonic framework.

Regional geological mapping (e.g., Pedreira et al., 1975; Miranda et al., 1982; Lima et al., 1982; Miranda et al., 1985), integrated the existing data and devised the first models of regional geological evolution. Despite their contribution to the geologic knowledge of the region, these studies lack important data, specially regarding the petrochemistry, the geochronology and the physico-chemical conditions that governed the orogenic and thermal phenomena that affected this part of the deep crust of Bahia.

Research carried out beginning in 1986 on petrochemistry, mineral chemistry, isotopic geology and geochronology, gave a new focus for the study of these high grade terrains of Bahia. Parameters were established that allowed a better cartography of the lithological units, the determination of their thermodynamic conditions of formation, the estimation of the age of the protoliths as well as the geotectonic phenomena that affected them. Outstanding among these works are those by Barbosa & Fonteilles (1986, 1989, 1992, in print), Barbosa (1986, 1988, 1990, 1991, 1992); Wilson (1987), Wilson et al. (1988), Figueiredo (1989), Xavier et al. (1989), Cruz (1989), Sá & Barbosa (1991); Conceição et al. (1991); Padilha et al. (1991); Silva (1991); Marinho (1991); Aillon and Barbosa (1992); Arcanjo et al. (1992), Alibert & Barbosa (1992) and Fornari & Barbosa (1992). These papers contributed in a significant way to the evolution of the geological concepts about the region. The data presented in this chapter and described further on were taken mostly from these papers.

GEOLOGICAL OUTLINE

Recent studies on the Jequié-Itabuna Granulitic Belt (Fig. I.2) performed by Barbosa (1986) and Marinho (1991) have shown from west to east outstanding differences regarding tectonics, petrology and chemistry of the existing rocks. This supported the division of the region into three geological domains: Jequié-Mutuípe-Maracás, Ipiaú and Atlantic Coast domain (Fig. II.1).

JEQUIÉ-MUTUÍPE-MARACÁS DOMAIN

This domain that roughly corresponds to the so-called Jequié Complex of Archean age (Cordani, 1973) is lithologically represented by: (i) enderbitic, charno-enderbitic, charnockitic and gabbro-anorthositic rocks, re-equilibrated in the granulite facies; and (ii) ortho- and paraderived rocks metamorphosed and sometimes migmatized in the granulite facies (Fig. II.1).

Endebitic, charno-enderbitic, charnockitic and gabbro-anorthositic plutonic rocks

The plutonic rocks occur in an important sector of the Jequié-Mutuípe-Maracás Domain, cropping out in the eastern part of Laje and Mutuípe regions (Barbosa, 1986) and in the western part, south of the town of Maracás (Marinho, 1991; Fig. II.1). Although these plutons are in most part strongly deformed (Costa & Mascarenhas, 1982; Barbosa, 1986; Marinho, 1991) they still have a coarse texture owing to the outstanding presence of large phenoclasts within a medium texture granoblastic matrix.

Enderbitic Charnockitic Plutonic Rocks of the Lage-Mutuípe Region

The plutonic rocks of the eastern part of

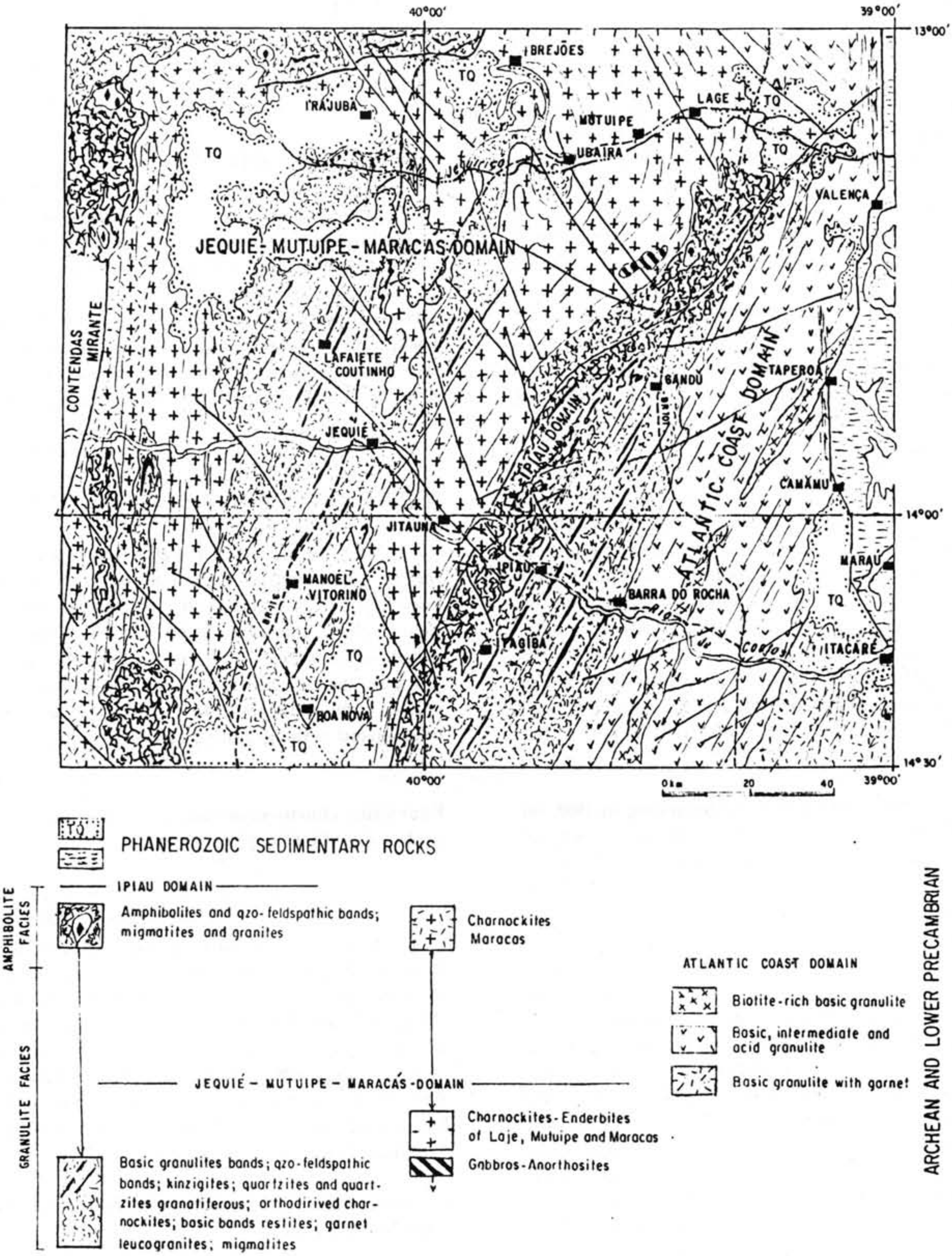


Figure II.1 - Simplified geological map of the Jequié-Itabuna Granulitic Belt - Bahia - Brazil.

the region are mostly enderbitic, charno-enderbitic and charnockitic types. In the case of the charnockites, the phenoclasts are mesoperthite or perthitic K-feldspar and in the case of the enderbites, antiperthitic feldspar. The matrix is composed by quartz, orthopyroxene, clinopyroxene, brown hornblende and biotite, the latter three minerals occurring in subordinate amounts. The accessory minerals of these rocks are ilmenite-magnetite, apatite and zircon (Table II.1) A series of observations on the textural relationships of these plutonic rock minerals show that they were subjected to different retro-metamorphic stages (Barbosa, 1986; Barbosa & Fonteilles, 1989) which are shown in Table II.1, that displays a list of retrograde minerals.

Besides a strong foliation, the plutonic rocks of the eastern part of the region display mineralogical banding (best observed on the weathered surface of the outcrops), characterized by intercalations of light and dark green bands dominated by feldspars and ferromagnesian minerals, respectively. This banding was probably created as a result of the accumulation of the different mineral phases during the magmatic differentiation and emphasized afterwards by tectonism (Barbosa, 1986). Also, mafic enclaves, deformed and oriented parallel to the banding, are found in the granulitized plutonic rocks of Laje-Mutuípe. These enclaves occur as lenses 10-20 cm wide and about one metre long (Fornari & Barbosa, 1992). In some outcrops there is evidence of the possible presence of enclaves of supracrustal rocks, difficult to set apart from the plutonic country rock, owing to the intensive deformations and recrystallizations to which both were subjected. Besides the enclaves, other petrographic and mineral-chemical data indicate the original plutonic character of these rocks. An outstanding testimony is the presence of some plagioclase grains, tiny inclusions of biotite and chlorine-rich euhedral hornblende of typical magmatic origin, as well as the fact that the centers of some orthopyroxene-clinopyroxene pairs are chemically similar to magmatic pyroxenes formed at high crystallization temperatures (Barbosa, 1986).

In these plutonic rocks that occur in the Laje and Mutuípe regions, pegmatite veins with orthopyroxene and milky-quartz veins, both parallel to or crosscuting the banding are also observed. The pegmatite veins probably formed during the peak of the granulitic metamorphism. They have coarse grained texture and mineralogical composition made up of orthopyroxene, mesoperthite and quartz. Two tiny inclusions in the latter mineral phase were studied, and it was demonstrated that CO_2 rich synmetamorphic fluids of low density (0.85 g/cm^3; Xavier et al., 1989) percolated these rocks during the metamorphism, being compatible with the low to medium PT conditions of the granulitic metamorphism, found through thermobarometric studies performed on mineral phases of regional rocks (Barbosa, 1986, 1988; Barbosa & Fonteilles, 1986). The quartz crystals of the milky-quartz veins that also crosscut the plutonic rocks of Laje and Mutuípe, also had some of their fluid inclusions analysed. The carbonic fluids of the inclusions show values of carbon isotopes ranging from -1 to -7 ‰. This range is in agreement with values δC^{13} (‰ PDB) found in charnockitic rocks elsewhere in the World as for instance in southern India (Iyer et al., in print).

The gabbro-anorthositic rocks are very scarce in the Jequié-Mutuípe-Maracás Domain (Fig. II.1). They also re-equilibrated in granulite facies, are banded and essentially composed by plagioclase, orthopyroxene, clinopyroxene with relatively rare opaque minerals (Cruz, 1989; Table II.1).

Although in some of these plutonic rocks geochronological studies have been done based in previous petrochemical analyses and in a combination of the Rb-Sr, Sm-Nd and Pb-Pb methods (Wilson, 1987; Wilson et al., 1988), in most radiometric determinations only the Rb-Sr method was used without strict geological constraints (see chapter IV). Recently, Alibert & Barbosa (1992) determined U-Pb ages by SHRIMP in zircons of enderbites and charnockites of the eastern sector of the domain. They found ages of 2689±7 Ma for the enderbites and 2810 Ma for the charnockites.

Table II.1 - Mineralogical composition of rocks from the Jequié-Itabuna granulitic belt, Bahia, Brazil.

