THE AMAZONIAN CRATON

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The chapter was coordinated by Colombo C.G. Tassinari, and it was organized in two sections assembled by different authors. The text on the eastern part of the Amazonian Craton was prepared by Moacir J.B. Macambira, Jean M. Lafon and Colombo C.G. Tassinari. The western part was described by Jorge S. Bettencourt, Mauro C. Geraldes and Colombo C G. Tassinari. Jorge S. Bettencourt and Colombo C. G. Tassinari are responsible for the overall conclusions of this chapter.

The Amazonian Craton is one of the largest cratonic areas in the world. It underlies the northern part of South America, and covers an area of about 430 000 km^2. It is divided into two Precambrian shields: the Guaporé Shield and the Guiana Shield that are separated by the Paleozoic Solimões and Amazonas basins, (Fig. 1). The craton is surrounded by Neoproterozoic orogenic belts (Tucavaca in Bolivia, Araguaia-Cuiabá in central Brazil, and Tocantins in northern Brazil), and it has been relatively stable since 1.0 Ga ago. The cratonic area includes parts of Brazil, French Guiana, Guyana Suriname, Venezuela, Colombia and Bolivia.

The isotope studies and the definition of geochronological provinces provide a useful base from which to understand crustal evolutionary processes and their tectonic implications at continental scale. For this reason we have summarized the geochronology of the Amazonian Craton with the aim of describing its tectonic history during Precambrian times. We have commented on the isotope and geological data, emphasizing their geographical distribution in accordance with the geochronological provinces established in previous work (Cordani *et al.*, 1979; Teixeira *et al.*, 1989; Tassinari *et al.*, 1996; Tassinari and Macambira, 1999).

The geochronological provinces are defined, following the principles of Tassinari and Macambira (1999) as major zones within cratonic areas, where a characteristic geochronological pattern predominates, and the age determinations, obtained by different isotopic methods for different geological units, are very coherent. The divisions are made mainly on the basis of the age of the metamorphic basement and the geological characteristics. In general, a broad time-interval for the provinces was established because the geology of most of the Amazonian Craton is poorly known and the geological surveys have generally been on a regional scale, due to the dense vegetation. Therefore, the provinces mainly differ from each other in the age of their respective metamorphic terranes, lithological assemblages and their geological history.

Each geochronological province may contain anorogenic igneous rocks and sedimentary of widely different younger ages, in agreement with the orogenic history of the neighbouring areas. Furthermore, geochronological provinces may include some older preserved nuclei, when their tectonic evolution has an ensialic character or some younger metamorphic rocks produced by later reworking processes.

The geochronological provinces may include one or more orogenic events, within their respective period. The term orogeny is here considered as a period of metamorphic episodes accompanied by deformation, partial melting and syn-tectonic granitic intrusions, rather than in the wider usage of the term a complete orogenic cycle, involving subsidence, deposition of sediments, metamorphism, syn and post-tectonic magmatism and anorogenic episodes. In this way, within those areas better studied, such as the Serra dos Carajás, the southwestern regions of the Amazonian Craton, and part of French Guiana for which some detailed studies are available, it is possible to define several orogenies and distinct terranes within the same geochronological province, in like manner to the Grenville Province of North America.

The geographical boundaries between geochronological provinces in the Amazonian Craton have been reasonably well defined mainly by geochronological data with some geological and geophysical support, although some limits are still not well defined due to the overprint of age determinations and/or lack of reliable geological information. Therefore, some boundaries are still open to question, and detailed geological surveying and more precise geochronological data must be obtained to establish the precise location of the geochronological boundaries in the field.

There are several syntheses on the tectonic setting of orogenies affecting the Amazonian Craton, which can be divided along two different lines. The first line of reasoning follows authors such as Amaral (1974) and Almeida (1978), and proposes that Precambrian tectonics are characterized by platform reactivation and by ensialic orogenies, with sea-floor spreading and subduction being of lesser importance in the orogenesis. Hasui *et al.* (1984) and Costa and Hasui (1997) proposed a similar model for the evolution of the Amazonian Craton, mainly based on structural geology and geophysics. They considered the evolution of the Amazonian Craton as a whole by the diachronous formation of continental blocks or paleo-plates by collision during Archean and Paleoproterozoic times that resulted in the agglutination of a megacontinent. Crustal blocks include granite-greenstone terranes and medium-grade gneiss. The limits of the blocks are marked by shear belts including high-grade rocks from the tectonic extrusion of lower crust domains (granulite belts). The second line of reasoning was proposed by Cordani *et al.* (1979) and followed and modified by Tassinari (1981), Cordani and Brito Neves (1982), Teixeira *et al.* (1989), Tassinari *et al.* (1996) and Tassinari (1996). It is based on modern orogenic concepts that include continuous crustal accretion during Archean and Paleo-Mesoproterozoic times. This hypothesis, based on the predominance of calc-alkaline magmatism in the Proterozoic terranes, is strongly supported by isotope data. This chapter describes the geological history of the Amazonian Craton in line with the second of the two views.

The Amazonian Craton can be subdivided into six major geochronological provinces based on the age determinations, structural trends, relative proportions of rock-types, and some geophysical evidence (Tassinari and Macambira, 1999). The majority of the radiometric ages, which comprises about 3000 age determinations, was obtained by Rb/Sr, K/Ar, Sm/Nd and zircon U/Pb methods, although whole-rock and zircon Pb/Pb ages are also available. The recognized geochronological provinces of the craton (Fig. 1) comprise a stable Archean nucleus (Carajás-Iricoumé and Roraima blocks), which are included in the Central Amazonian Province (CAP), and Paleoproteorozic and Mesoproterozoic provinces such as Maroni-Itacaiúnas (2.25 - 1.95 Ga), Ventuari-Tapajós (2.0 - 1.8 Ga), Rio Negro-Juruena (1.8 - 1.55 Ga), Rondonian-San Ignacio (1.55 - 1.30 Ga) and Sunsas (1.30 - 1.0 Ga).

Sr, Pb and Nd isotope composition of igneous or orthogneissic rocks demonstrate that the Proterozoic crustal growth in the Amazonian Craton involved the addition of juvenile material as well as the reworking of the older continental crust. Part of the Maroni-Itacaiúnas and Rondonian-San Ignacio, and the whole of Ventuari-Tapajós and Rio Negro-Juruena provinces appear to have evolved through successive episodes of continental accretion with associated mantle-derived magmatism. By comparison, the Sunsas and part of the Rondonian-San Ignacio and Maroni-Itacaiúnas provinces may have been associated mainly with events involving continental collision. Sm/Nd model ages on granitoid samples from the Amazonian Craton indicate that about 30% of the continental crust was derived from the mantle during the Archean, and about 70% in the Proterozoic times. During the Proterozoic the main crustal formation episodes took place around 2.0 Ga.

Paleoproterozoic orogenies are typically developed in the border zone of the stable Central Amazonian Province, and are well represented in the eastern and northern part of this province by the Maroni-Itacaiúnas Province, and on the western side by the Ventuari-Tapajós Province. The paleoproteozoic belts included within the Maroni-Itacaiúnas Province weld three former microcontinents: the Archean Carajás-Iricoumé and Roraima blocks, and the Archean part of the West Congo Craton. The Ventuari-Tapajós Province seems to be slightly younger than Maroni-Itacaiúnas because its structural trends crosscut the structural pattern of the latter. The U/Pb, Rb/Sr, Sm/Nd and Pb/Pb age determinations have suggested that the Ventuari-Tapajós and Rio Negro-Juruena provinces evolved through successive magmatic arcs during the period from 1.95 to 1.55 Ga. The Rondonian-San Ignacio Province was developed through a magmatic arc phase between 1.55 and 1.4 Ga and thereafter by continental collision between 1.4 and 1.3 Ga. Finally, the Sunsas Province, composed mainly of metavolcano-sedimentary sequences and granitoid plutons, includes older terranes reworked between 1.3 and 1.0 Ga together with a small amount of juvenile material. Its evolution has been associated with the inversion of the marginal belt during continent-continent collision.

For purposes of discussion the crustal evolution of the Amazonian Craton will be divided into two parts based on geography: the eastern part, consisting of the Central Amazonian, Maroni-Itacaiúnas and Ventuari-Tapajós provinces, and the western part consisting of the Rio Negro-Juruena, Rondonian-San Ignacio and Sunsas provinces. This division is based on the fact that within the western part, the younger metamorphic and magmatic overprinting is more important than that which occurs on the eastern side.

Eastern Amazonian Craton

Central Amazonian Province (CAP)

The Central Amazonian Province is composed of the oldest continental crust of the Amazonian Craton that was not affected by the 2.2 - 1.9 Ga Transamazonian Orogeny. However, during the Paleoproterozoic it was the scene of expressive magmatic and sedimentary events. The basement of the CAP probably comprises a number of contrasting geological units in relation to their lithology, age and extent of geological knowledge. In the southeastern CAP, the Archean Carajás Metallogenetic Province represents the better-studied region of the Amazonian Craton. On the other hand, the western adjacent region and its continuity to the N of the Paleozoic Amazonas Syneclise, is not well exposed; is poorly known and for which very little geochronological data are available. Taking into accounts these dissimilarities, and for the purpose of description and discussion of the geochronology, the CAP will be divided into two domains, separated by the Maroni-Itacaiúnas Province. The first domain is named Carajás-Iricoumé Block, which is subdivided into the Carajás and the Xingu-Iricoumé areas. The second domain consists of the Roraima Block. The geochronological pattern of the CAP is summarized in Table 1.