TABLE II-1 - MINERALOGICAL COMPOSITION OF ROCKS FROM THE JEQUIÉ-ITABUNA GRANULITIC BELT, BAHIA, BRAZIL

ROCKS	PRINCIPLE METAMORPHIC MINERALS (modal composition)	ACESSORY MINERALS	RETROGRADE METAMORPHIC MINERALS
JEQUIÉ -MUTUÍPE-MARACÁS DOMAIN			
. Plutonic rocks (west part)			
Enderbites	Plag antp(60%)(An30);Opx(2-5%);Cpx(5-10%);Hb(2-5%)Qz(20-30%);Mp(1-5%);Bl	Op;Zr;Ap	Plag;Mu;Se;Bt;Mir
Charno-enderbites	Mp(15-20%);Plag antp(30-40%)(An25);Opx (2-5%);Cpx(1-5%);Hb(1-5%);Qz(10-30%)	Op;Zr;Ap	Hb;Bl;Se;Clr;Bt;Mir
Charnockites	Mp(40-50%);Qz(30%);Plag antp(5-10%) (An23);Opx(5-8%);Cpx(2%);Hb;Bl	Op;Zr;Ap	Hb;Bl;Mic;Plag;Clr;Bt;Mir
Gabbros-Norites-Anorthosites	Plag(70%);An(45-50);Cpx(20%);Opx(10%); Hb(5-10%)	Op;Ap	Hb;Bl;Clr;Bt
. Plutonic rocks (east part)			
Charnockites	Mp(30-65%);Plag(35-55%)(An12-15); Qz(10-45%);Hb(1-15%);Cpx(0-7%);Opx (0-3%);Ol(0-3%);Bl(0-3%)	Zr;Ap;All;Op	Mic;Hb;Bl
. Supracrustal rocks			
Basic granulites bands	Plag(50%);Opx-Cpx(30%);Hb(15%);Bl(5%)	Op;Ap	Bl
Quartz feldspatic bands	Qz(50%);Plag(40%);Mp(5-10%)	Op;Opx;Bl;Gt	Se
	Qz(50%);Mp(40%);Plag(10%)	Op;Opx;Bl	Se
Kinzigites	Gt(35%);Qz(30%);Plag(15%);Cd(10%); Bl(5%);Sill	Op;Ap;Zr;Gf	
Garnetiferous quartzites with orthopyroxene	Qz(70-90%);Gt(5-10%);Plag(1-5%);Opx;Bl	Op	Bl;Clr
Orthoderived (or anatectics) charnockites	Mp(20-60%);Plag antp(5-20%)(An25-30); Opx(5-10%);Qz(5-20%);Cpx;Hb;Bl	Op;Zr;Ap;Gt	Hb;Bl;Mic;Plag;Clr;Bt; Mir;Mu;Epi;Tr
Quartz-feldspatic veins	Mp(50-60%);Qz(20-30%);Plag antp(5%) (An25-30);Opx;Cpx;Hb;Bl	Op;Zr	Hb;Bl;Plag;Clr;Bt;Mir;Mic
Basic bands restites	Plag(40-60%);An(30-35%);Opx-Cpx (20-40%);Hb;Bl	Op;Ap;Zr;Qz	Hb;Bl
Garnet leucogranites	Mp(60-70%);Qz(10-20%);Gt(5%);Plag-Opx	Op;Zr	Se;Mir
IPIAÚ DOMAIN			
. Supracrustal rocks			
Amphibolites bands	Plag(45%)(An25-30);Hb(40%);Cpx(5%); Qz(1-5%)	Op;Ap	Se
Quartz feldspatics bands	Qz(60%);Mic(35%);Plag(5%)	Op	Se
Granitic rock	Qz(40%);Mic(50%);Bl(10%)		
ATLANTIC COAST DOMAIN			
Biotite-rich basic granulite	Plag antp(30%);Mp(20%);Opx(15%);Cpx (15%);Bl(15-20%)	Op;Qz;Ap;Zr	Bl;Qz;Bt
Basic granulites	Plag(50%)(An55-60);Opx-Cpx(40%);Bl; Hb(5%)	Op;Qz;Ap;Zr	Hb;Bl;Qz;Bt
Intermediate granulites	Plag(70%)(An50);Opx-Cpx(25%)	Op;Qz;Ap;Zr	Bl;Bt
Acid granulites	Plag(80%);Opx-Cpx(5-10%);Qz(10%)	Op;Ap;Zr	Bl;Qz;Bt;Mir
Basic granulites with garnet	Plag(50%);Opx(20%);Cpx(20%);Gt(5%)	Op;Qz;Bl;Hb;Ap;Zr	

ABBREVIATIONS: Opx-ortopyroxene; Cpx-clinopyroxene; Plagantp-antiperthitic plagioclase; Mp-mesoperthite; Hb-hornblende; Bi-biotite; Qz-quartz: Gt-garnet; Cd-cordierite; Sill-sillimanite; Mic-microcline; Op-opaque minerals; Zr-zircon; Ap-apatite; Gf-graphite; Clr-chlorite; Mu-muscovite; Se-sericite; Bt-bastite; Mir-mimerkite; Epi-epidote; Tr-tremolite; Ol-olivine; All-allanite.

Charnockitic Plutonic Rocks of The Maracás Region

According to Marinho (1991) the plutonic rocks of the western sector of the region occur south of Maracás (Fig. II.1). They are interfingered with the ortho- and paraderived rocks, forming N-S oriented bands, because of the tectonic deformations overprinted on them. They display a medium grained texture and foliated structure that is characterized by the orientation of the mafic minerals, although some outcrops show large mesoperthite phenoclasts that reach up to 4 cm in length and are oriented according to the foliation. The local presence of supracrustal enclaves (gneisses and amphibolites) suggest that these charnockitoids are intrusive in origin and equilibrated in the granulite facies. They are composed by quartz, mesoperthite or perthitic feldspar, rare antiperthitic plagioclase, greenish brown hornblende, clinopyroxene, reddish brown biotite, orthopyroxene and olivine, the two latter never found in contact. The accessory and retrograde minerals are shown in Table II.1.

For these charnockitic rocks, Marinho (1991) obtained Rb-Sr data scattered between two reference lines with ages of 2800 and 2300 Ma; Pb-Pb isochrons of 2660±76 Ma and T_{DM} Sm-Nd model-ages of about 3200 Ma (see chapter IV).

Ortho- and paraderived rocks metamorphosed in granulite facies

Another expressive lithological component of the Jequié-Mutuípe-Maracás Domain is composed by ortho- and paraderived rocks, that are deformed, metamorphosed and sometimes migmatized in the granulite facies.

. *Basic granulite bands* showing fine to medium grained texture, with sometimes polygonal, regular contacts between mineral grains and essentially composed by plagioclase, orthopyroxene-clinopyroxene, greenish brown hornblende and titaniferous red biotite. Opaque minerals are the most common accessories (Table II.1). Radiometric dating performed in several of these rocks by Sm-Nd model-age method show a polyphasic evolution for these lithologies (see Chapter IV).

. *Quartzo-feldspathic bands* generally have medium grained texture with irregular contacts between the mineral phases and are composed either by (i) quartz, antiperthitic plagioclase and rare perthitic microcline or by (ii) quartz, mesoperthite-perthitic microcline and rare plagioclases. The opaque minerals, orthopyroxene, biotite and garnet are accessory (Table II.1). Macroscopicaly the rocks sometimes show a mylonitic texture with stretched quartz crystals parallel to the foliation, but also displays a graphic, pegmatoid texture. The bands of quartzo-feldspathic material have variable thickness that range from centimetres to metres and occur not only intercalated with the basic granulites, but also with quartzites, graphitic layers, kinzigites and banded iron formations.

. *Kinzigites* form altered, reddish bands with variable thicknesses (30 cm up to 5 m) intercalated with garnetiferous quartzo-feldspathic bands and, sometimes, with basic granulites. These rocks are composed by garnet, quartz, plagioclase, cordierite and biotite. Sillimanite and orthopyroxene are rare and pyrite, apatite, zircon and graphite are the most common accessory minerals (Table II.1). Some outcrops of kinzigite are migmatized with the quartzo-feldspathic bands well recrystallized and with pegmatoid texture. Bodies of leucogranites sometimes garnet-bearing and sometimes cordierite-bearing, possibly of anatectic origin, are found associated with the kinzigitic rocks. Iyer et al. (in print) studied carbon isotopes in the graphites of kinzigites and of the graphitic layers previously cited, concluding that these latter could have been the relicts of the original Archean organic carbon.

. *Orthopyroxene-bearing garnetiferous quartzites and other quartzites* crop out in scattered places within the supracrustal rocks. The quartzites are formed by more than 95 % quartz and occur in centimetre thick beds that alternate with quartzo-feldspathic bands, or occur associated to the graphitic layers and to the kinzigites. In all cases they form layers parallel to the rock banding that may be in a horizontal (Brejões region; Fig. II.1) or sub-vertical position (Ubaira region; Fig. II.1). The best outcrops of garnet-orthopyroxene quartzites are in two sub-parallel ranges that run for about 10 km from west to east (Fig. II.1). These rocks, when little weathered are light green and have fine to medium grained texture. The orthopyroxene-bearing garnetiferous quartzites are intercalated with 5-10 cm thick seams of basic material. They display penetrative foliation distinguished by the presence of red garnet and dark green orthopyroxene. The metamorphic paragenesis and accessory minerals of these quartzites can be found in Barbosa (1986) and are summarized in Table II.1. It should be noted that the carbon isotope ratios found in CO_2 present in the fluid inclusions of the quartz crystals of these rocks are very different from those found for the fluid inclusions of the quartz veins that randomly crosscut the previously described plutonic rocks. The former values are similar to those found in Archean quartzites and the latter are similar to those of plutonic charnockitoid rocks of granulitic terrains elsewhere in the World (Iyer et al., in print).

. *Orthoderived charnockites* within the ortho- and paraderived rocks, occur as greenish gray, rather homogeneous rocks whose coarse grained texture is recorded by xenomorphic crystals of mesoperthite and perthitic microcline, antiperthitic plagioclase, orthopyroxene and quartz. Clinopyroxene, brown hornblende and red biotite are rare, but always are in thermodynamic equilibrium with the orthopyroxene (Barbosa, 1986, 1988; Table II.1). The rocks do not show pronounced deformation, in contrast to the surely plutonic charnockites of the Laje and Mutuípe regions (Fig. II.1). Under the microscope the difference between these two types of charnockites is not easily seen; however the geochemical comparison between them, described further on, shows sharp contrasts. In some outcrops the rock shows dark rounded patches with diameter of a few centimetres scattered in a grayish green coarse matrix. These small patches are basic granulite resisters that possibly were not completely absorbed by the intermediate magma that formed these rocks. In this type of outcrop feldspathic quartz veins crosscuting these rocks and the basic granulite resisters are observed. They are relatively homogeneous and undeformed. Their mineralogy is shown in Table II.1. Radiometric dating was performed on these orthoderived charnockites by Wilson (1987) both in the Mutuípe and in the Jequié areas. In the former a Rb-Sr isochron of four samples gave an age of 2699 Ma and a Sm-Nd model-age of 3100 Ma was obtained for one sample. In the latter, he determined not only a Pb-Pb isochron with ten samples, with age of 1970 Ma, but also Sm-Nd model-ages in two samples, with ages of 2900 and 2600 (see chapter IV).

. *Basic restite bands* occur as blocks, enclaves and boudins of variable sizes (centimetres to metres) and included within the grayish-green orthoderived charnockite and migmatitic granulite country rock. They have the same mineralogical composition of the basic granulite bands cited above; however, a great majority of them are richer in biotite and hornblende, mostly in their border zones. In these cases the pyroxenes are partially transformed into red biotite and greenish-gray hornblende. However, the plagioclases are not altered. Small grains of perthitic microcline and some myrmekites are rarely present (Table II.1). The opaque minerals are also partly transformed into biotite. It is worth noting that in some outcrops of these high grade migmatites, the basic granulite bands occur as boudins. At the rim of these boudins occur a centimetre thick orthopyroxene-rich aureole. This is interpreted as consequence of the progressive granulitic metamorphism. In these outcrops, coarse grained quartzo-feldspathic mobilisates with large pyroxene crystals are observed. They are supposed to have been formed during the peak of the metamorphism after the end of the ductile deformations (Barbosa, 1986).

. *Garnet leucogranites* also occur in this domain in association with the supracrustal rocks. They are generally light gray with fine to medium grained texture and in most cases are weakly deformed, in comparison with the Laje-Mutuípe plutonites. Sometimes they contain vestiges of basic material, almost completely consumed by this granitic magma. They are composed by mesoperthite, and perthitic microcline, quartz and almandine. Antiperthitic plagioclase and orthopyroxene are seldomly found, and opaque minerals occur only sporadicaly (Table II.1). Finally it should be noted that similar granites are found associated with kinzigites, and seems to have an anactectic origin, so they can be classified as S-type granites (Hine et al., 1978).