The Carajás-Iricoumé Block (Carajás Area)

The Carajás Area is the only well recognized and preserved Archean region of the Amazonian Craton. It represents the most important mineral province of Brazil, hosting deposits of iron, copper, gold, maganese, nickel, and others. The Maroni-Itacaiúnas Province to the N and Araguaia Belt to the E limit the area (Fig. 1). It is covered by the Phanerozoic sediments of the Parecis-Alto Xingu Basin to the S, and by the Paleoproterozoic volcanic rocks of the Uatumã Supergroup and sediments of the Gorotire Formation to the W. Of the regional geological surveys in the Carajás area, it is necessary to mention the synthesis made by the geologists of the Companhia Vale do Rio Doce-C.V.R.D. (Hirata *et al.*, 1982; DOCEGEO, 1988), besides those of Companhia de Pesquisas de Recursos Minerais-C.P.R.M. in the Grande Carajás Program (Araújo *et al.*, 1988; Araújo and Maia, 1991; Oliveira *et al.*, 1994; Macambira and Vale, 1997), summarized by Costa *et al.* (1995). Students and researchers from several Brazilian and foreign universities

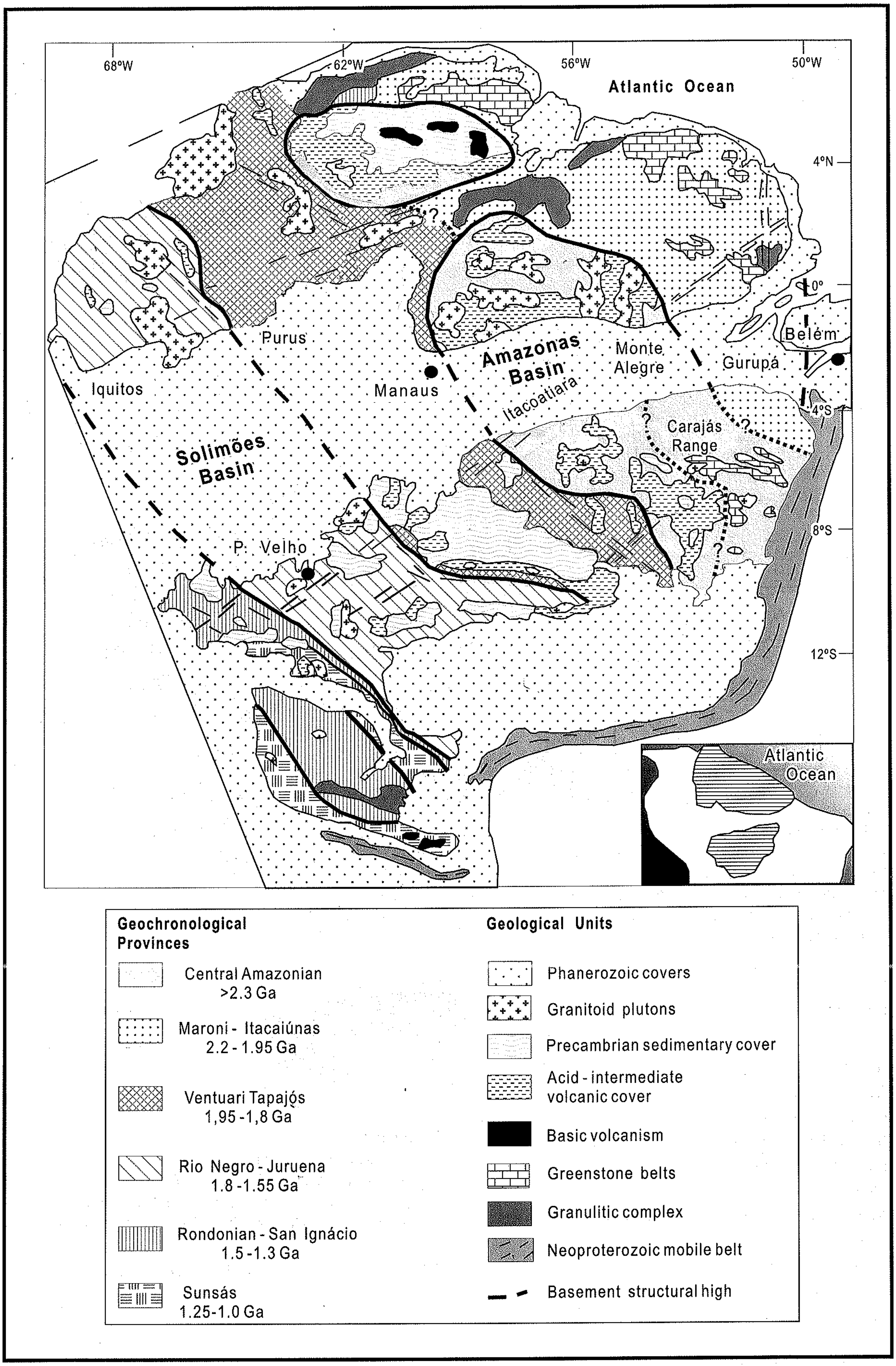


FIGURE 1 - Major geochronological provinces and main lithological associations of the Amazonian Craton (modified after Tassinari and Macambira, 1999).

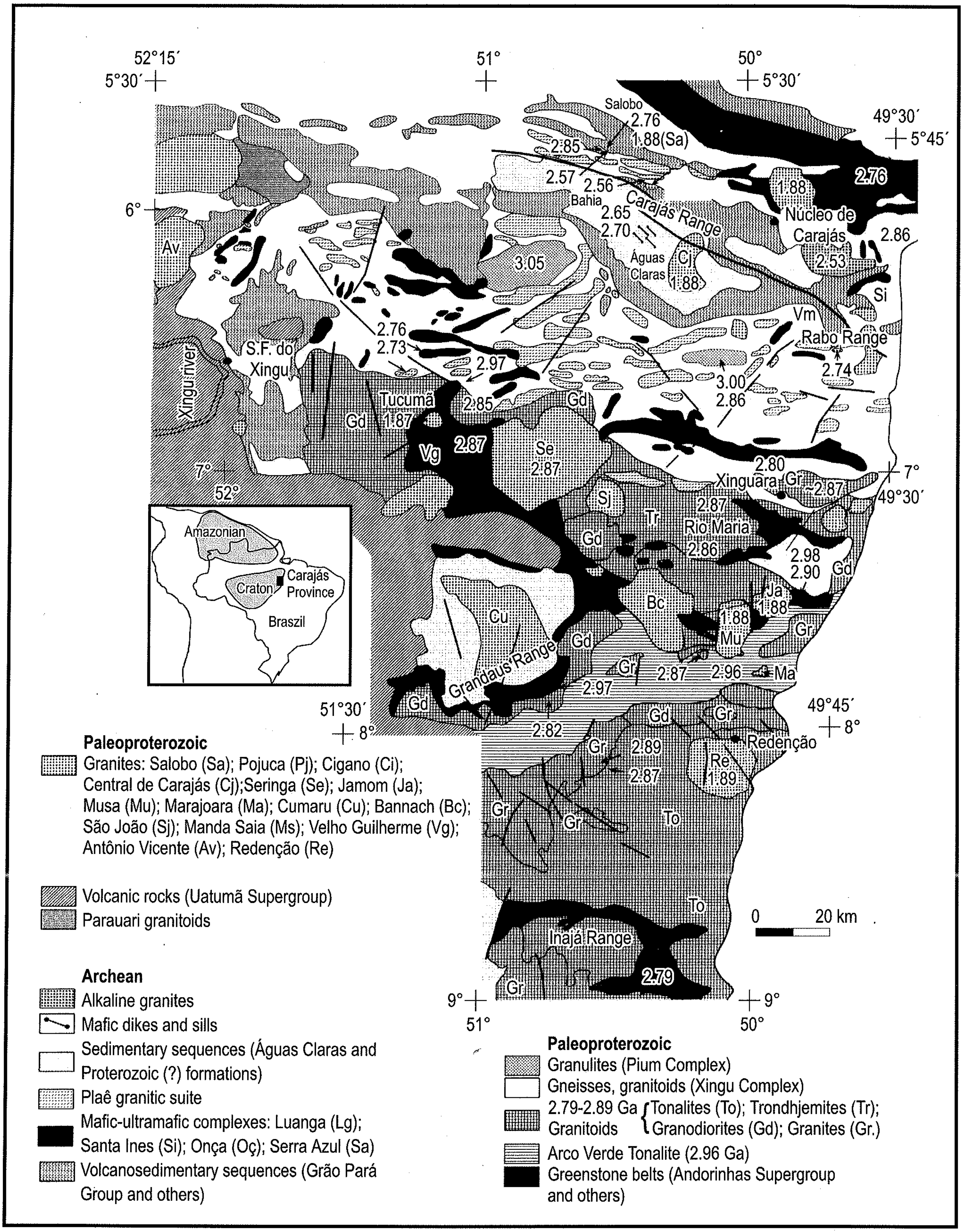


FIGURE 2 - Geology of the Carajás area, showing major unit locations and respective age determinations.

have also dedicated their studies to the CAP, including those attached to the of Universities of Pará, Brasília, São Paulo, Vale do Rio dos Sinos and Campinas.

Although a large amount of work has already been carried out in the Carajás area making a significant contribution to geological knowledge and leading to the development of geological models that are sometimes conflicting, important questions still remain open. The Carajás area was formed and tectonically stabilized in the Archean. Furthermore, it was only affected by a Paleoproterozoic extensive thermal event that was accompanied by the emplacement of granitic intrusions and felsic and mafic dykes. Phanerozoic mafic dykes have also been reported. The area was divided into three tectonic domains (DOCEGEO 1988; Costa *et al.*, 1995), named by the last-cited authors, as the Rio Maria granite-greenstone terranes, the Northern Itacaiúnas Shear Belt and the Southern Pau D´Arco Shear Belt (Fig.2). The three domains are roughly E-W structured, according to the regional foliation. The Rio Maria terranes are interpreted as a preserved nucleus whereas, at least part of both the semi-surrounding shear belts, are considered as the result of deformation and shearing of the units of the Rio Maria terranes. An important difference between the two shear belts is that the Itacaiúnas Belt also presents significant Neoarchean volcanism and plutonism whereas, in the Pau D´Arco Belt, the rock units appear to be lithologically and temporally similar to those of the Rio Maria terranes. The similarities between the Rio Maria terranes and the Pau D´Arco Belt led Althoff *et al.* (1991) and others to suggest that the southern belt could be considered as just an extension of the Rio Maria terranes.

The Itacaiúnas Belt is divided into two sub-domains: the E-W imbricated system, in the S, and the E-W, WNW-ESE and N-S transcurrent systems, in the N (Costa *et al.*, 1995). The Itacaiúnas Belt is mainly composed of high grade rocks (Pium Complex), gneiss (Xingu Complex), volcano-sedimentary sequences (*e.g.*, Grão Pará Group) and contemporaneous mafic-ultramafic complexes, and granitoid plutons (Plaque Suite, Estrela Granite and others). The oldest rocks of the Carajás area (Macambira and Lafon, 1995) and the Pau D´Arco Belt, consist of greenstone sequences, named the Andorinhas Supergroup (DOCEGEO, 1988), including TTG associations.