IPIAU DOMAIN

This domain is in the center of the studied region. Its shape is triangular and its orientation is NNE-SSW being bounded in the west by the Teolandia Fault and in the east by an amphibolite-granulite facies transitional zone (Fig. II.1). In this domain intercalations of amphibolites and quartzo-feldspathic material dominate although quartzites and banded iron formations also occur.

Ortho- and paraderived rocks metamorphosed in amphibolite facies

. *Amphibolite bands* are characterized by a medium grained texture recorded by the presence of large hornblende crystals oriented according to the foliation. They are composed by plagioclase, green to bluish green hornblende, clinopyroxene and quartz. Opaque minerals and apatite are the most common accessory minerals. In the same way that for the basic granulites of the supracrustal rocks discussed for the Jequié-Mutuípe-Maracás Domain, in the amphibolites of the Ipiau Domain, radiometric dates by the Sm/Nd method were also obtained. The model ages found, like for the basic granulites already discussed, also show poliphasic evolution (see chapter IV).

. *Quartzo-feldspathic bands* generally have fine to medium grained texture, sometimes showing a coarse graphic texture formed by quartz and K-feldspar. Late remobilizations are observed in the form of small veins both parallel to and crosscuting the foliation. They are mostly composed by quartz and sometimes perthitic microcline. Plagioclase is scarse and observed as small sericitized crystals (Table II.1). These bands represent a type of occurrence similar to the quartzo-feldspathic bands of the weakly migmatized zones of the Jequié-Mutuípe-Maracás Domain, previously described.

In the transition from the Ipiau Domain to the Atlantic Coast Domain described below, one can observe the transformation of the amphibolite bands into basic granulite bands. Samples of these mafic lithologies, collected along this transition zone, show an increase in the amount of pyroxenes towards the Atlantic Coast Domain as well as greenish-brown hornblende surrounded by pyroxene crystals. These textures reflect dehydration metamorphic reactions of the type:

$$Hb + Qz \rightleftharpoons Opx + Cpx + Plag + H_2O$$

so that it can be assumed that the Ipiau Domain amphibolite facies rock were formed during progressive metamorphism. However, hornblendes around pyroxenes are interpreted as retrograded (Barbosa, 1986, 1992, in print).

It is worthy to record that in the Ipiau Domain migmatite occurences are also observed (Barbosa, 1991) and granites with or without deformation that, according to their mineral assemblage never reached the granulite facies.

ATLANTIC COAST DOMAIN

This domain encompasses part of the so called Itabuna Block (Pedreira et al., 1975), or Atlantic Coast Mobile Belt (Costa & Mascarenhas, 1982). Like the enderbites, charno-enderbites and charnockites of the Jequié-Mutuípe-Maracás Domain the rocks of the Atlantic Coast Domain are rather difficult to be distinguished one from the other during geological mapping. They are rather homogeneous, greenish gray coloured and their texture in general is fine to medium grained. With geochemical and petrographic support it was possible to distinguish three main rock groups with distinct features.

It is worth noting that Barbosa (1991, 1992) found quartzitic rocks, kinzigites, iron formations, baryte and manganese layers, not described in this review, associated to intermediate granulites of this domain.

Biotite-rich basic granulites

These rocks crop out in the western part of the Atlantic Coast Domain. They are black coloured and have a recrystallized fine grained texture; because the rocks are very homogeneous it is difficult to identify the foliation. In some outcrops, biotite flakes either scattered in the rock, or oriented parallel to the vertical foliation that predominate in the domain (F_2; Costa & Mascarenhas, 1982; Barbosa, 1986) are observed. These basic granulites are composed by strongly antiperthitic plagioclase, mesoperthite, orthopyroxene, clinopyroxene and red biotite, this latter mineral in thermodynamic equillibrium with the orthopyroxene (Barbosa, 1986). Quartz, apatite, zircon and ilmenite are common accessory minerals (Table II.1). In some outcrops antiperthitic plagioclase phenoclasts are observed. These phenoclasts are deformed and oriented parallel to the rock foliation, suggesting a plutonic origin for these granulites. Sm-Nd model-ages around 2.4 Ga suggest this age as the epoch of extraction of the material from the mantle (see chapter IV).

Basic, intermediate and acid granulites

These rocks, of dark green colour, medium grained and rather homogeneous character predominate in the Atlantic Coast Domain (Fig. II.1). They are strongly sheared in the ductile state, resulting in the development of a clearly gneissic texture recorded by milimetre to centimetre thick bands of light colour (plagioclase predominating upon the pyroxenes) that alternate with dark ones (large amount of pyroxenes). The grain size is uniform and the contacts between the grains are rather straight. Good exemples of polygonal textures are observed in the basic granulites. These granulites are composed essentially by plagioclase, orthopyroxene-clinopyroxene, with red biotite and greenish brown hornblende. The intermediate granulites and especially the felsic ones are distinct from the basic granulites due to their higher percentage of plagioclase, antiperthite, quartz, opaque minerals and smaller amount of pyroxene. They are devoid of hornblende, but myrmekite appears in some thin sections (Table II.1). In outcrop these granulites sometimes show coarse grained texture, similar to that of the plutonic rocks. This texture is still visible despite the deformations associated with the metamorphism. In these cases, large (0.5 - 1.0 cm) plagioclase phenoclasts (An_{55} for the intermediate granulites) deformed and oriented parallel to the foliation/banding of the rock are noticed. These phenoclasts are surrounded by smaller plagioclase crystals (An_{40-44}). Two distinct orthopyroxene-clinopyroxene couplets are sometimes identified in these samples: one with larger crystals; other with smaller ones. The coarser ones are sometimes zoned and have a greater amount of exsolution flakes than the finer ones; in a few cases they contain euhedral crystals of plagioclase. From the geothermometric point of view, they show temperatures in the center of the large crystals near to 950°C . The finer ones are more homogeneous and their crystallization temperatures are around 830°C . The coarser couplets are considered to be plutonic with partial re-equilibrium due to the granulitic metamorphism. The finer couplets are assumed to be metamorphic (Barbosa, 1991). The modal analysis of the rocks using the Streckeisen (1976) diagram, show that they could have been gabbros and/or basalts, andesites-dacites and/or tonalites and rhyolites and/or trondhjemites, before the granulite metamorphism. Using the Sm-Nd T_{DM} model age method, an age range between about 2.6 and 2.9 Ga has been attributed to these rocks (see chapter IV).

Basic granulites with garnet

These rocks crop out in the easternmost part of the Atlantic Coast Domain (Fig. II.1). They are of greenish-black colour, medium grained textured and with the same deformational features of those described earlier. They are composed of plagioclase, orthopyroxene, clinopyroxene and garnet with irregular edges, related to retrometamorphic phenomena that formed reactional symplectitic coronas of plagioclase and vermicular pyroxene (Barbosa, 1986, 1988). Biotite, hornblende and quartz are rarely found. The accessory minerals are ilmenite and zircon. Preliminary Sm-Nd model-age data have shown that these rocks may have been formed around 2.9 Ga ago (see chapter IV).

GEOCHEMICAL CHARACTERIZATION

The lithogeochemical studies using major and trace elements and rare earths (REE), particularly those considered to be of low mobility or even inert during metamorphic processes, have provided means of identifying the characteristics of the pre-granulitization protoliths and thus the magma types that generated them, besides the degree of evolution of their differentiation. Additionaly, the identification of the protoliths, has made it possible to map these rocks according to their original nature and devise geotectonic models to explain the evolution of this part of the lower continental crust of Bahia (Figueiredo, 1989; Barbosa, 1990, 1992).

JEQUIÉ-MUTUÍPE-MARACÁS DOMAIN

Enderbitic, charno-enderbitic, charnockitic and gabbro- anorthositic plutonic rocks

Enderbitic-charnockitic plutonic rocks of the Laje-Mutuípe region and gabbro-anorthositic rocks

Recent studies of major and trace elements as well as REE in a large number of samples (Fornari, 1992) have suggested that the Laje and Mutuípe enderbitic, charno-enderbitic and charnockitic plutonic rocks are actually two different sequences and not one as interpreted by Barbosa (1986), Barbosa & Fonteilles (1989) and Fornari & Barbosa (1992). Thus, both high Ti and low Ti enderbite-charno-enderbite-charnockite sequences are present (Figs. II.2, II.3 and II.4). In the high-Ti sequence the amounts of brown hornblende and opaque minerals, both titanium rich, are higher (Fornari, 1992). The distinction in the field between these two sequences has not been possible owing to the dearth of outcrops and to the difficulty of their macroscopic differentiation since they occur (i) mixed in different proportions and (ii) their mineralogical composition is very similar. However, it can be noticed that roughly, the high Ti sequence predominates to the west, while the low Ti sequence predominates to the east of Mutuípe (Fig. II.1). A calc-alkaline affiliation is found for both sequences (e.g., Brown, 1982). This trend is also recorded in the REE patterns. The high Ti sequence is richer in REE than the low Ti one (Fornari, 1992.; Fig. II.5).

Data points for the gabbro-anorthosites are displaced from the trends of the other plutonites (Fig. II.2, II.3). This appears to indicate that these rocks were generated from another magma type. In fact, the tholeiitic characteristic of these rocks (Fig. II.5) has been demonstrated by Cruz (1989; Table II.2).

Charnockitic plutonic rocks of the Maracás region

The olivine-bearing charnockitic rocks studied by Marinho (1991) in the western part of this domain, south of Maracás are chemically different from the two sequences previously described. The Maracás charnockitoids have higher concentrations of alkalis, ranging from 7 to 9.5 %, as well as Y (60 to 115 ppm), Nb (18 to 55 ppm) and Zr (400 to 1000 ppm), thus suggesting an alkaline affiliation (Table II.2). The diagrams of Figs. II.2, II.3, II.4 and II.5 display the geochemical differences between the plutonic rocks of the eastern and western part of this domain (Fig. II.1).

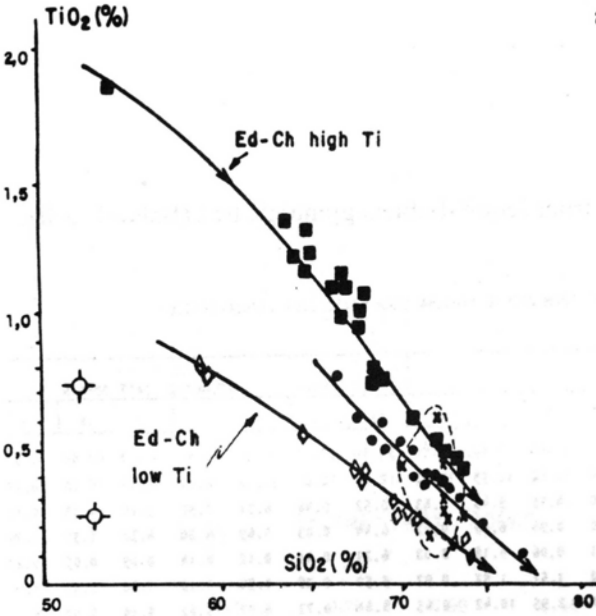
Finally, the petrochemical characteristics of these rocks appear to suggest that these three plutonic suites were formed from enderbitic-charnockitic liquids and that the granulite metamorphism did not superimpose important chemical transformation.

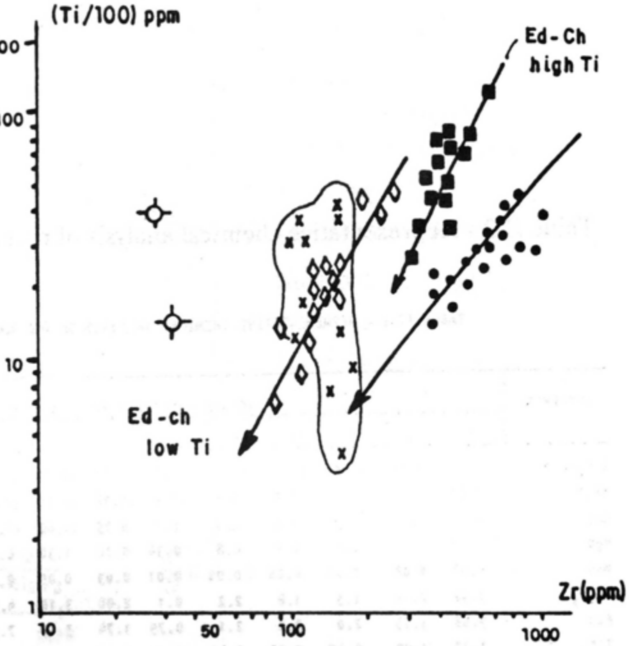
Ortho- and paraderived rocks metamorphosed in granulite facies

. *Basic granulite bands* - these rocks, according to the geochemical diagram of Garrels and Mackenzie (1971) are in the field of igneous rocks (Fig. II.6). Their REE patterns are relatively flat (Fig. II.7) and they have a Y/Nb ratio close to 3, high concentration of Ti, Fe, Cr as well as low concentrations of K_2O, Al_2O_3 and P_2O_5 (Table II.2). These chemical features suggest that these rocks may have been tholeiitic ocean floor or back arc basin basalts and/or gabbros (Fig. II.8, II.18; Barbosa, 1990, 1991).

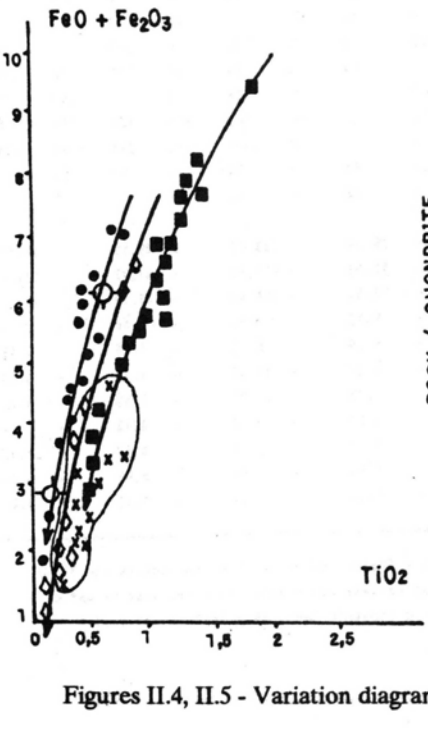
. *Quartzo-feldspathic bands* - are in the field of sedimentary rocks in the Garrels and Mackenzic (1971) diagram (Fig. II.6). However, the determination of its original nature has been a complex task. When the amount of mesoperthite instead of antiperthitic plagioclase is high, their chemical composition is similar to that of feldspathic arkoses, although their persistence and compositional uniformity (over 300 m) do not exclude a magmatic origin, such as acid tuffs (Barbosa, 1986; Barbosa & Fonteilles, 1989) or even aplitic granites. When the opposite occur, that is, antiperthitic plagioclase predominates instead of mesoperthite, they may have been graywackes or even dacites and/or tonalites, that are tectonicaly intercalated with earlier basic rocks, owing to the intense deformations simultaneous with the regional metamorphism. Table II.2 shows the average chemical composition of these quartzo-feldspathic rocks.

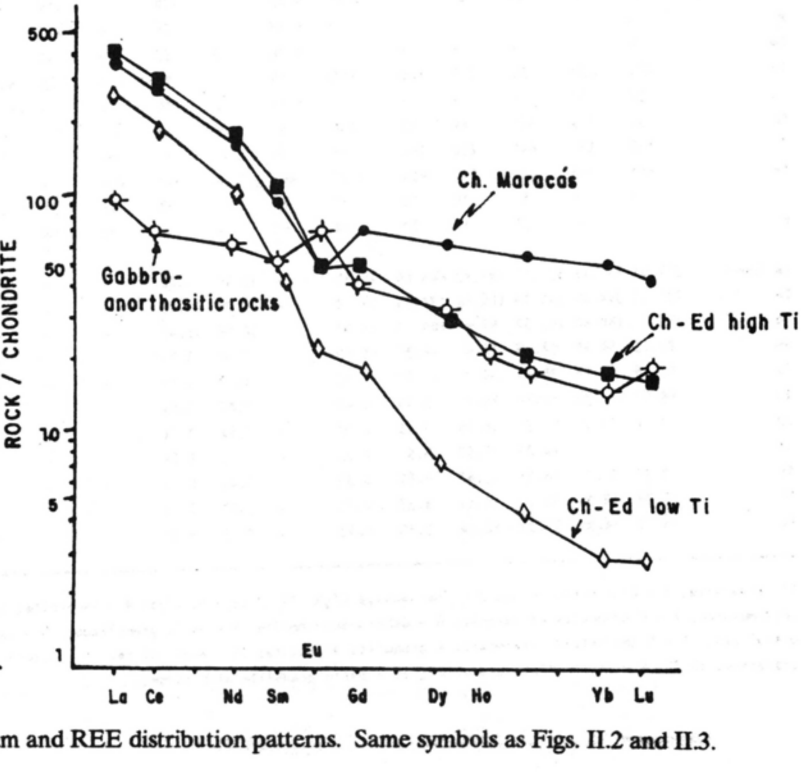
. *Kinzigites* - probably resulted from the granulitization and migmatization of pelitic layers. The points representing these rocks are in the sedimentary field (Fig. II.6). Their mineralogy reflects their chemical composition: they contain more than 40 % garnet when the amounts of total iron and alumina are greater than 15 and 16 %; when the Al_2O_3 concentrations are higher than 16 %, sillimanite also appears in the primary metamorphic paragenesis, thus indicating that the pressure and temperature of metamorphism in the region were relatively homogeneous (Barbosa & Fonteilles, 1986; Barbosa, 1986). The composition of a typical kinzigite from this Jequié-Mutuípe-Maracás domain is shown in Table II.2.





Figures II.2, II.3 - Variation diagrams for: Enderbite-charnockite sequences of Laje and Mutuípe (■) (◊); Charnockitic sequence of Maracás (●); Gabbro-anorthositic rocks (-◊-); Granulitic migmatites and ortho-derived (or anatectic?) charnockites (x).





Figures II.4, II.5 - Variation diagram and REE distribution patterns. Same symbols as Figs. II.2 and II.3.

Table II.2 - Representative chemical analysis of rocks from Jequié-Itabuna granulitic belt (Bahia-Brazil).

TABLE II-2 - REPRESENTATIVE CHEMICAL ANALYSIS OF THE ROCKS FROM JEQUIÊ-ITABUNA GRANULITIC BELT (BAHIA-BRAZIL)

ELEMENTS	JEQUIÊ-MUTUÍPE-MARACÃS DOMAIN												IPIAU DOMAIN		ATLANTIC COAST DOMAIN				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2 (wt%)	65.29	66.88	72.5	64.8	67.5	73.9	73.89	51.70	50.20	71.48	48.82	73.94	50,10	77.28	57.93	53.90	61.10	67.84	50.57
Al_2O_3	12.87	12.27	12.4	15.9	15.1	13.9	13.98	25.20	12.80	12.82	12.39	13.52	12.06	12.87	13.96	16.60	15.30	16.10	16.77
CaO	4.2	3.13	1.3	4.2	2.9	1.2	0.75	11.60	11.40	4.35	9.45	1.63	10.52	0.46	6.31	7.90	5.40	4.03	10.33
MgO	1.07	0.9	0.4	2.2	0.8	0.34	0.20	1.30	6.70	0.96	6.58	0.27	6.44	0.09	5.69	4.50	4.30	1.39	5.79
MnO	0.08	0.08	0.06	0.08	0.04	0.01	0.03	0.05	0,21	0,06	0.18	0.02	6.21	0.01	0.12	0.14	0.09	0.05	0.27
Fe_2O_3	3.96	2.16	1.5	1.8	2.2	0.1	2.00	3.10	4.90	1.51	1.52	0.92	5.50	0.98	0.54	3.10	1.50	0.57	0.01
FeO	3.58	3.75	2.0	2.2	2.1	0.79	1.74	3.15	7.50	2.95	10.42	0.65	8.64	0.72	6.07	5.62	5.19	2.50	14.05
TiO_2	1.23	1.00	0.47	0.55	0.45	0.13	0.30	0.76	1.30	0.62	2.60	0.23	1.78	0.37	1.07	1.20	0.93	0.40	1.04
P_2O_5	0.48	0.31	0.1	0.38	0.25	0.08	< 02	0.03	0.11	0.12	0.95	0.25	0.10	0.04	0.77	0.54	0.25	0.16	0.12
Na_2O	3.17	2.79	2.9	4.4	4.1	3.5	3.00	2.94	3.09	2.27	2.43	3.40	3.10	1.85	3.18	3.81	4.60	4.94	1.36
K_2O	3.26	4.95	5.6	2.8	3.1	5.5	5.00	0.39	0.90	4.98	4.60	4.50	0.91	4.95	4.47	1.26	1.30	1.78	0.50
	99.19	98.22	99.23	99.31	98.54	99.43	100.80	100.22	99.11	101.65	99.94	99.33	99.36	99.61	100.32	99.66	99.96	99.76	100.81
V (ppm)	-	-	-	-	-	-	< 20	-	290	-	174	-	320	-	-	160	144	-	-
Cr	27	24	< 20	32	-	< 20	< 25	-	230	33	210	20	160	55	-	180	37	118	-
Ni	-	-	-	-	-	-	< 10	-	76	-	117	18	95	20	81	56	19	-	83
Co	-	-	-	-	-	-	< 10	9	35	-	41	-	60	144	-	26	12	-	-
Sr	287	293	90	710	680	440	39	-	99	-	229	405	143	22	1125	-	320	-	90
Cu	37	33	-	-	-	-	< 10	52	20	10	31	< 10	80	10	34	26	18	10	61
Rb	92	113	360	64	58	210	162	16	18	199	161	190	-	102	226	17	-	187	10
Zr	400	372	610	250	740	93	449	16	60	344	-	70	90	197	307	200	180	104	78
Ba	1448	2165	670	910	1470	1520	942	-	110	816	-	-	275	233	3500	1180	740	1503	123
Y	-	-	91	30	10	12	89	-	48	28	51	24	52	19	51	32	24	36	-
Nb	-	-	35	10	20	12	42	-	-	13	18	9	28	13	13	-	-	8	-
La (ppm)	307.93	420,37	571,68	191,49	265.66	70.48	-	19.66	10.02	-	-	-	16.04	-	233.88	-	29.95	-	10.56
Ce	229.99	304.26	340.33	166.48	192.35	54.29	-	43.09	21.75	-	-	-	32.99	-	438.80	-	51.72	-	23.06
Nd	143.67	180.88	165.57	97.4	100.13	25.43	-	30.46	15.64	-	-	-	20.97	-	225.80	-	27.33	-	11.76
Sm	83.25	98.50	98.18	56.6	44.35	13.99	-	7.50	3.71	-	-	-	4.15	-	43.62	-	5.88	-	3.11
Eu	57.48	57.28	29.44	30.33	21.89	11.23	-	3.23	1.11	-	-	-	1.20	-	6.33	-	1.06	-	1.05
Gd	45.91	51.98	55.46	29.47	19.63	6.46	-	7.87	3.88	-	-	-	4.07	-	21.82	-	4.23	-	3.62
Dy	27.78	30.14	49.35	16.09	7.75	2.68	-	6.62	3.71	-	-	-	4.08	-	11.75	-	2.89	-	4.29
Ho	-	-	46.29	14.57	5.9	2.33	-	1.25	0.84	-	-	-	0.80	-	2.10	-	0.42	-	-
Er	19.39	20,7	46.35	13.67	4.82	2.03	-	3.63	2.24	-	-	-	2.67	-	5.18	-	0.87	-	2.55
Yb	17.38	18.35	42.22	10.54	3.33	1.39	-	3.07	2.04	-	-	-	2.43	-	3.69	-	0.86	-	3.00
Lu	15.75	16.94	37.34	12.96	3.35	4.13	-	0.49	0.31	-	-	-	0.34	-	0.49	-	0.15	-	0.44

1 - Enderbite; 2 - Charno-enderbite; 3 - Charnockite Hight Ti of Laje-Mutuípe; 4 - Enderbite; 5 - Charno-enderbite; 6 - Charnockite Low Ti of Laje-Mutuípe; 7 - Charnockite of Maracás; 8 - Gabbro-anorthosite; 9 - Mafic granulites; 10 - Quartz-feldspatic band; 11 - Restites of mafic granulites; 12 - Orthoderived charnockite - granulite migmatite; 13 - Amphibolite; 14 - Quartz-feldspathic band; 15 - Basic-biotite rich granulite; 16,17,18 - Intermediate granulite; 19 - Basic granulite with garnet.