High grade terranes (Pium Complex)

According to Araújo and Maia (1991), the granulitic rocks of the Pium Complex occur as a number of elongated bodies (maximum length of 35 km), sub-parallel to the regional E-W foliation. They have so far been described only in the imbricated domain of the Itacaiúnas Belt, and were interpreted as fragments of lower crust emplaced along shear zones (Araújo *et al.*, 1988). The two main occurrences are those in the Pium River (in the central part of the Itacaiúnas Belt) and in the Catete River (in the western part of Itacaiúnas Belt), and they are mainly composed of mafic and felsic granulite, respectively. The mafic granulite seems to be older than the dominant felsic granulite, as xenoliths of the former have been found in the latter. The hypersthene calc-alkaline felsic granulite rocks are charnokite, enderbite and, subordinate charno-enderbite. The tholeiitic mafic granulite rocks are phaneritic, medium-grained, melanocratic, and isotropic hypersthene-plagioclase granulite (Araújo and Maia, 1991).

Rodrigues *et al.* (1992) analysed eleven samples of charnokite from the Catete River area and obtained an age of 3.05 ± 0.114 Ga (MSWD = 72) by the Pb/Pb on whole-rock method. The age was interpreted by the authors as the age of the crystallization of the protolith of the Pium Granulite. On the other hand, the analyses of the oscillatory zoned cores of the zircon of an enderbite from the Pium River area yielded, by the U/Pb (SHRIMP) method, an age of 3.002 ± 0.012 Ga (Pidgeon *et al.*, 1998). These authors share the same interpretation as the previous authors for the similar age, demonstrating that the two main occurrences of the Puim Granulite are coeval. Moreover, analysing the nebulously zoned rims of the zircon, Pidgeon *et al.* (1998) obtained, by the same method, an age of 2.861 ± 0.002 Ga, interpreted as dating the granulite facies metamorphism.

Granite-greenstone terranes

The granite-greenstone terranes of the Carajás area were first reported in the Rio Maria region (Cordeiro and Saueressig, 1980). A number of projects were carried out in these terranes that extended their occurrences over other areas (Hirata *et al.*, 1982; Macambira *et al.*, 1986; Medeiros *et al.*, 1987; DOCEGEO, 1988; Costa *et al.*, 1995).

The greenstone belt sequences

DOCEGEO (1988) proposed the term Andorinhas Supergroup to name all the greenstone sequences of the Carajás region. The unit is composed of mafic to ultramafic volcanic rocks (including komatiitic flows) interlayered with sediments (pellite, BIF, chert), at the base (Babaçu Group), grading from intermediate to felsic volcanic rocks associated with shale, greywacke and BIF, at the top (Lagoa Seca Group). The Babaçu Group is divided into the Igarapé Encantado and Mamão formations, whereas the Lagoa Seca Group is divided into the Fazenda do Quincas and Recanto Azul formations. Three geochemical series were defined in volcanic rocks: komatiite, low-K tholeiite and sodic calc-alkaline (Souza *et al.*, 1997). The E-W sequences, showing spinifex texture and pillow lava structure, are metamorphosed in the greenschist to amphibolite facies, and crosscut by shear zones, where the gold-mineralization associated with hydrothermal alteration are found (Huhn, 1991; Souza, 1994). The greenstone belts are covered by a pelitic sequence named by DOCEGEO (1988) as the Rio Fresco Group, and considered as Paleoproterozoic in age. However, Costa *et al.* (1995), taking into account the deformational similarities, considered the pelitic sequence as an upper part of the greenstone belt. Dating detrital zircon from this sequence, Macambira *et al.* (1998) reported ages of 3.2, 3.4 and 3.7 Ga, previously unrecorded in the rocks of this region.

Besides the Rio Maria greenstone belts, other undated units have been described in the Carajás area. In the southernmost part, these sequences are known as the Serra do Inajá Supergroup, which is divided into the Santa Lúcia and Rio Preto groups, and considered as chrono-correlated to the Andorinhas Supergroup (DOCEGEO, 1988). Costa *et* *al.* (1995) gave the name Tucumã Group to the greenstone sequences that occur in the homonymous region (central-western Carajás Area). These authors called Sapucaia Group the several elongated greenstone sequences of the imbricated domain of the Itacaiúnas Belt. They considered both Groups coeval with the Andorinhas Supergroup, but the Sapucaia Group was affected by a further deformational event. In the northeastern part of the Carajás Area, Hirata *et al.* (1982) reported the presence of a greenstone belt, named the Rio Novo Sequence. DOCEGEO (1988) proposed that this sequence had been an extension of the Andorinhas Supergroup, separated by further erosion, whereas Araújo and Maia (1991) believed that it was contemporaneous with the Grão Pará Group (2.76 Ga).

The zircon U/Pb results of the felsic volcanic rocks of the Lagoa Seca Group (Andorinhas Supergroup) of the Rio Maria region yielded ages of 2.904 + 0.029 / - 0.022 Ga (Macambira, 1992) and 2.979 ± 0.005 Ga (Pimentel and Machado, 1994). In the Tucumã region, a Pb/Pb evaporation age of 2.868 ± 0.008 Ga was obtained in zircon from a felsic volcanic rock of the Tucumã Greenstone Belt (Avelar *et al.*, in press). Minimum ages have been proposed for the greenstone belts through the dating of the zircon from the intrusive mafic-ultramafic layered complexes, such as that of Luanga (2.763 ± 0.006 Ga; Machado *et al.*, 1991) and that of Serra Azul (2.97 ± 0.007 Ga; Pimentel and Machado, 1994), in the Gradaus Ridge, to the W of the Rio Maria region. The neighbouring Guarapará Complex (olivine-gabbro, peridotite and dunite) seems to be contemporaneous with the Serra Azul Complex, as well as with the associated greenstone sequence.

The granitoid plutons

A voluminous set of Archean granitoid plutons and batholiths have been reported in the Rio Maria terranes. They have been named as the Arco Verde and Parazonia Tonalite, Rio Maria Granodiorite, Mogno Trondhjemite, and the Mata Surrão, Guarantã and Xinguara granites. Dall'Agnol *et al.* (1996) have classified these granitoid plutons according to geochemical criteria: the tonalite and trondhjemite are similar, but enriched in N_2O and depleted in K_2O in relation to the Archean trondhjemitic series. The granodiorite follows the trend of the Archean K_2O-moderate calc-alkaline series, whereas the granite bodies are highly fractionated calc-alkaline leucogranitoid similar to those associated with Archean late magmatic events. Costa *et al.* (1995) have applied the same terms used in the Rio Maria region to name similar bodies mentioned in the southern Redenção and western Tucumã regions. In the Rio Maria region, field relationships and geochronological data have shown that these granitoid plutons are younger than the greenstone belt sequences. The exception is the Arco Verde Tonalite, which is contemporaneous with the greenstone belts. The granitoid plutons, as well as the greenstone sequences, were deformed by a WNW-ESE to E-W ductile deformation that generated mylonitic zones (Dall'Agnol *et al.*, 1996). The younger granitoid bodies are considered to be syn-tectonic, showing evidence for contact metamorphism in the country rocks.

The Arco Verde Tonalite (Althoff *et al.*, 1991) presents an age of 2.957 + 0.025 / - 0.021 Ga. It is clearly intruded by the 2.87 Ga Mata Surrão Granite. Detrital zircon crystals from a greywacke of the adjacent Lagoa Seca Greenstone Belt, with a zircon U/Pb age of 2.971 ± 0.018 Ga (Macambira, 1992), were interpreted as having come from the Arco Verde Tonalite. The similarity of the morphology, internal structures and chemistry between both populations of zircon support this hypothesis. According to the last-named author, the Arco Verde Tonalite could represent part of a sialic margin of the greenstone basin. The greywacke resulting from the erosion of the Arco Verde Tonalite had already been deposited when the Lagoa Seca Group was being formed.

The available geochronological pattern constrains a short interval, around 2.87 Ga, for the Archean younger granitoid emplacement in the Rio Maria region (Macambira, 1992; Pimentel and Machado; 1994; Lafon *et al.*, 1994). Similar granitoid plutons of the central-southern region of Carajás seem to be coeval, taking into account the experimental errors and the constraints of the methods:

- Cumaru Granodiorite (Gradaus region): 2.817 ± 0.004 Ga (Pb/Pb on zircon; Lafon and Scheller, 1994);
- Rio Maria Granodiorite (Tucumã region): 2.852 ± 0.016 Ga (Pb/Pb on zircon; Avelar *et al.*, in press);
- Mata Surrão Monzogranite (Redenção region): 2.894 ± 0.019 Ga and 2.798 ± 0.028 Ga (Pb/Pb on whole-rock; Barbosa and Lafon, 1996);
- Arco Verde Orthogneiss (Redenção region): 2.872 ± 0.025 Ga (Pb/Pb on whole-rock; Barbosa and Lafon, 1996).

The evolution of the Carajás granite-greenstone terranes terminated with the intrusion of these granitoid plutons, which established a short episode (<150 Ma) of continental crust formation. On the other hand, Sm/Nd mantle-depleted model ages obtained in seven Archean granitoid samples from Rio Maria region (2.73, 2.86, and five samples ranging from 2.95 to 3.04 Ga), as well as their ε_{Sr} and ε_{Nd} values suggest that there was a short interval between the moment of mantle-extraction and the emplacement of these granitoid plutons (Sato and Tassinari, 1997; Dall'Agnol *et al.*, 1999a).

Regional Basement Rocks

The regional basement rocks were named by Silva *et al.* (1974) as the Xingu Complex, which are mainly composed of polymetamorphosed granodioritic rocks occurring over a large area of the southern part of the Amazonian Craton. With the advance of geological knowledge, new units were defined in the complex and its domain became reduced. A good example is the Rio Maria region, where the complex presently is no longer recognized as such. In the Itacaiúnas Shear Belt, the Xingu Complex is still an important stratigraphic unit, comprising gneiss, granitoid and amphibolite, and has been considered as the regional basement (Costa *et al.*, 1995).

The only U/Pb zircon ages available for the Xingu Complex are those obtained by Machado *et al.* (1991), in the northeastern Carajás Area. Analyzing four samples (amphibolite, gneiss and leucosome) of the same outcrop, they obtained similar ages (2.859 ± 0.002 Ga and 2.851 ± 0.004 Ga), interpreted as dating the last migmatization event affecting the region. Macambira and Lafon (1995) remarked that these ages are similar to those of the granitoid of the Rio Maria region. Costa *et al.* (1995) admitted that at least part of the Xingu Complex gneiss could be the result of the reworking of granitoid, similar to that preserved in the Rio

Maria region. Sm/Nd data support this hypothesis, since the model ages (T_{DM}), obtained from two samples (gneiss and tonalite) from the northeastern CAP, are 3.03 and 2.98 Ga, similar to those of the Rio Maria Granodiorite (Sato and Tassinari, 1997). Additionally, the authors observed that the Sr initial ratios and ε_{Nd} values suggest a short crustal residence for the material source of these granitoid plutons. On the other hand, the protolith (3.0 Ga) and the metamorphism (2.85 Ga) of the Pium Granulite are coeval with the mantle extraction and the emplacement of the Xingu Gneiss, suggesting that the same regional event generated both rocks. Another interesting piece of data was obtained by Machado *et al.* (1991), who used a zircon age of 2.851 ± 0.004 Ga for the Cascata Gneiss (base of the overlying Salobo Group) to propose that the group should be considered as part of the Xingu Complex. The data was further reconsidered by Lindenmayer *et al.* (1995), who interpreted the gneiss as a part of the complex. So, if this is confirmed, it represents another result indicating an age of 2.85 Ga for the Xingu Complex.

In addition, a Rb/Sr isochron age was obtained in gneiss considered as belonging to the Xingu Complex (Cunha *et al.*, 1981), from the Inajá Ridge region in the southernmost part of the Carajás area. The age of 2.696 ± 0.158 Ga (Sr initial ratio = 0.701), interpreted as that of the emplacement of the protolith of the gneiss, is not different, taking into account the experimental errors, from those of the other Archean granitoid plutons referred to so far.

Metavolcano-sedimentary sequences (Northern Carajás Area)

The Neoarchean metavolcano-sedimentary sequences of the northern Carajás area host the more important mineral deposits of the province, which have been described in the literature. The sequences form a WNW-ESE synclinal belt underlain by the Xingu Complex and cut by Paleoproterozoic granite intrusives and mafic dykes (Beisiegel *et al.*, 1973; DOCEGEO, 1988). The sequences are heterogeneously affected by several different types of overprinting (igneous crystallization, hydrothermal alteration, contact metamorphism, regional deformation, shearing recrystalization) and in general are poorly exposed. These aspects have made it difficult to reconstruct adequately the geological evolution of the sequences. In any event, they are lithologically and temporally different from those of the Andorinhas Supergroup.

Araújo and Maia (1991) redefined the Grão Pará Group as equivalent to the Itacaiúnas Supergroup (DOCEGEO, 1988), but including the sediments of the Rio Fresco Group. The group was thus divided into three formations (from base to top):

• Parauapebas Formation - mainly composed of basalt and dacite, with subordinated rhyolite, metamorphosed in the greenshist facies;

• Carajás Formation - essentially composed of BIF with subordinated jaspilite and very rare limestone units;

• Águas Claras Formation - composed of psammite and pelite with a subordinated chemical contribution, undeformed in the center of the belt. The sandstone beds generally are conglomeratic, subarkosic and locally brecciated. Nogueira *et al.* (1995) divided the Águas Claras Formation into the Lower Member (marine) and Upper Member (littoral and fluvial). Sequences similar to the Grão Pará Group have been reported to the N of the Carajás region including the Tapirapé, Misteriosa and Buritirama groups (Costa *et al.*, 1995).

Reliable geochronological data have been very important in the establishment of the contemporaneity of the volcano-sedimentary sequences of the northern Carajás area at *c.* 2.76 Ga (Wirth *et al.*, 1986; Machado *et al.*, 1991; Trendall *et al.*, 1998). From indirect dating, it was also demonstrated that the BIF are also coeval with the volcano-sedimentary sequences (Macambira, 1996; Trendall *et al.*, 1998). Dating of zircon from mafic dykes crosscutting the Lower Member of the Águas Claras Formation indicates that these sediments are older than 2.645 ± 0.012 Ga (Dias *et al.*, 1996) or 2.708 ± 0.037 Ga (Mougeot *et al.*, 1996). Zircon crystals from the Upper Member and aged 2.681 ± 0.005 Ga are interpreted as coming from a syn-depositional volcanism (Trendall *et al.*, 1998), indicating a minimum age for the sedimentation.

There is no consensus on the tectonic environment of the formation and evolution of the Carajás Basin. Some defend continental rifting (Gibbs *et al.*, 1986; DOCEGEO, 1988), whereas others propose an island arc model (Dardenne *et al.*, 1988; Teixeira and Eaggler, 1994). According to Araújo *et al.* (1988) and Araújo and Maia (1991), the structural evidence does not agree with the more recent hypotheses. For these authors, the Carajás Basin is the result of a transcurrent process and was filled by the volcano-sedimentary sequences (Grão Pará Group) in the distensive phase. In the inversion phase, the sequences were separated in lenses, which were imbricated. At that time, the southern Carajás area was tectonically stable.

Neoarchean intrusive bodies

Scattered mafic and felsic intrusive bodies occur in the Itacaiúnas Belt, crosscutting the Xingu Complex and the metavolcano-sedimentary sequences. They are generally elongated according to the E-W regional foliation, and interpreted as having a syn to tardi-tectonic emplacement. Some of them have been studied and dated. They will be described according to their similarities.

Plaquê Granitic Suite

Stratum-like granitic bodies, named the Plaquê Suite by Araújo *et. al.* (1988), have been reported in the Itacaiúnas Belt, especially in the imbricated domain. They are biotite and/or muscovite granite showing a varied degree of deformation, more intense in the border facies and considered as the result of the friction of a crustal collision during the development of the Itacaiúnas Belt (Araújo and Maia, 1991). Zircon crystals from a granitic body in the Tucumã region were dated at 2.736 ± 0.024 Ga (Avelar *et al.*, in press), and interpreted as the age of the Itacaiúnas Belt structuration.

A-type granite

Some foliated alkaline granitic bodies have been only identified in the transcurrent domain of the Itacaiúnas Belt crosscutting and metamorphosing the volcano-sedimentary sequences. The best studied granitic intrusive is the 2.53 Ga Estrela Granitic Complex (Rb/Sr isochron, Barros *et al.*, 1992) in the northeastern Carajás area. Similar bodies are the "Old Salobo" Granite (Lindenmayer *et al.*, 1995) dated at 2.573 ± 0.002 Ga (U/Pb on zircon, Machado *et al.*, 1991) and the deformed "Old Pojuca" Granite of the Itacaiúnas River dated at 2.525 ± 0.038 Ga (Pb/Pb on zircon, Souza *et al.*, 1997). Recently, Huhn *et al.* (1999) dated zircon from the alkaline Planalto Granite (Rabo Ridge) at 2.747 ± 0.002 Ga. Zircon from an associated dioritic intrusive body yielded an age of 2.738 ± 0.006 Ga, with an inherited zircon of 2.953 ± 0.002 Ga, enlarging the established interval for the occurrence of the Archean alkaline granite in the Carajás area. It is also interesting to note that the alkaline granite intrusives are contemporaneous with the tectono-metamorphic events (2.58 - 2.5 and 2.77 - 2.73 Ga) proposed by Machado *et al.* (1991) as having affected the northern part of the studied area.

Mafic-ultramafic layered complexes

Zircon crystals from the Luanga Complex, a sill-like differentiated intrusion composed of chromite bearing bronzitite, norite and leucogabbro (Medeiros Filho and Meirelles, 1985), were dated by Machado *et al.* (1991) at 2.763 ± 0.006 Ga. The age of the surrounding Rio Novo greenstone belt is unknown, but Oliveira *et al.* (1994) observed a great deformational contrast between both units considered as coeval. The complex is well preserved, showing only brittle deformation, whereas the greenstone is intensely deformed and metamorphosed in the greenschist facies. So, if the greenstone is 2.76 Ga old, the complex emplacement occurred in an immediate distensive event as was proposed for the Grão Pará Group by Araújo and Maia (1991).

In the Tucumã region, Macambira and Vale (1997) recognized a set of E-W elongated mafic to ultramafic bodies and proposed the term Catetê Intrusive Suite to name these complexes. The layered complex of Serra da Onça (serpentinite, piroxenite and gabbronorite) is the best known (Macambira, 1996). A Sm/Nd (whole-rock and mineral) age of 2.378 ± 0.055 Ga (MSWD = 3.9) was proposed for its emplacement, which could have occurred in a distensive system, taking into account that the body is undeformed and unmetamorphosed. The ε_{Nd} of the samples indicate a mantle source. A U/Pb (SHRIMP) age of 2.763 ± 0.006 Ga was obtained by Lafon and others (personal communication) on zircon from the Serra da Onça Complex. This age, which is the same as that of the Luanga Complex, could indicate that the complex, after its formation was stored in the low level of the continental crust, and during the 2.4 Ga distensional event ascended to the higher crustal level. This contemporaneity, as well as the lithological and structural similarities strongly suggests that the Serra da Onça and Luanga complexes are products of the same tectonic and petrogenetic process.

Among other mafic-ultramafic bodies of the imbricated domain of the Itacaiúnas Belt, Araújo and Maia (1991) referred to the Vermelho Complex, SW of the Rabo Ridge, hosting an important Ni ore deposit. It is composed of serpentinized dunite and peridotite metamorphosed at the greenschist facies. No geochronological data are avalaible for the complex, but the authors proposed a Paleo to Mesoproterozoic age. The Santa Ines Gabbro is another body showing the same NE-SW orientation as the Vermelho Complex, but these rocks have received little study.