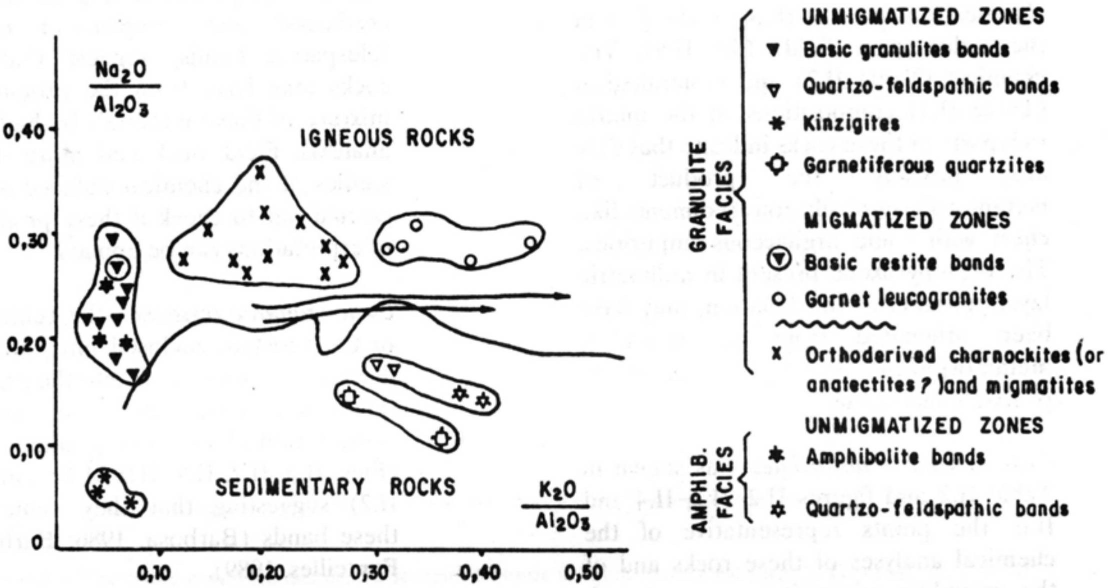


Figure II.6 - Supracrustal rocks of the Jequié-Mutuípe-Maracás and Ipiau Domains plotted on the diagram used to differentiate sedimentary from igneous rocks (diagram after Garrels and Mackenzie, 1971). Arrows indicate differentiation trends of the charnockitic-enderbitic sequences of Laje and Mutuípe.

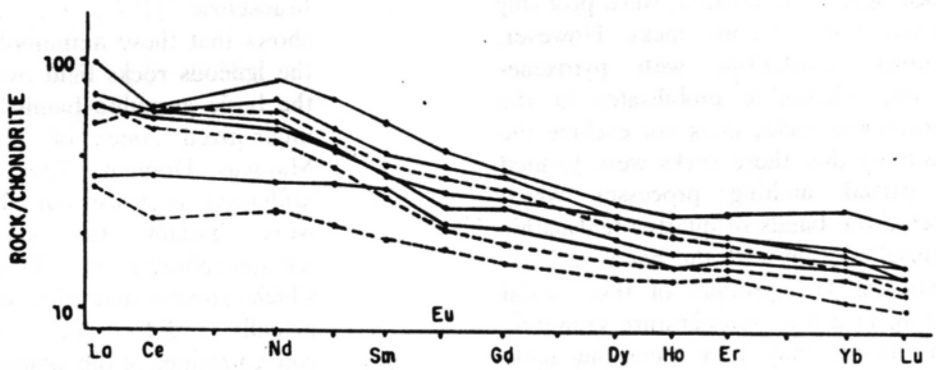


Figure II.7 - REE patterns of the basic granulite bands, basic restite bands (Jequié-Mutuípe-Maracás-Domain) and amphibolite bands (Ipiaú Domain) showing similarities with tholeiitic rocks. Heavy line: basic granulite bands and basic restite bands (unmigmatized zone and migmatized zones). Broken line: amphibolite bands.

. *Orthopyroxene-bearing garnetiferous quartzites and other quartzites* - the chemical analyses of these rocks plot in the sedimentary field (Fig. II.6). The chemical (Table II.2) and mineralogical (Table II.1) compositions of the quartz rich parts of these rocks indicate that they are possibly the product of metamorphism of siliceous sediments like chert with some argilaceous impurities. The orthopyroxene present in milimetric layers parallel to the foliation, may have been originated from the granulitic metamorphism of basic material, probably tuffaceous.

. *Orthoderived charnockites* - as shown in Table II.2 and figures II.2, II.3, II.4 and II.6, the points representative of the chemical analyses of these rocks and of the granulitic migmatites are scattered, while the rocks of the two calc-alkaline sequences, formed by enderbites, charno-enderbites and charnockites (Laje-Mutuípe) and charnockites (Maracás), show often a certain regularity in their distribution. This is a consequence of the fact that, while the plutonic rocks (Laje, Mutuípe and Maracás) form a differentiated magmatic lineage, these rocks and the migmatitic granulites seem to represent an intermediate assemblage between the basic and the felsic bands. It is worth noting that the charnockitic rocks, here in discussion, were probably derived from igneous rocks. However, chemical similarities with pyroxene-bearing migmatitic mobilisates in the supracrustal rocks, does not exclude the possibility that these rocks were formed by partial melting processes which affected the bands of quartzo-feldspathic material coevally with the bands of basic granulites. The product of this partial melting in a high temperature granulitic environment may have been an early formed charnockitic anatectic magma generated where the fluid pressure was adequate. The intermediate position of the samples of these charnockites and mobilized parts of the migmatites between samples of basic granulite bands (resisters) and samples of quartzo-feldspathic bands, suggest that these rocks may have been the product of a mixture of these materials by high grade anatexis. Field work and more detailed studies of the chemical balance must be carried out to check if these preliminary interpretations can be applied.

. *Basic granulite resisters* - the central part of the resisters enclosed into the ortho-derived charnockites or into the granulitic migmatites have the same chemical composition of the basic granulite bands (Figs. II.6, II.7, II.8, II.9, II.10 and Table II.2) suggesting that they came from these bands (Barbosa, 1986; Barbosa & Fonteilles, 1989).

. *Garnet leucogranites* - these granites have average Na_2O/K_2O ratios of 0.83 and they may be anatectic, since they are found associated to the kinzigites. In Fig. II.6 they plot in the igneous field.

IPIAU DOMAIN

Ortho- and paraderived rocks metamorphosed in amphibolite-facies

. *Amphibolite bands* - the Garrels and Mackenzie (1971; Fig. II.6) diagram shows that these amphibolites cluster in the igneous rocks field overlapping with the basic granulite bands of the weakly migmatized zones of Jequié-Mutuípe-Maracás Domain. This compositional affiliation suggests that all these rocks were initially the same material, metamorphosed in different grades, which shows that the metamorphism actually did not change the concentrations of the elements Na, K and Al. In Fig. II.7 it can be seen that they could have been tholeiitic and, in Figs. II.8 and II.18, that they could have been an ocean floor or back arc basin basalt

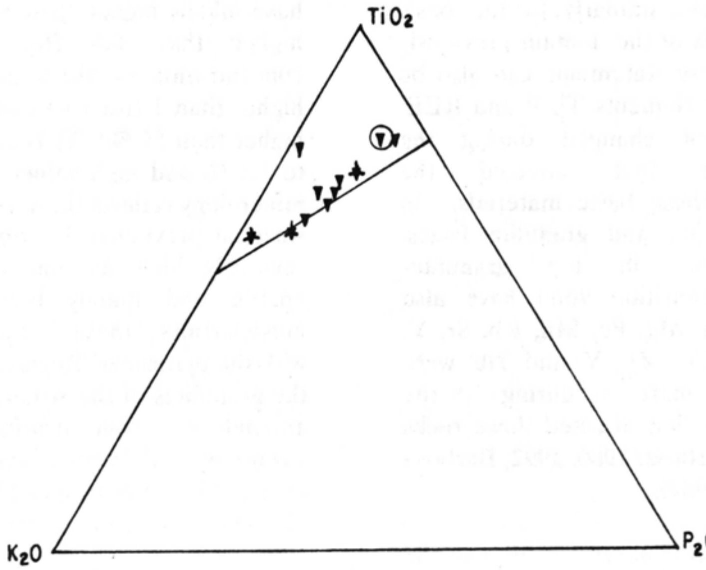
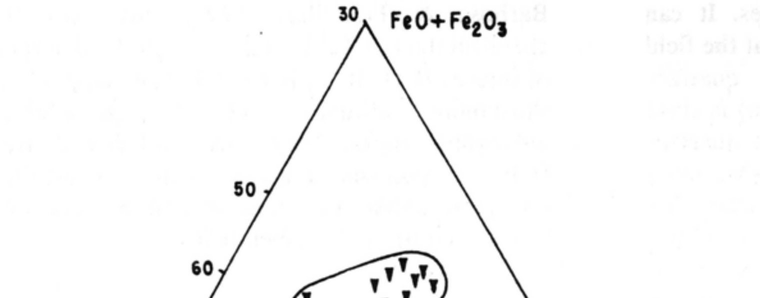
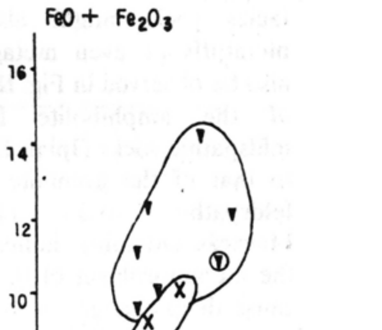


Figure II.8 - The basic granulite bands, basic restite bands (Jequié-Mutuípe-Maracás Domain) and amphibolite bands (Ipiaú Domain) plotted on the field of ocean floor basaltic-gabbroic rocks (diagram after Pearce et al., 1975). Symbols as in Fig. II.6.





Figures II.9, II.10 - The charnockites associated to supracrustal rocks of the Jequié-Mutuípe-Maracás Domain seems to be ortho-derived; however the diagrams above show that is not entirely discarded the possibility that these rocks and mostly the granulitic migmatites, be originated from the mixture of basic granulite bands with quartz-feldspathic bands. Symbols as Fig. II.6.

and/or gabbros, similarly to the basic granulite bands of the domain previously described. These statements can also be applied to the elements Ti, P and REE, that were not changed during the metamorphism that affected the protoliths of these basic materials, in both amphibolite and granulite facies. Similar studies in the granulite-amphibolite transition zone have also shown that Ca, Mg, Fe, Mn, Rb, Sr, V, Cr, Ni, Co, Cu, Zr, Y and Nb were practically inert during the metamorphism that affected these rocks (Table II.2; Barbosa, 1986, 1992; Barbosa & Fonteilles, 1989).