Paleoproterozoic granite plutons and associated rocks

Paleoproterozoic granitic plutons and batholiths and associated felsic and mafic dykes are widespread in the Carajás area indistinctly crosscutting the Archean units. They are undeformed, high-level granite bodies emplaced in a rigid crust and containing xenoliths from the country rocks that are thermally metamorphosed (Dall'Agnol *et al.*, 1997). They are mainly composed of syenogranite and monzogranite with subordinated alkali-feldspar granite and granodiorite. Geochemically, they are alkaline, metaluminous and similar to the A-type and within-plate granite bodies (Dall'Agnol *et al.*, 1994). Dall'Agnol *et al.*, (1997) proposed a subdivision of the granite plutons into three groups, according to their magnetic susceptibility (MS), geochemistry and metallogenesis:

- The high MS, magnetite bearing Jamon and Musa granite bodies, locally W-mineralized;
- The moderate MS, Serra dos Carajás, Cigano and Pojuca granite bodies, locally with Cu and Mo mineralization;
- The low MS, Antonio Vicente, Velho Guilherme, Mocambo and Benedita granite plutons, frequently with Sn-mineralization.

The estimated time for the emplacement of the Paleoproterozoic granite of the Carajás area is well constrained at 1.88 Ga by U/Pb zircon dating (Wirth *et al.*, 1986; Machado *et al.*, 1991). These granite plutons are interpreted as the result of an extensive thermal event (Costa *et al.*, 1995) probably responsible for the warming of the region that induced the *c.* 2.0 Ga Rb/Sr and K/Ar "Transamazonian" ages of some country rocks (Macambira and Lafon, 1995). The granite plutons show high Sr initial ratios (0.707 to 0.715, Macambira *et al.*, 1990) and, some from the Rio Maria region, show negative ε_{Nd} (- 9.3 to - 10.0, Dall'Agnol *et al.*, 1999a) suggesting an origin by the anatexis of crustal rocks, probably induced by underplating or intrusion of mantle-derived mafic magma (Dall'Agnol *et al.*, 1994). According to Nd isotope data and geochemical modeling, the 2.87 Ga quartz diorite of the Rio Maria region have the adequate composition to generate the Musa and Jamon granite plutons, as well as the associated dacite porphyry dykes (Dall'Agnol *et al.*, 1999a). However, Archean inherited zircon, as old as 3.2 Ga, found in these granite bodies (Machado *et al.*, 1991), indicate additional contribution or contamination of the granitic magma.

Rock units younger than 1.9 Ga

Due to the lack of clear field evidence and geochronological data, some geological units, such as certain sedimentary sequences and mafic dykes of the Carajás area, do not have a well established stratigraphic and temporal positions and could be younger than the 1.9 Ga granite. DOCEGEO (1988) considered all the sedimentary sequences of the area (Rio Fresco Group), covering the Archean units and locally cut by the Paleoproterozoic granite, of an age between 2.0 and 1.8

Ga. However, other authors (Figueiras and Villas, 1982; Ramos *et al.*, 1984) do not accept this regional correlation, since these sedimentary sequences show important differences according to the region of occurrence, stratigraphy, degree of deformation, and presence of coal. For Ramos *et al.* (1984), the coal layer of 3 m thick enclosed in a sedimentary sequence of the Fresco River Basin is impossible to find in a Precambrian sequence. In the Northern Carajás Area, the Aguas Claras Formation has been proved to be Archean but, other sequences, such as the Gorotire Formation, are believed to be younger (Costa *et al.*, 1995).

A number of mafic dykes indistinctly crosscutting the Archean units are widespread in the area. Some of them are Archean, probably associated with the volcanism of the Carajás Basin, whereas others are contemporaneous with the Paleoproterozoic granitic magmatism. However, some of these dykes have a Phanerozoic age (560, 500 and 225 Ma) as is the case of the dolerite dykes occurring in the Carajás Ridge according to the K/Ar dating (Gomes *et al.*, 1975; Cordani *et al.*, 1984; DOCEGEO, 1988).

Carajás - Iricoumé Block (Xingu – Iricoumé Area)

The Xingu-Iricoumé area is a NW-SE trending domain parallel to the younger Maroni-Itacaiúnas and Ventuari-Tapajós provinces. It is limited by the Carajás area to the SE; by the Central Guiana Belt to the NW; and divided by the Phanerozoic Solimões-Amazonas basins. The domain is poorly known, and the very few available geochronological results were mainly obtained by the Rb/Sr and K/Ar methods. The area is composed of Paleoproterozoic plutonic, volcanic and sedimentary rocks, which crosscut and rest unconformably on an undated basement complex. A pre-Transamazonian age, older than 2.3 Ga, is proposed for the basement, taking into account some Archean Nd model ages (T_{DM}) and the presence of granitoid plutons of *c.*1.96 Ga, intrusive in the northern Central Amazonian Province.

The oldest granitoid plutons of the Xingu-Iricoumé area are the calc-alkaline Água Branca Monzogranite (1.96 to 1.91 Ga; Santos and Reis Neto, 1982; João *et al.*, 1985; Almeida *et al.*, 1997), of the northernmost part of the domain. Additionally, there are some granitoid bodies included in the Parauari Granitic Suite (1.921 ± 0.069 Ga; Macambira, 1992), situated close to the Xingu River. These 1.96 Ga old granitoid plutons are interpreted as post-collisional in relation to the Transazonian Orogeny (João *et al.*, 1985), but those of the Xingu River are also considered as the first product of a distensive regional event (Costa *et al.*, 1995). Recently, Faria *et al.* (1999) reported that some granitoid plutons occurring in the southeastern part of the State of Roraima, believed to be the Água Branca Monzogranite, are peraluminous, similar to the S-type granite, and proposed the term Igarapé Azul Granite to name these rocks.

The Uatumã Supergroup (Santos, 1982) is composed of felsic to intermediate volcanic and plutonic rocks. In the northern area (Iricoumé), they are called Iricoumé and Mapuera groups, whereas those of the southern area (Xingu) are named the Iriri and Maloquinha/Rio Dourado groups, respectively. Zircon from the Iricoumé Rhyodacite collected from the tin Pitinga Mine yielded an age of 1.966 ± 0.009 Ga (Schobbenhaus *et al.*, 1994), similar to the age of the Água Branca Monzogranite. In the southern part of the area, a similar age (1.888 ± 0.002 Ga and 1.888 ± 0.007 Ga) was obtained on zircon from the Iriri Rhyolite of the Tapajós and Jamanxim rivers by Dall'Agnol *et al.* (1999b) and Moura *et al.* (1999), respectively. The former authors characterized a typical A-type signature for the studied fayalite-hedembergite rhyolite. Analyzing rhyolite and andesite from a region close to the São Felix do Xingu (Xingu River), Teixeira *et al.* (1998) obtained a similar age of 1.875 ± 0.079 Ga by the Pb/Pb on whole-rock method.

Sub-alkaline to alkaline granite showing similarities with the A-type and rapakivi granite, and interpreted as anorogenic (Dall'Agnol *et al.*, 1994), is widespread in the Xingu-Iricoumé area. In the northernmost domain, some of these bodies are highly mineralized with respect to Sn and intrusive in the Iricoumé Group. Examples include the Madeira (1.834 ± 0.006 Ga; Fuck *et al.*, 1993) and Água Boa granite bodies of the Pitinga tin mine, or the Água Branca Monzogranite and the Moderna Granite (1.814 ± 0.027 Ga; Santos *et al.*, 1997). In the southern area, very few geochronological data are available for these granite plutons. However, in the Tapajós Gold Province, enclosed in the adjacent Ventuari-Tapajós Province, recent geochronological results were obtained for the Uatumã Supergroup and Parauari Granite (Vasquez *et al.*, 1999; Lamarão *et al.*, 1999). These data indicate at least two Paleoproterozoic volcano-plutonic events: 1.89 - 1.88 Ga and 2.0 - 1.98 Ga. The older event is calc-alkaline, whereas the younger is sub-alkaline to alkaline, but a calc-alkaline plutonism is also reported, suggesting that a review of the terms Iriri Volcanism and Parauari Granite is needed. On the other hand, the Nd model ages (T_{DM}) indicate values between 2.6 and 2.5 Ga for the source of rhyodacite and intrusive granite from the Iriri-Xingu region (Sato and Tassinari, 1997). These Archean signatures contrast with the Paleopreoterozoic Nd model ages (T_{DM}) of the rocks of the neighbouring Tapajós Gold Province, which is included in the younger Ventuari - Tapajós Geochronological Province.

The Roraima Block

The Roraima Block occurs in the northern part of the AC and the 2.2 - 1.95 Ga Maroni-Itacaiúnas Province separates it from the Iricoumé-Carajás Block. It is completely covered by the 2.0 - 1.95 Ga Surumu acid and intermediate volcanic rocks (Schobbenhaus *et. al.*, 1994), and by the sedimentary sequences of the Roraima Group, which overlie the Surumu volcanic rocks.

The Roraima Group consists of a variety of sedimentary rock-types, which mainly include sandstone, feldsphatic sandstone, conglomerate and dark shale. The deposition of the Roraima Group was developed in the following principal environments: fluvial, deltaic, coastal lagoon, beach and shallow marine environments (Ghosh, 1981). The paleocurrent measurement on sedimentary sequences of the Roraima Group (Ghosh, 1981), suggest a northeasterly, easterly and southeasterly source of sediments, probably from areas occupied now by the Maroni-Itacaiúnas Belt.

Interbedded with the middle and upper Roraima sediments, sills of mafic rocks and zones of pyroclastic volcanic rocks dated at 1.65 Ga (Priem *et al.*, 1973) are observed. Furthermore the Roraima Group is intersected by several 1.88 - 1.6 Ga mafic sills and dykes (Snelling *et. al.*, 1969; Hebeda *et. al.*, 1973; Teixeira, 1978). Therefore the Roraima sediments may be at least as old as 1.88 Ga and their sedimentation occurred until at least 1.6 Ga.

An age older than 2.3 Ga for the Roraima Block metamorphic basement is here assumed based on the fact that the block is covered by ancient unmetamorphosed acid and intermediate volcanic rocks (1.95 Ga), which have the same age as the neighbouring high-grade metamorphic terranes of the Maroni-Itacaiúnas Province. Thus it is possible to interpret that the Roraima Block acted as a stable foreland to the marginal Paleoproterozoic Maroni-Itacaiúnas Belt.

Maroni - Itacaiúnas Province (MIP)

The Central Amazonian Province is surrounded to the N and NE by the 2.2 - 1.95 Ga MIP, a characteristic of which is a large exposure of metavolcanic and metasedimentary units, deformed and metamorphosed in the greenschist to amphibolite facies. In addition to which there occur granulite facies rocks and and gneiss-migmatite terranes. The southern boundary between the CAP and the MIP, in the northern part of the Serra dos Carajás area, is still uncertain, due to the lack of reliable geological and geochronological information (Table 2).

The Maroni Itacaiúnas Province extends over the eastern part of the Guiana Shield. In the aftermath of the original paper of Cordani *et al.* (1979), several synthesis have delineated the principal features of the MIP (Cordani and Brito Neves, 1982; Bosma *et al.*, 1983; Teixeira *et al.*, 1989; Gibbs and Barron, 1983, 1993). Most of the data on the MIP have been acquired before the 80s. Since that time, only a small number of works have been carried out; most of them in the eastern part of MIP (French Guiana and northern Brazil). New geochronological contributions including Sm/Nd, U/Pb and Pb/Pb results have recently improved the knowledge on the MIP (Gaudette *et al.*, 1996; Tassinari 1996; Sato and Tassinari, 1997; Fraga *et al.*, 1997; Lafon *et al.*, 1998; Vanderhaeghe *et al.*, 1998).

The geographical extension of the MIP includes the eastern part of Venezuela, the Guyana, Suriname, French Guiana and the easternmost part of northern Brazil (Amapá, northern Pará and northeastern Roraima). The MIP represents a widespread domain strongly marked by the Transamazonian Orogeny (2.2-1.95 Ga), which consists of large extensions of Paleoproterozoic crust and some remnants of Archean crust. The MIP covers most of the northeastern part of the Guiana Shield and also includes the northeasternmost part of the Guaporé Shield, S of the Solimões-Amazonas basins, where Paleoproterozoic Rb/Sr and K/Ar ages have been obtained on metamorphic sequences (Santos *et al.*, 1988). The limits of the MIP with adjacent provinces are not well constrained for geographical reasons (rainforest cover, and difficulties of field access) and to the lack of geochronological data. To the N, the Orinoco sedimentary basin limits the MIP. To the W, post-Transamazonian sedimentary cover and widespread Paleo and Mesoproterozoic igneous rocks (Roraima Group and Uatumã Group) overlie the MIP units. In the State of Roraima, the magmatic rocks of the Ventuari Tapajós Province limit the MIP. To the S, in the Guaporé Shield, the limit with the Central Amazonian Province has been estimated to lie to the N of the Carajás Archean Province (Cordani *et al.*, 1984).

The main tectonic features consist of roughly WNW-ESE structural trends from Venezuela to the State of Amapá in Brazil. NE to ENE trending structures are also present. In northeastern Venezuela, the NE-SW striking Guri Fault limits the Archean terranes of the Imataca Complex from the Paleoproterozoic granite-greenstone sequences and gneissic complexes. In Suriname, Guyana, and in northern Roraima, high-grade metamorphic belts are delineated by SW-NE oriented structures that crosscut the E-W trending structures of the granite-greenstone terranes (Bosma *et al.*, 1983).

The geochronological pattern of the Maroni-Itacaiúnas Province is very complete and concordant throughout the whole province, suggesting that its evolution took place during a major event in the Paleoproteorozic between 2.25 and 1.95 Ga (Table 2). In turn, remnants of some older Archean basement within the MIP have been identified. They generally consist of high-grade polymetamorphic rocks, such as the allocthonous (>3.0 - 2.0 Ga) Imataca Complex, in Venezuela (Montgomery and Hurley, 1978; Teixeira *et. al.*, 1999), and the exotic (2.9 - 2.6 Ga) Cupixi terranes in Amapá, Brazil (Lima *et al.*, 1986) that show a strong Paleoproteorozic metamorphic overprint. These ancient nuclei, together with 2.0 - 1.9 Ga Rb/Sr age determinations with high Sr initial ratios of 0.710 obtained on metamorphic rocks from the southern part of the MIP (Santos *et. al.*, 1988), suggest a partial ensialic character for the tectonic evolution of the Maroni-Itacaiúnas Province.

The isotope data for the high-grade metamorphic rocks, considered as the Central Guiana Granulitic Belt, including the Falawatra and Kanuku groups, indicate zircon U/Pb ages and Rb/Sr isochron ages between 2.1 to 1.9 Ga (Priem *et al.*, 1978), and Sm/Nd mantle-depleted model ages ranging from 2.2 to 2.0 Ga (Ben Othman *et al.*, 1984; Vignol, 1987). The geochronological results clearly indicate that the granulitic terranes were separated from the upper mantle during Paleoproteorozic times.

The Rb/Sr, Pb/Pb, Sm/Nd and U/Pb age determinations obtained for syntectonic granitoid plutons and gneissic-migmatitic terranes of "Série Ille de Cayenne", indicate ages in close agreement of 2.1 - 1.95 Ga, with coherent Sr initial ratios around 0.7018 - 0.7024, μ_1 value of 8.2 and positive ε_{Nd} values. These parameters suggest that the rocks were added to the crust during the Paleoproteorozic (Teixeira *et al.*, 1985; Milési *et al.*, 1995).

Detrital zircon U/Pb ages from metagreywacke and conglomerate yielded ages between 2.2 and 2.1 Ga (Gibbs, 1980; Milési *et al.*, 1995). The older ages were interpreted as the basement rock-forming ages. The associated bimodal volcanism gave a Sm/Nd whole-rock isochron of 2.1 Ga (Gruau *et al.*, 1985), which is in close agreement with the detrital zircon U/Pb ages around 2.1 Ga (Egal *et al.*, 1994).

The supracrustal sequences are intruded by different types of granite, with ages around 2.08 Ga (Milési *et al.*, 1995).

Based on the isotope data discussed above, Tassinari (1996) divided the MIP in two domains. The first domain consists of a "sialic" domain composed of reworked old Archean nuclei during the Transamazonian Orogeny as "inliers" within Paleoproterozoic crustal rocks and it is restricted to the southeastern part of the MIP (Pará and Amapá states in Brazil) and the northwestern part of the MIP (Imataca Complex in northeastern Venezuela). The second domain, which covers most of the MIP, corresponds to a "simatic or juvenile" domain developed by juvenile crustal accretion during the Paleoproterozoic era.

Most of the models have been the subject of controversy since the evolution of the MIP is based on geochronological and isotope results. For this reason it is important to review and discuss the results. Several syntheses of the radiometric results have been published (Gibbs and Barron, 1993; Teixeira *et al.*, 1989), but recent geochronological studies have furnished additional geochronological constrains on the evolution of the MIP (Sato and Tassinari, 1997; McReath and Faraco, 1997; Lafon *et al.*, 1998; Vanderhaeghe *et al.*, 1998). Even considering the new data that has appeared in the literature, it is necessary to emphasize the scarcity of reliable radiometric data in such a huge domain. Most of the data have been obtained by Rb/Sr and K/Ar methods, and with the exception of some restricted areas (Central Amapá region: Montalvão and Tassinari, 1984; Lima *et al.*, 1982; João and Marinho, 1982a; Bakhuis Mountains in Surinam: Gaudette *et al.*, 1976) all the Rb/Sr and K/Ar results gave a Paleoproterozoic age. This roughly constrains the Transamazonian evolution in the MIP between 2.1 - 1.8 Ga (Spooner *et al.*, 1971; Amaral, 1974; Lima *et al.*, 1974; Berrangé, 1977; Priem *et al.*, 1977, 1978, 1980; Gibbs and Olszewski, 1982; Bosma *et al.*, 1983; Montalvão and Tassinari, 1984; Teixeira *et al.*, 1984; Gaudette and Olszewski, 1985; Gruau *et al.*, 1985). These ages do not permit us to establish the geochronological succession of the different lithotectonic units in the MIP. Most of the available ages are widely dispersed within the 2.1 - 1.8 Ga range and they must been considered only as cooling ages (see for example the K/Ar results on minerals from the Vila Nova Group in Amapá; Hurley *et al.*, 1968). These dates mainly reflect the end of the Transamazonian Orogeny.

Recently, Sm/Nd (model and isochron ages), Pb/Pb and U/Pb zircon dating has permitted a solution to some problems that the Rb/Sr and K/Ar determinations have not solved and to better constrain the timing of the Transamazonian evolution of the MIP. Geochronological results showing Archean ages in the MIP are very scarce and mostly ambiguous. Only in the northeasternmost part of the MIP, U/Pb and Rb/Sr results on metamorphic and igneous rocks from the Imataca Complex are admitted as recording a complex Archean history (Montgomery, 1979; Montgomery and Hurley, 1978; Teixeira *et al.*, 1999). A Rb/Sr age of about 2.76 Ga on granulitic rocks from the Central Guiana Granulitic Belt in Suriname led Gaudette *et al.* (1976) to propose an Archean age for the protolith of the high-grade rocks but further Rb/Sr dating on whole- rock and U/Pb results on zircon (Priem *et al.*, 1978) do not indicate any involvement of an Archean crust in the metamorphic rocks even if this possibility has not to be definitively discarded (Priem *et al.*, 1978; Bosma *et al.*, 1983). In central Amapá (Cupixi - Tartarugal region), Rb/Sr ages of 2.45 and 2.9 Ga obtained on charno-enderbite and tonalitic orthogneiss, respectively, also suggest the existence of old Archean crustal domains in the MIP (João and Marinho, 1982a; Montalvão and Tassinari, 1984). Pb/Pb ages of about 2.55 - 2.49 Ga obtained on zircon from the Amapá Granulite (Lafon *et al.*, 1998) and Sm/Nd model ages of 3.1 - 2.94 Ga on the tonalite (Sato and Tassinari, 1997) strongly reinforce the involvement of an Archean crust in the southeastern part of the MIP. The existence of detrital zircon in quartzite associated with the Paramaca Formation in the S of French Guiana (Camopi region) suggests that the extension of the Archean crust reworked during the Transamazonian Orogeny in the MIP must be greater than previously believed. The range of ages on the detrital zircon (3.19 - 2.73 Ga) confirms that the segment of Archean crust is similar to that known in the Carajás Archean province (Lafon *et al.*, 1998) as previously suggested by Tassinari (1996).