. *Quartzo-feldspathic bands* - similar to the mesoperthite rich quartzo-feldspathic bands of the granulite facies, these amphibolite facies microcline-rich quartzo-feldspathic bands are comparable to arkosic sediments. Taking into account their chemical similarity to feldspathic arkoses, these amphibolite-facies rocks might also be rhyolitic metatuffs or even metagranites. It can also be observed in Fig. II.6, that the field of the amphibolite facies quartzo-feldspathic rocks (Ipiau Domain) is close to that of the granulite facies quartzo-feldspathic rocks (Jequié-Mutuípe-Maracás Domain), indicating again that the metamorphism of the region did not cause deep changes in the Na, K and Al concentrations. Relative to other major and trace elements, similar studies carried out on these felsic rocks in the amphibolite-granulite transition zone also show that there was no great changes in their concentrations (Table II.2; Barbosa, 1986, 1992; Barbosa & Fonteilles 1989).

ATLANTIC COAST DOMAIN

Biotite rich basic granulites

Regarding major elements, these rocks have alkalis higher than 5 %, K_2O/Na_2O ratios higher than 0.6 (for rocks with SiO_2 concentration of about 50 %) and K_2O/Na_2O higher than 1 (for rocks with silica concentration higher than 55 %), TiO_2 amounts ranging from 1 to 1.5 % and high values of P_2O_5 (0.8 %). The mineralogy reflects these chemical concentrations since, as previously described, these rocks have a relatively high amount of ilmenite-magnetite, apatite and mainly biotite, antiperthite and mesoperthitic, these latter ones in equilibrium with the pyroxenes. Regarding the trace elements, the granulites of the Atlantic Coast Domain have anomalous concentrations of zirconium, strontium and barium, the latter two probably included into the antiperthites and mesoperthites (Table II.1; Barbosa, 1991).

The chemical analyses of these metamorphic rocks when used in discrimination diagrams for plutonic rock classification plot in the monzonite and quartz-monzonite fields (Barbosa, 1991; Arcanjo et al., 1991, in print). However, if the discrimination diagrams used are those for volcanic rocks, they plot in the shoshonitic field (Barbosa, 1986, 1990, 1991; Barbosa & Fonteilles, 1989). Not only the chemical data of Table II.2, but also the diagrams of figures II.11, II.12, II.13 and II.14, support the shoshonitic affiliation of the granulitized monzonitic rocks. They are probably derived from a potassic magma with calc-alkaline tendency, unlike the calc-alkaline magma that formed the rocks described below.

Basic, intermediate and acid granulites

Figure II.11, a graph that uses K_2O vs SiO_2, adapted from Ewart (1982) and figure II.15, a triangular diagram using total Fe vs Al_2O_3 vs MgO (Fonteilles, 1976), show that the points representative of the chemical analyses of the so called basic, intermediate and acid granulites are relatively well distributed in the island arc calc-alkaline field (Barbosa, 1986, 1989, 1990, 1991; Barbosa & Fonteilles, 1989). This continuous chemical distribution is shown by the mineralogy: the intermediate granulites of chemical composition similar to andesitic basalts/diorites

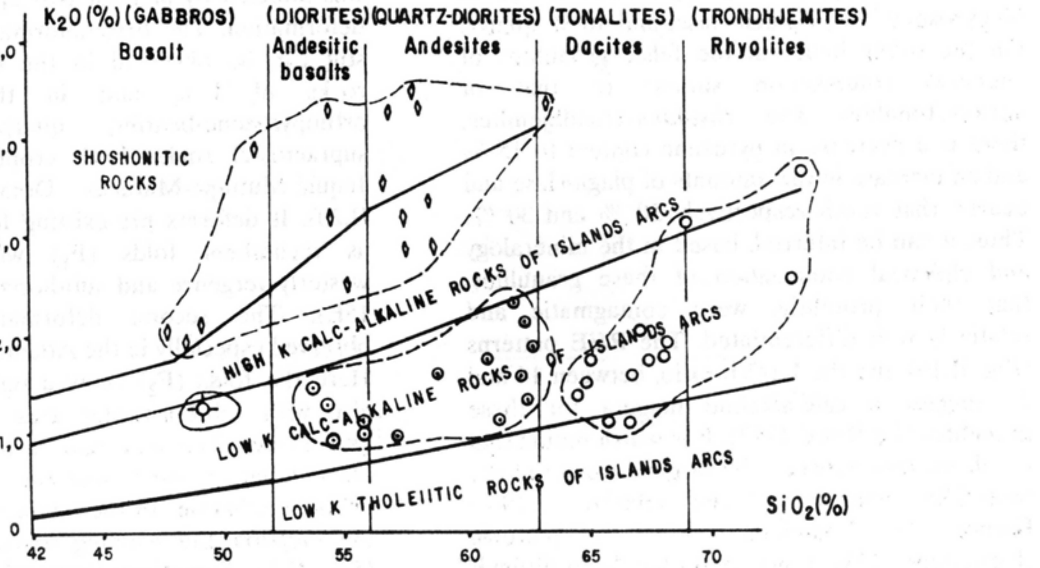
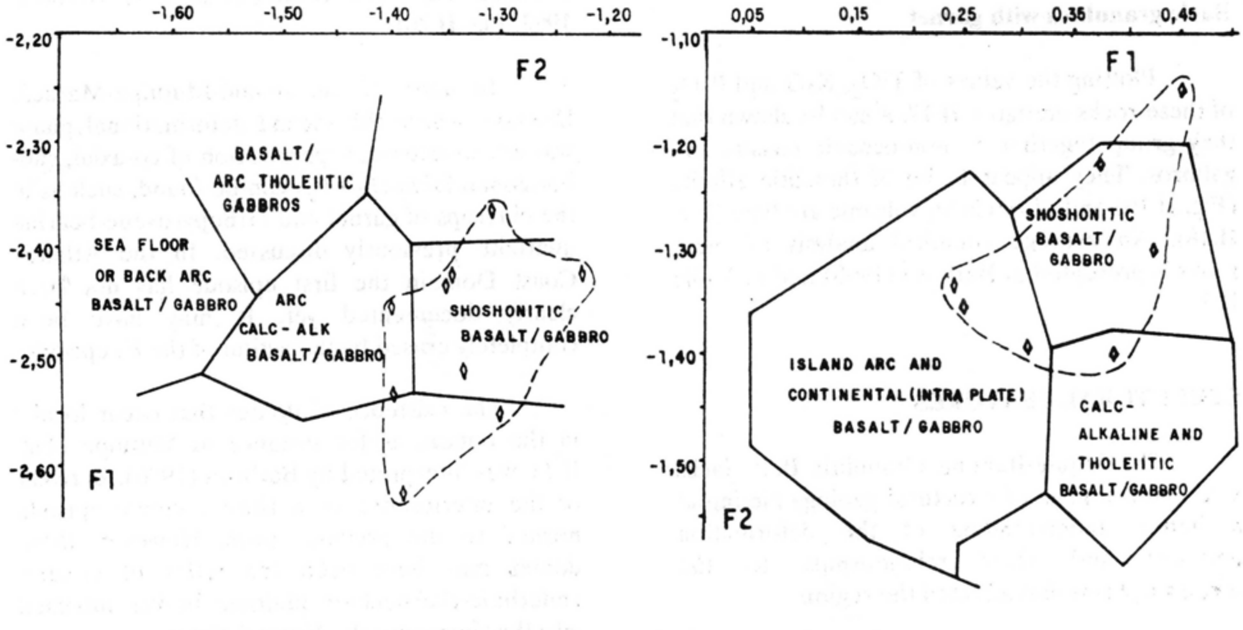


Figure II.11 - The biotite-rich basic granulites (◊) plot in shoshonitic field. The basic (-◊-), intermediate (⊙) and acid (○) granulites plot in the low K island arc type calc-alkaline rock field (Atlantic Coast Domain). Diagram adapted from Ewart (1982), after Thorpe (1982).



Figures II.12, II.13 - The biotite-rich basic granulites also plot in the shoshonitic field of the diagrams. To identify the discriminant functions F_1 and F_2, see Pearce (1976). Symbols as Fig. II.11.

and andesites/quartz-diorites, contain about 40 % pyroxene, 50 % plagioclase, and 10 % quartz. On the other hand, in the felsic granulites of chemical composition similar to that of dacites/tonalites and rhyolites/trondhjemites, there is a decrease in pyroxene content to 15 % and an increase in the amounts of plagioclase and quartz, that reach respectively 50 % and 30 %. Thus, it can be inferred, based in the mineralogy and chemical composition of these granulites, that their protoliths were comagmatic and relatively well differentiated. The REE patterns (Fig. II.16) and the La/Yb ratio, between 14 and 21 suggest a calc-alkaline magma for these granulites (Le Roex, 1987). It is worth noting that the distinction between the original nature of the protoliths, wheter volcanic (Barbosa, 1986; Barbosa & Fonteilles, 1989) or plutonic (Figueiredo, 1989; Silva, 1991) has been difficult in the granulite facies environment. Due to these difficulties, this compilation and Barbosa (1990, 1991, 1992) have given priority only to showing that the magma type is clearly low-K calc-alkaline, setting aside discussions that try to classify these rocks as volcanic or plutonic previous to the granulitization.

Basic granulites with garnet

Plotting the values of TiO_2, K_2O and P_2O_5 of these rocks on figure II.17, it can be shown that they group together as non-oceanic basalts and gabbros. They appear to be of tholeiitic affinity (Fig. II.19) and of Archean volcanic arc type (Fig. II.18). An average chemical analysis of these rocks is presented in Barbosa (1990) and in Table II.2.

STRUCTURAL FEATURES

The Jequié-Itabuna Granulitic Belt lacks systematic studies of structural geology aiming at a better understanding of the deformation episodes and their relationships to the metamorphism that affected the region.

Based in the present state of knowledge, one can interpret in a simplified way that this belt was affected by at least two episodes of ductile deformation. The first deformational event (F_1) still can be observed in the charno-enderbitic rocks of Laje and in the garnet and orthopyroxene-bearing quartzites of the supracrustal rocks, both cropping out in the Jequié-Mutuípe-Maracás Domain (Fig. II.1, II.20). It deforms pre-existing foliation/banding, as recumbent folds (F_1) with aproximately westerly vergence and sub-horizontal axes (N10-15E). The second deformational event is observed especially in the Atlantic Coast Domain. Here the folds (F_2) show a tight isoclinal style also with sub-horizontal axes and sub-vertical axial planes. This deformation produced an axial plane foliation which sometimes transposes the previous foliation. In the Atlantic Coast Domain the foliation and banding strike close to N20E (Fig. II.1). Sometimes mineral lineations with sub-vertical plunges to 10°-20° SSW are seen which may have been produced by tectonic transport (or may reflect the direction of tectonic transport). It is assumed that the granulitic material, after undergoing maximum compression at the end of the E_2 episode, was displaced at depth in the form of megablocks, conforming to a system of frontal and lateral tectonic ramps (Padilha et al., 1990; Gomes et al., 1991; Barbosa, 1992; Fig. II.20).

In parts of the Jequié-Mutuípe-Maracás Domain, where the second deformational phase was not so intense, superposition of co-axial, sub-horizontal folds ($F_1 + F_2$) can be found, such as in the outcrops of garnet and orthopyroxene-bearing quartzite previously discussed. In the Atlantic Coast Domain the first episode has not been clearly documented yet. It may have been completely erased by the action of the F_2 episode.

The existence of domes that occur locally in the region, as for instance in Mutuípe (Fig. II.1), was interpreted by Barbosa (1986), as result of the interference of a third tectonic episode normal to the previous ones. However, these domes may have been the reflex of circular enderbitic-charnockitic plutonic bodies intruded into the supracrustals (Fornari,1992).