The U/Pb and Pb/Pb on zircon ages and Sm/Nd, ranging between 2.26 and 2.11 Ga indicate an early Transamazonian age for the emplacement of the greenstone sequences (Gibbs and Olszewski, 1982; Gruau *et al.*, 1985; Gaudette *et al.*, 1996; McReath and Faraco, 1997; Norcross *et al.*, 1998; Vanderhaeghe *et al.*, 1998). The geochronological data are insufficient to establish if all the greenstone sequences are coeval at the scale of the MIP as well as the duration of the greenstone processes. In French Guiana, Pb/Pb and Sm/Nd ages; (Vanderhaeghe *et al.*, 1998) suggest a southward decreasing age for the greenstone sequences, but the large error (± 90 Ma) on the Sm/Nd age of the southern greenstone rocks (Gruau *et al.*, 1985) strongly limits such an interpretation. On a MIP scale, no evident relationships between geographical situation and age of the greenstone sequences may be pointed out. The greenstone belts occur in both juvenile and reworked domains of the MIP but the available Nd isotope data do not suggest any crustal contribution.

The orthogneiss and granitoid rocks widespread in the MIP have given ages Rb/Sr and K/Ar ages mostly between 2.1 and 1.9 Ga. In the juvenile domain, Pb and Sr isotopes (initial Sr: 0.702 - 0.704; $\mu 1 = 8.09$) show that this magmatism has a mantle-derived origin or comes from early Transamazonian crust involved in the orogeny (Teixeira *et al.*, 1985, 1989; Gruau *et al.*, 1985). This hypothesis is strongly reinforced by the existence of 2.22 Ga inherited lead in zircon from French Guiana granitoid plutons (Vanderhaeghe *et al.*, 1998). Granitoid rocks from the Archean reworked domain indicate high initial Sr values (0.712 < initial Sr < 0.760) related to the participation of an old crustal component in the generation of the granite (Santos *et al.*, 1988; Montalvão and Tassinari, 1984). Although high initial Sr has been obtained for high-K granite from central Amapá (Montalvão and Tassinari, 1984), the ε_{Nd} for the same rocks gave a positive value (+ 1.8), which exclude an origin through melting of old crustal material.

The most detailed chronology of the Transamazonian magmatic episodes has been obtained in the northern part of French Guiana (Vanderhaeghe *et al.*, 1998). These authors drawn attention to an episode of trondjhemitic magmatism at 2.17 Ga followed by the emplacement of calc-alkaline intrusions at 2.144 to 2.115 Ga and a late high-K magmatism at 2.09 to 2.08 Ga. The main units of the MIP can be divided into high-grade metamorphic complexes, including granulite and amphibolite gneiss, greenstone terranes and other supracrustal units and granitoid and related magmatic rocks (Teixeira *et al.*, 1989).

High Grade Metamorphic Terranes

Granulite

The main occurrences of granulite in the MIP are found in the Imataca Complex (Venezuela), Central Guyana Granulitic Belt (Suriname, Guyana and northern Roraima) and in the Tumucumaque Granulite Belt in Amapá, Brazil (Kroonenberg, 1976; Lima *et al.*, 1982; Gibbs and Barron, 1983).

The Imataca Terrane

This complex belongs to a 450 km long and 100 km wide belt of high-grade rocks in northernmost Venezuela, limited to the S by the Guri Fault. These rocks are mainly felsic granulite with some intermediate and mafic granulite. They are considered to be of igneous origin and derived from Archean protoliths (3.7 - 3.4 Ga; Montgomery and Hurley, 1978; Montgomery, 1979; and 3.23 - 2.93 Ga and 2.82 - 2.60 Ga; Teixeira *et al.*, 1999). Metasediments are also present. The age of granulitic metamorphism is related to the Transamazonian event between 2.2 - 2.0 Ga (Montgomery and Hurley, 1978), when the Imataca allocthonous block had been juxtaposed to the Maroni - Itacaiúnas Belt.

The Central Guyana Granulitic Belt

The Central Guyana Granulitic Belt is a WSW-ENE elongated belt stretching over at least 1000 km from Roraima (Apiú Complex) to southern Guyana (Kanuku Complex) and Suriname (Falawatra Complex in the Bakhuis Mountains). Most of the rocks are felsic granulite (enderbite dominant and charnockite), with minor amounts of basic granulite and sillimanite gneiss. Two phases of metamorphism have been identified. Whether these phases represent independent metamorphism events or a prograde and a retrograde stage of the same event is yet an outstanding problem.

All the attempts to date the belt gave Transamazonian ages, even if an Archean age has been suggested for the protoliths of the granulite (Gaudette *et al.*, 1976). For the Bakhuis Granulite, a U/Pb zircon age of 2.026 ± 0.02 Ga (Priem *et al.*, 1978) and Sm/Nd model age of 2.3 Ga (Ben Othman *et al.*, 1984) were obtained. The Kanuku Granulite in Guyana gave ages of 2.05 Ga (Rb/Sr, Spooner *et al.*, 1971) and 2.2 Ga (Sm/Nd model age, Ben Othman *et al.*, 1984). In the State of Roraima, zircon U/Pb, Rb/Sr and Sm/Nd ages resulting from analysis of the Kanuku Charnockite are scattered between 2.02 and 1.85 Ga (Lima *et al.*, 1986; Gaudette *et al.*, 1996). Nevertheless, the set of radiometric data, together with the Pb/Pb age of 1.966 ± 0.037 Ga on zircon from a charnockite intrusion (Fraga *et al.*, 1997), strongly suggest that the high-grade rocks are related to a late phase of the Transamazonian Orogeny (*i.e.*, 2.0 Ga or younger). Fraga *et al.* (1997) discussed the nature of this high-grade episode, and suggested that it may be related to charnockitic magmatism. These authors also demonstrated the existence of 1.56 Ga charnockite bodies in the same area, very close to the boundary with the Ventuari-Tapajós Province, associated with 1.54 Ga rapakivi-type granite (Gaudette *et al.*, 1996), reflecting an overprinting of a Mesoproterozoic thermal event related to younger orogenies.

The Tumucumaque Granulitic Belt

The Tumucumaque Granulitic Belt is found in the southeasternmost part of the MIP, mainly in Amapá, with an apparent NW-SE trend. The main occurrence is the Tartarugal Grande Metamorphic Suite in central Amapá. As in others areas, most of the rocks are felsic gneiss and granulite (charnockite, enderbite and hyperstene-free gneiss). Mafic rocks with minor occurrences of quartzite and kinzigite have also been described (João and Marinho, 1982a). These mafic-sedimentary rock associations have been considered as the high-grade equivalents of the greenstone terranes (Vila Nova Group) of Amapá. Rb/Sr dating of charnockite and enderbite indicate an age of 2.45 ± 0.074 Ga (João and Marinho, 1982a) or 2.674 Ga (Montalvão and Tassinari, 1984) depending on the samples included in the isochron calculation. Zircon crystals from a garnet granulite have furnished Pb/Pb ages in the range of 2.58 - 2.49 Ga (Lafon *et al.*, 1998). These ages clearly indicate the existence of Archean protoliths in the Tumucumaque Belt, but do not constrain the age of the granulitic episode.

Gneiss and Migmatite

Other high-grade rocks including amphibolite gneiss and migmatite have been described in the MIP. They have been generally associated with the granulitic rocks even if their relationships are not well defined. In Venezuela, granitic gneiss, amphibolite and migmatite occur in the Imataca Complex. Petrological studies indicate that they represent felsic rocks metamorphosed in the amphibolite facies. A large migmatitic body (La Ceiba Migmatite) has given a Rb/Sr age of about 2.7 Ga for the migmatization.

The Supamo Complex also includes quartz-feldspathic gneiss and migmatite. In the southeastern part of Venezuela, U/Pb and Rb/Sr dating of granitic and quartz-diorite augen gneiss furnished a range of 1.86 to 1.76 Ga for the amphibolite facies metamorphism (Gaudette and Olszewski, 1985). In Guyana, the eastern part of the Kanuku Complex consists mainly of rocks metamorphosed in the amphibolite facies, whereas granulite is dominant in the western part (Berrangé, 1977). The Bartica granitoid and gneiss, may be considered as the equivalent in Guyana of the Supamo Gneiss, and represent an early phase of the Transamazonian magmatism at about 2.25 Ga (Gibbs and Olszewski, 1982).

In southwestern Suriname, amphibolite and sillimanite gneiss are associated with granulite in the Coeroeni Group. These rocks are considered to be mainly of sedimentary origin and have a metamorphic history similar to the Falawatra Group, but were formed at lower pressures (Bosma *et al.*, 1983; De Vletter *et al.*, 1998). Quartz feldspathic gneiss is also described in northeastern Suriname (De Vletter *et al.*, 1998). Geochemical and petrological characteristics suggest that they could represent metamorphosed early Transamazonian granitoid plutons. Amphibolite grade gneiss, mostly of igneous origin, is also present in the northeastern part of the State of Roraima, in association with granulite (Kanuku Complex). The relationships with the granulite are not well defined. Gaudette *et al.* (1996) considered these as syn-tectonic intrusives in the granulite, whereas Fraga *et al.* (1997) suggested that granulite was emplaced within the surrounding orthogneiss. U/Pb ages between 1.94 and 1.88 Ga have been obtained for the protholith emplacement of the orthogneiss which led Gaudette *et al.* (1996) to exclude them from the MIP.

Orthogneiss and migmatite are widespread in French Guiana (Choubert, 1974; Gruau *et al.,* 1985; Marot, 1988, Vanderhaeghe *et al.,* 1998). Metamorphic conditions are generally in the amphibolite facies with local anatexis. In the northern part of French Guiana, the Ille de Cayenne and Central Guyana complexes are considered as high-grade equivalents of Paramaca Volcanics and metamorphic conditions are related to regional contact metamorphism with numerous calc-alkaline plutonic intrusions. (Vanderhaeghe *et al.,* 1998). In the State of Amapá, migmatite also occurs in the central part of the state and is related to high-K magmatism at about 2.06 Ga (Montalvão and Tassinari, 1984). In the Altamira region (Guaporé Shield) amphibolite facies metamorphism, migmatization, and anatexis also affects most of the basement rocks at about 1.99 to 1.93 Ga (Santos *et al.,* 1988).