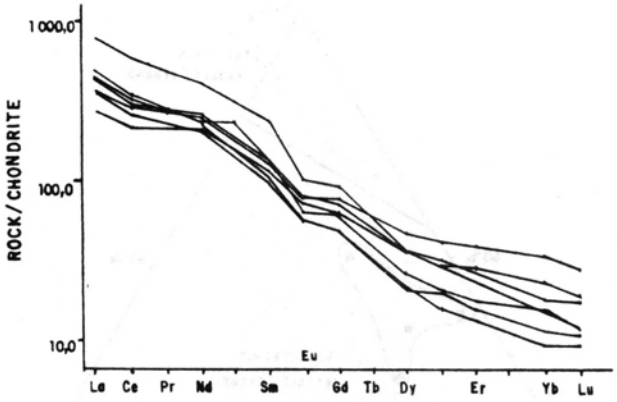


Figure II.14 - REE patterns of the biotite-rich basic granulites confirm the shoshonitic affiliation of these lithologies.

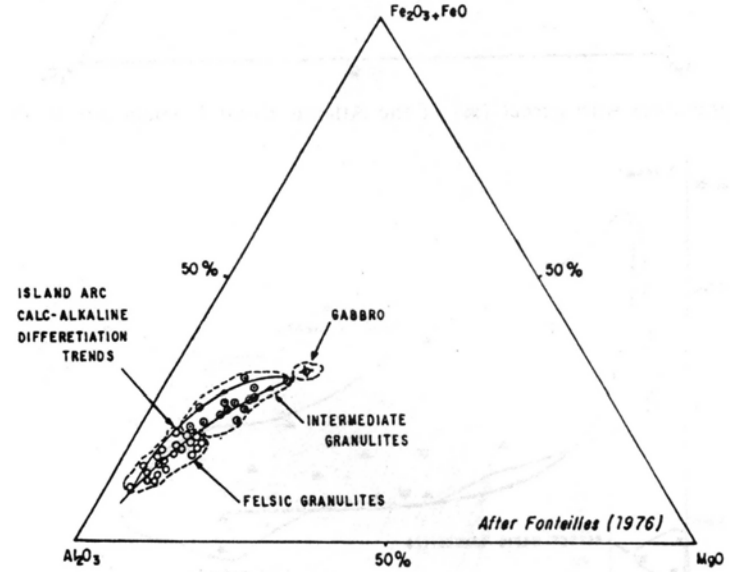


Figure II.15 - Basic, intermediate and felsic granulites of the Atlantic Coast Domain plot on differentiation trends of island arc calc-alkaline rocks. Symbols as Fig. II.11.

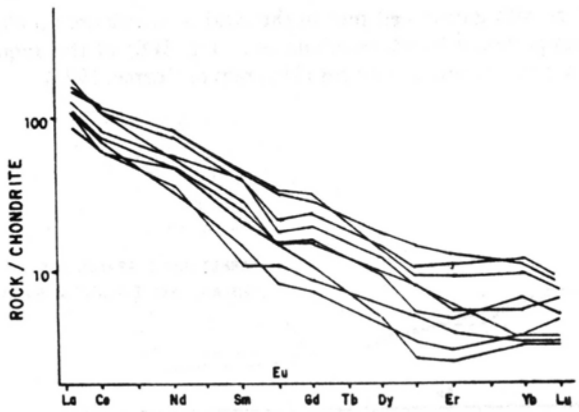


Figure II.16 - REE patterns of the intermediate and felsic granulites of the Atlantic Coast Domain, suggesting a calc-alkaline affiliation for these lithologies.

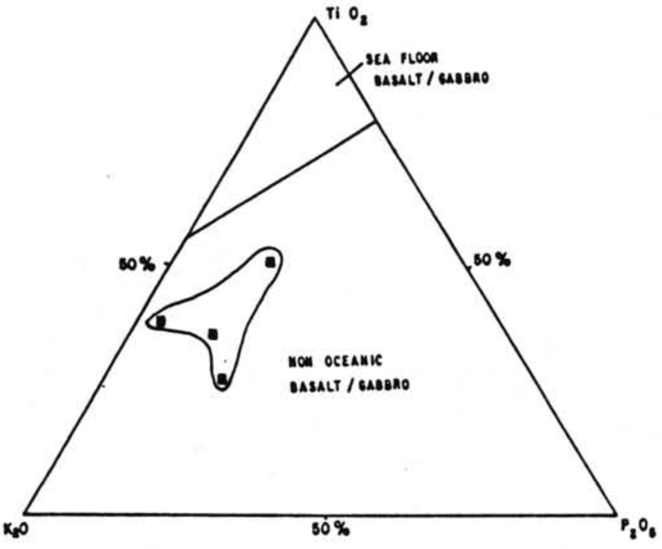


Figure II.17 - The basic granulites with garnet (■) of the Atlantic Coast Domain plot in the field of non-oceanic basalts/gabbros.

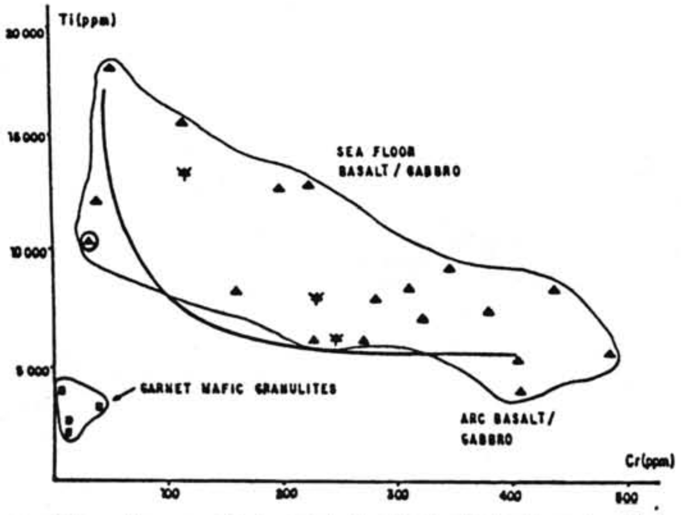


Figure II.18 - The basic granulites with garnet (■) plot in the field of island arc basalts/gabbros. The basic granulite bands, basic restite bands and amphibolite bands (symbols as in Fig. II.6) of the Jequié-Mutuípe-Maracás and Ipiaú Domains, plotted in the field of sea floor basalts/gabbros (Diagram of Pearce, 1975).

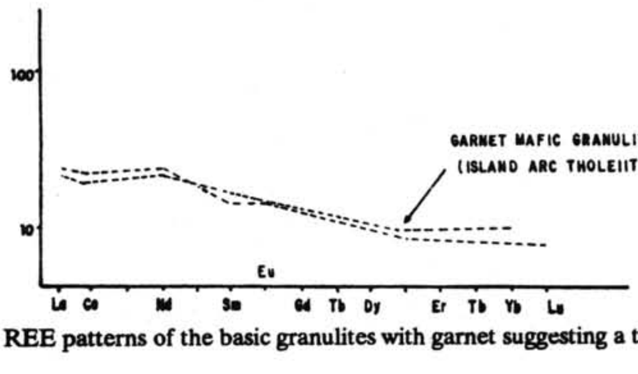


Figure II.19 - REE patterns of the basic granulites with garnet suggesting a tholeiitic affiliation for these rocks.

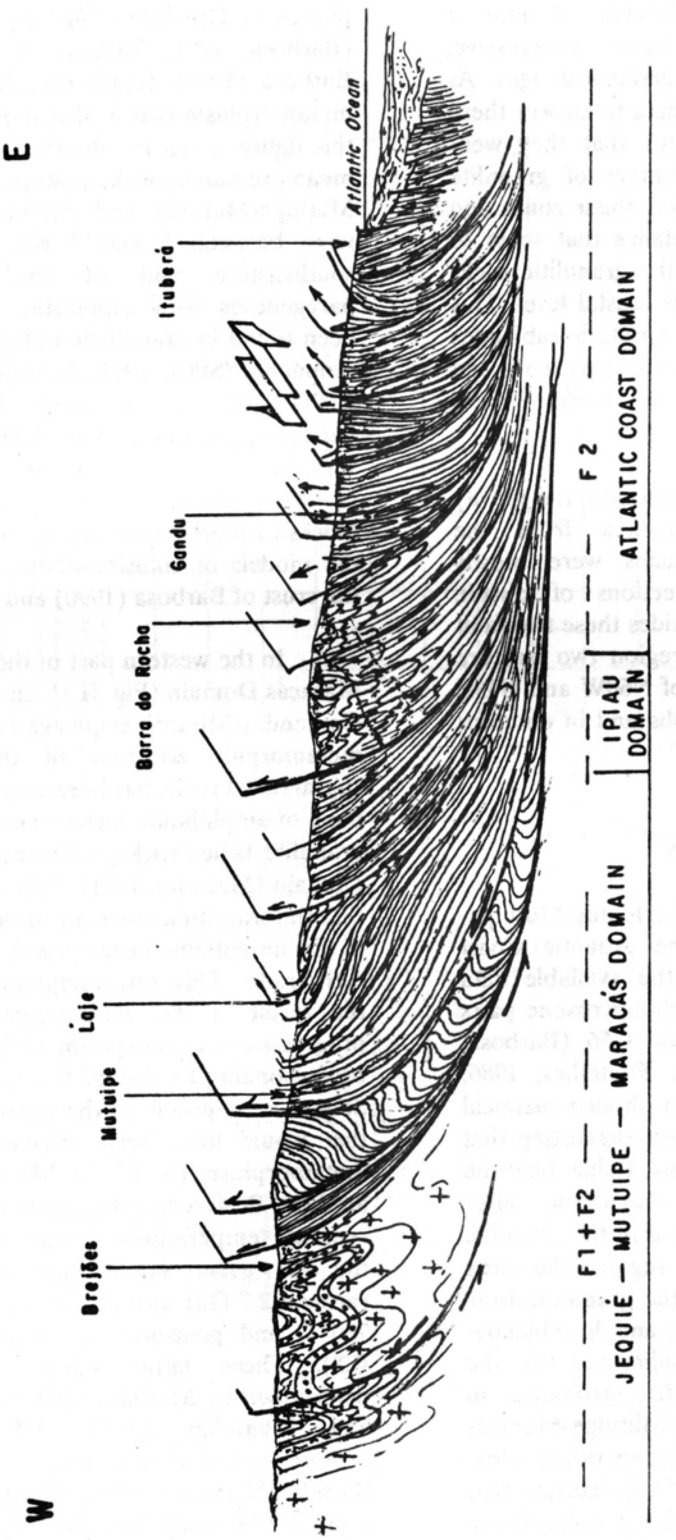


Figure II.20 - Geologic-structural schematic section in the Jequié-Itabuna Granulitic Belt.

The F_1 and F_2 deformations may have been separated by a long interval of time or alternatively may have been progressive, continous and with similar geological ages. At present, there is not enough data to answer these questions. Everything indicates that they were produced in a deep environment of granulite facies. Exceptions occur in N-S shear zones and in certain F_2 transposition planes that seem to have been reactivated when the granulitic rocks were in the amphibolite facies crustal level. This is evidenced by stretched retrograde hornblendes originated from the destruction of pyroxenes and opaque minerals, found on these shear/ transposition planes.

Regarding the brittle tectonics; the gravity faults separating the granulites from the Phanerozoic sedimentary basins were mostly controlled by the two directions of ductile shearing (N20E and N-S). Besides these two fault directions, there are in the region two fracture systems with average strikes of N60W and N45E seen both in aerial photographs and in outcrops (Fig. II.1).

METAMORPHIC FEATURES

In the eastern part of the Jequié-Mutuípe-Maracás Domain and in the Atlantic Coast Domain (Fig. II.1) most of the available data show that the orthopyroxene-clinopyroxene pairs have K_d values of Mg around 0.56 (Barbosa, 1986, 1989, 1990; Barbosa & Fonteilles, 1986, 1992). This reflects the uniform physico-chemical conditions of the metamorphism suggesting that in these parts of the southeast Bahia belt the progressive granulitic metamorphism after reaching its peak, re-equilibrated in the granulite facies most of the rocks of the region. The rocks of the Ipiau Domain escaped the granulitization, presenting undeformed biotite and hornblende-bearing granites and re-equilibrated in the amphibolite facies. Thermometric estimatives in the eastern part of the Jequé-Mutuípe-Maracás and Atlantic Coast domains, based in the Opx-Cpx and Gt-Cpx pairs (Table II.3), indicate that the maximum temperature of the granulite facies reached 830-850°C. Temperatures of 900-1000°C were partially preserved in the center of relict phases of Opx-Cpx from certain plutonic rocks (Barbosa, 1991; Barbosa & Fonteilles, 1992). Barbosa (1990) details the characterists of this metamorphism that is also shown in Fig. II.21. In this figure it can be observed that the estimated mean pressures for the eastern part of the Jequié-Mutuípe-Maracás and Atlantic Coast domains were between 5 and 7 Kb. However, in the southeastern end of this latter domain, parageneses with sapphirine plus quartz have been found in granulitized aluminium magnesian sediments (Silva, 1991; Arcanjo et al., in print; Kienast et al., in prep.; Seixas, in prep.) indicating pressures above 9 Kb. These values, at variance with the regional average, may be related to the tectonic transport of deeper-level blocks to more superficial levels, as envisaged by the models of collision-obduction-duplication of the crust of Barbosa (1990) and figure II.20.

In the western part of the Jequié-Mutuípe-Maracás Domain (Fig. II.1), close to the so called Contendas-Mirante Sequence (see chapter III), a metamorphic zonation of the plutonic and supracrustal rocks has been revealed by a western band of amphibolite facies that contrasts with the granulite facies rocks of the eastern part of this Domain (Marinho, 1991). This author considered that the transition from the granulite facies (east) to the amphibolite facies (west) is gradational and retrograde. This retrometamorphism would be the result of the interference of a (younger) progressive metamorphism of lower grade (M_2) corresponding to that of the Contendas-Mirante Sequence, imposed on the older granulitic rocks, that would have been affected by a previous metamorphism (M_1). The M_2 event would have an Early Proterozoic age (around 2.0 Ga), having reached temperatures around 630±30°C, while the M_1 event would have an Archean age (around 2.7 Ga) with temperatures reaching 750-780°C and pressures of about 6-8 Kb (Table II.3). These latter values were accurately determined by Marinho (1991) using the Bohlen and Boettcher (1981) PT diagram and orthopyroxene-quartz-olivine paragenesis (fayalite 95 and ferrosilite 85) of the charnockites south of Maracás. For the M_1 metamorphism, Marinho (1991) obtained values of K_d of the Mg

Table II.3 - Temperature and pressure estimates for the Jequié-Itabuna Granulitic Belt, Bahia, Brazil.

ROCKS AND ASSEMBLAGES	TEMPERATURES											PRESSURES					
	Wood & Banno (1973)	Wells (1977)	Ellis & Green (1979)	Ganguly (1979)	Krogh (1988)	Newton & Haselton (1981)	Perchuk & Aranovich (1984)	Indares & Martingnole (1985)	Sengupta et. al. (1990)	Harley (1984)	Ganguly & Saxena (1984)	Wells (1979)	Newton & Perkins (1982)	Harley (1984)	Newton & Haselton (1981)	Perkins & Chipera (1985)	Bohlen et.al. (1983)
Basic granulites bands (Opx-Cpx-Plag) (Cores)	847	901															
Basic restites (Opx-Cpx-Plag) (Cores)	811	838															
Garnet leucogranites (Gt-Opx-Plag) (Cores)												5,2	5,9	5,7			
Kinzigites (Gt-Plag) (Cores)						850									4,8		
Basic granulites with garnet (Gt-Cpx-Opx-Plag) (Cores)	827	850	790	870	785							5,8	6,3	6,5			
Basic granulite with garnet (Gt-Cpx-Opx-Plag)	800	837	810	824	790							5,2	6,7	6,2			
Basic granulite with garnet (Gt-Cpx-Opx-Plag) (Cores)	820	845	820	870	795							5,9	7,9	5,1			
Basic granulite with garnet (Gt-Cpx-Opx-Plag) (rims)	748	759	715	725	667							5,8	6,1	4,2			
Basic granulite with garnet (Gt-Cpx-Opx-Plag)(rims)(Gt-Cpx simplectites)	730	735	693	723	626							3,5	3,1	3,5			
Charnockite Maracás (Opx-Cpx-Plag) (Cores)	807	868															
Charnockite Maracás (Opx-Cpx-Plag) (Cores)	810	855															
Quartz-feldspatic band-supracrustal (Gt-Opx-Bi-Plag) (Cores)							797	800			750						
Quartz-feldspatic band-supracrustal (Gt-Opx-Bi-Plag) (Cores)									789								
Quartz-feldspatic band-supracrustal (Gt-Opx-Bi-Plag) (Cores)										828			6,8			8,1	7,5
Garnetiferous quartzites (Gt-Opx-Plag) (Cores)												4,7	6,1	5,1			

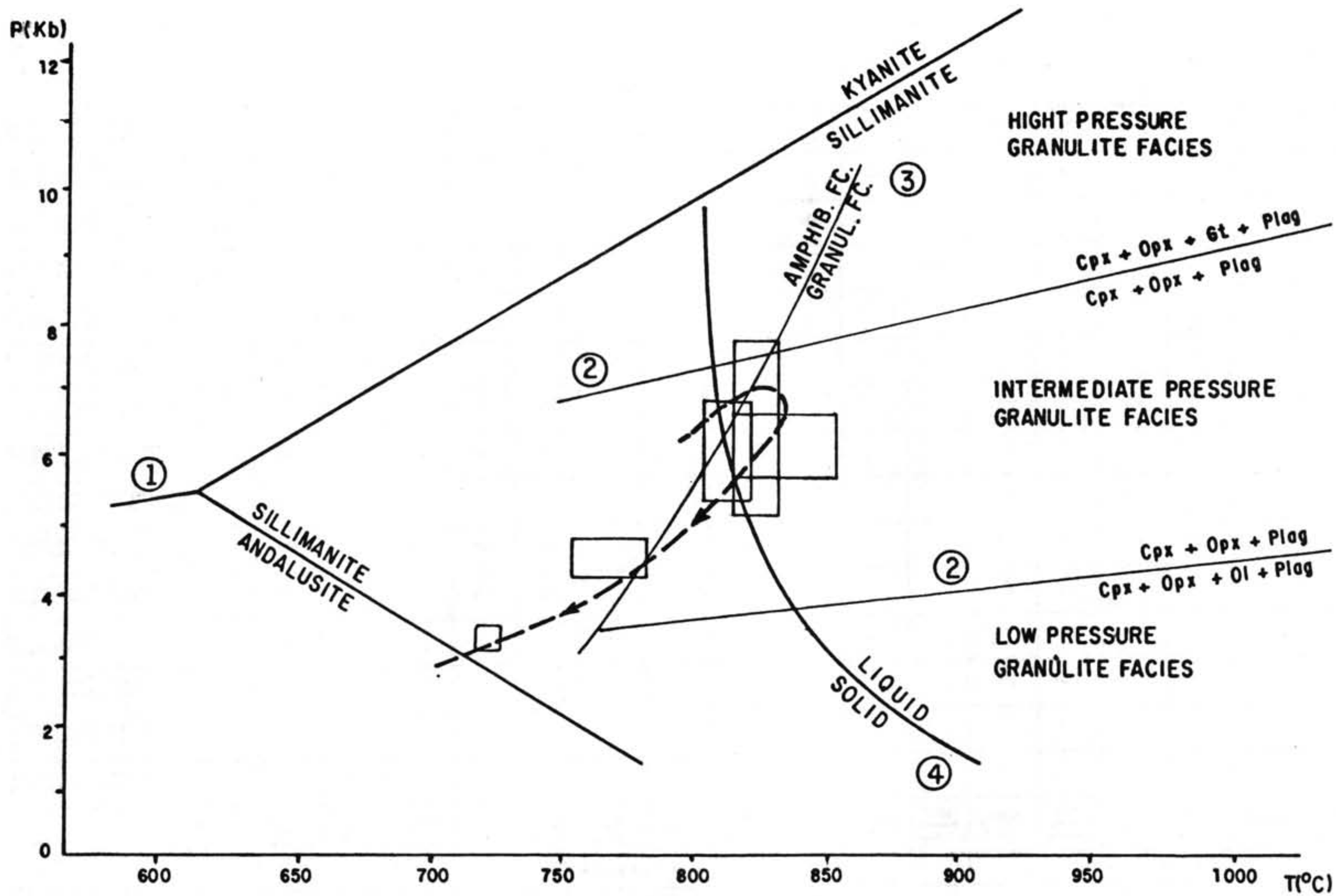


Figure II.21 - Schematic Pressure - Temperature path of the granulites. 1. Al_2SiO_5 stability diagram after Richardson et al. (1969); 2. Granulite facies boundaries after Irving (1974); 3. Hornblende breakdown reaction curve valid for PH_2O ~ 0.3 Pt (Wells, 1979); 4. Beginning of melting of granite under conditions of PH_2O ~ 0.3 Pt (Manna & Sen, 1974). The rectangles represent P-T conditions estimated for studied area samples using different calculation methods (see Table II.3). The broken line represent the proposed path for the metamorphism.

around 0.57 very close to that estimated by Barbosa (1986), stated in the beginning of this item.

In the possibility of the occurrence of two metamorphic events, the 2.7 Ga ages previously cited for the ortho-derived charnockites of the ortho- and paraderived domain located east of Mutuípe, would be related to the M_1 event, while the event around 2.0 Ga, found in the rocks of Jequié, would be associated to the M_2 episode (see chapter IV). On the other hand, it is also possible that only one metamorphic event ocurred in the entire Jequié-Itabuna Granulitic Belt. In this case, (i) the metamorphic event would have an age either of 2.0 Ga or between 2.0 and 2.4 Ga; (ii) the metamorphic event would not have changed the 2.7 Ga age, which would be of ortho-derived rocks and not anatectic ones; (iii) the Contendas-Mirante Sequence would be the greenschist facies equivalent of this metamorphism, related to the amphibolite facies (eastern border of Contendas-Mirante Sequence and Ipiau Domain) and granulite facies (Jequié-Mutuípe-Maracás and Atlantic Coast Domain); (iv) the deformation episodes F_1 and F_2 would be continuous without a long interval of time separating them and with the granulitic migmatite mobilisates being formed after the end of these deformations and (v) the two metamorphic events would not interfere in the eastern border of the Contendas-Mirante Sequence as stated previously. In this case the metamorphism recorded in the Contendas-Mirante Sequence would be the result of the unstable nature of the granulitic paragenesis during the isostatic rise of the region. The path of this rise is shown in figure II.21, through the two small rectangles at about 4 Kb-750°C and 3 Kb-720°C, that represent the conditions of retrograde metamorphism. These conditions were defined by thermobarometric study of exsolution flakes of pyroxenes and symplectites of Gt-Cpx that occur in reaction coronas around pyroxenes (Barbosa, 1986, 1989; Barbosa & Fonteilles, 1992, in print).

The isostatic rise of the region was followed in some places by tectonic deformations. These are recorded by the presence of N-S shear zones and reactivation of transposition planes of the F_2 episode as reported above. Syenitic rock bodies may have intruded the retrograded granulites, during these deformations, in a crustal level corresponding to the amphibolite facies (Conceição et al., 1989, 1991; Aillon & Barbosa, 1992).