Greenstone terranes

The Maroni-Itacaiúnas Province is mainly underlain by metavolcano-sedimentary sequences, metamorphosed in the greenschist to amphibolite facies, which are associated with Paleoproteorozic granite-greenstone terranes (Gibbs, 1980). Low-grade to medium-grade volcano-sedimentary rock associations are distributed throughout the MIP, with their major extension in the northwestern part of the Province (Venezuela/Guyana). They show similarities to Archean greenstones of which they are considered as the Proterozoic equivalent (Choudouri, 1980; Gibbs, 1980; Gibbs and Barron, 1993). In like manner to typical Archean greenstone belts, they consist of lower sequences of mainly metavolcanic rocks (ultramafic rocks and basalt with subordinate andesite) and upper sequences consisting mainly of felsic volcanics and metasedimentary rocks. The thickness of the whole sequence may attain 10 km. Gibbs and Barron (1993) have reviewed distribution, rock-types, stratigraphy and correlation between the different belts in each country in detail, but these authors do not speak about the associated granite intrusives, which characterise the granite greenstone associations. Bosma *et al.* (1983) in Suriname, and Gruau *et al.* (1985) and Vanderhaeghe *et al.* (1998) in French Guiana discussed the relationships between granitoid plutons and greenstones sequences. We will comment on this point in the chapter on the granitogenesis in the MIP.

Venezuelan greenstone belts are roughly oriented N-S. They have been included in the Pastora Group that consists of two principal belts: the Paragua-Caroni Belt (western belt) and the Guasipati Belt (central belt). No geochronological data are available for the Pastora Group, but a Paleoproterozoic age has been generally accepted.

In Guyana, three greenstone belts trending NW-SE have been described (Gibbs, 1980), and have been included in the Barama - Mazaruni Supergroup (from N to S: Barama Belt, Cuyuini Belt and Mazaruni Belt). In the Barama Belt some komatiitic rocks have been mentioned (Gibbs and Barron, 1993). An U/Pb age of 2.245 ± 0.086 Ga has been obtained on zircon from metagreywacke of the Cuyini and Mazaruni belts, which support a Paleoproterozoic age for the formation of the greenstones (Gibbs and Olszewski, 1982).

The greenstone belts in Suriname are grouped in the Marowijne Group, and occur in the northern and eastern part of the Suriname. Bosma *et al.* (1983) distinguished a lower Paramaka Formation (mostly mafic volcanics with subordinate intermediate volcanic rocks) from an upper Armina Formation consisting mainly of metagreywacke layers. Metamorphism of the Marowijne Group took place in the greenschist facies, but amphibolite facies rocks are locally described in the proximity of diapiric intrusions of tonalite and trondjhemite. Based on geochemical criteria, Bosma *et al.* (1983) suggested an island arc - back-arc marginal basin for the depositional environment of the Paramaka Volcanics. A Rb/Sr dating on metavolcanic rocks from the Paramaka Formation gave an age of 1.95 ± 0.15 Ga (Priem *et al.,* 1980)

In French Guiana, Choubert (1974), Gibbs and Barron (1983), Gruau *et al.* (1985) and Marot (1988) have described greenstone belts with some modifications in the nomenclature, but all of them are included in the Paramaca Group. They occur mostly in the central and northern parts of French Guiana. Recent work (Egal *et al.,* 1995; Vanderhaeghe *et al.,* 1998) has focused on the greenstones from the northern part of the country (Cayenne - Régina region). The greenstones appear as two belts, which underlie the eastern part of French Guiana and Suriname. The southern belt consists of metamorphosed ultramafic and mafic units (including komatiite) with intermediate to felsic volcanics, followed by the deposition of mainly sedimentary rocks (Choubert 1974; Gruau *et al.,* 1985).

In the northern part of French Guiana, Vanderhaeghe *et al.* (1998) described the northern greenstone belt as two main complexes separated by a sedimentary basin (Orapu Basin). These complexes (Isle de Cayenne and Central Guyana complexes) include metavolcanic and volcaniclastic rocks of the Paramaca Formation (mainly dacitic and andesitic rocks with subordinate basaltic and rhyolitic rocks) that have undergone metamorphism from the greenschist to amphibolite facies. These sequences together with the sediments of the Armina Formation constitute the Lower Volcanic and Sedimentary Unit. Gruau *et al.* (1985) provided a Sm/Nd age of 2.11 ± 0.09 Ga for the metavolcanics for the formation of the greenstones of the southern belt. In the northern greenstone belt, the age of formation of the greenstones is indirectly constrained by the 2.216 ± 0.004 Ga, 2.174 ± 0.007 Ga and 2.144 ± 0.006 Ga on associated trondjhemite and calc-alkaline plutons (Vanderhaeghe *et al.,* 1998).

In northern Brazil greenstone sequences occur as sub-parallel belts defining trends roughly oriented in a NW-SE in Amapá and northeastern Pará. They have been grouped in the Vila Nova Group (Lima *et al.*, 1974) and their rock-types mainly consist of mafic and ultramafic schist at the base to dominantly metasedimentary formations at the top (mostly quartzite, BIF and metaconglomerate). The high Mg character of the mafic-ultramafic rocks suggests a komatiitic affinity (João *et al.*, 1979). The stratigraphic position and nomenclature have been controversial (Lima *et al.*, 1982; João and Marinho 1982a). This applies especially to the central part of Amapá because of the uncertain relationships with neighbouring high-grade rocks and ambiguous geochronological results in the country rocks, which led some authors to consider them as Archean (João and Marinho, 1982a). Rb/Sr results on whole-rock and K/Ar on mica and amphibole from amphibolite of the Serra do Navio greenstone belt range between 2.09 and 1.76 Ga (Hurley *et al.*, 1968; Basei 1977; Montalvão and Tassinari, 1984). Recently, McReath and Faraco (1997) reported a Sm/Nd age of 2.264 ± 0.034 Ga for the Vila Nova Group in northeastern Pará (Ipitanga Greenstone Belt) in close agreement with the previous Sm/Nd and U/Pb ages available for the others greenstones in the MIP (Gibbs and Olszewski, 1982; Gruau *et al.*, 1985).

Other supracrustal formations

Other supracrustal formations may be distinguished from the greenstone belts mainly because of the lack of basic volcanic rocks and the predominance of metasedimentary sequences (Gibbs and Barron, 1993). Relationships with the greenstone belts are generally controversial. For example, in Roraima, the NW to WNW trending Parima - Cauarane belts have been considered as greenstone belt sequences and dated at 2.235 ± 0.019 Ga (Gaudette *et al.*, 1996), whereas Gibbs and Barron (1993) described them as separate units. In southwestern Suriname, quartz-feldspathic and pelitic gneiss with amphibolite, quartzite and calc-silicate rock mainly constitute the Coeroeni Group (Kroonenberg, 1976). Bosma *et al.* (1983) considered the Coeroeni Group as an intracratonic basin similar to the present-day Amazonas River Basin. The age of the Coeroeni Group is poorly constrained by a Rb/Sr age of 2.042 ± 0.097 Ga (Priem *et al.*, 1977). In French Guiana, Ledru *et al.* (1991, 1994) have discussed the relationships between the Paramaca Formation and Orapu and Bonidoro series and resolved discrepancies on correlation with the Suriname formations (Armina and Rosebel formations). They describe a Lower Volcanic Sedimentary Unit and an Upper Sedimentary Unit which have been formed, respectively, in oceanic (volcanic rocks, tholeiitic and with calc-alkaline affinities) and intra-continental (fluvio-deltaic deposits) environments. The former stage corresponds to a pre 2.1 Ga magmatic accretion episode, whereas the latter stage is related to a post 2.1 Ga crustal recycling episode (Vanderhaeghe *et al.*, 1998).

Granitoid plutons

The most representative rocks in the whole MIP are granitoid and orthogneiss. Excluding the orthogneissic rocks from the Imataca Complex, and tonalitic orthogneiss from the central-southern part of Amapá in Brazil (Cupixi region), all the granitoid plutons present paleoproterozoic ages, related to the Transamazonian Orogeny. Distinctions between different types of granitoid have been proposed according to geographical occurrence, petrological and structural features, relationships with supracrustal sequences and, more recently, on geochronological criteria. Even if some local peculiarities between different countries can be pointed out, two main phases of granitogenesis are normally accepted in the MIP (Teixeira *et al.*, 1989; Gibbs and Barron, 1993).

The first granitic episode consists of syn-tectonic intrusions and orthogneiss, mostly of tonalitic, trondjhemitic and granodioritic composition and with high Na content (Supamo Granitoid in Venezuela, Bartica Orthogneiss in Guyana, "Guianais" Granite in French Guiana). These granite bodies are coeval with the main deformational event and are associated with the greenstone belts. The second granitic phase is represented by late to post-tectonic granite intrusives with K or calc-alkaline affinities ("Caraïbes" Granite in French Guiana). In Suriname, Bosma *et al.* (1983) described the Transamazonian granite intrusives in the domain of the MIP. Granitoid plutons associated directly with the greenstone sequences consist of mainly tonalitic to trondjhemitic diapiric intrusions within the Paramaca Formation, whereas the two-mica leucogranite results from anatexis of crustal rocks within the Armina Formation. This distribution roughly corresponds to the different granite-types described in French Guiana. Most of the available ages on the Transamazonian granites have been obtained by Rb/Sr and K/Ar methods and gave a range of ages between 2.3 - 1.8 Ga (Teixeira *et al.*, 1989; Gibbs and Barron 1993; Tassinari, 1996). In the northern part of French Guiana, Vanderhaeghe *et al.* (1998) refer to the existence of granitoid of calc-alkaline affinity (tonalite and granodiorite) associated with continental crust accretion (2.144 - 2.115 Ga) and late crustal derived K-rich granite and peraluminuous granite related to crustal recycling (2.093 - 2.083 Ga). U/Pb ages in the same range have been obtained by Norcross *et al.* (1998) for a post-tectonic intrusion in northwestern French Guiana. In northern Brazil (Amapá), the distinction between different phases of granite intrusion are difficult. In the central part of Amapá, K-rich granite has been dated at 2.06 Ga (Montalvão and Tassinari, 1984). Early Na-rich and late K-rich granite bodies have also been described in central Amapá (João and Marinho, 1982b)

Post Transamazonian units

The thermal evolution of the Transamazonian Orogeny is shown by the Rb/Sr and K/Ar systems of minerals indicating that they decreased from 500 to 300°C between 2.08 and 1.76 Ga (Montalvão and Tassinari, 1984; Tassinari, 1996). After the end of the Transamazonian Orogeny, the Maroni-Itacaiúnas Province behaved as a cratonized area, and no widespread magmatic-metamorphic event has yet been described. Locally, some magmatic activity has been observed. In Amapá, some felsic intrusions (Falsino Suite) and alkaline intrusions (Mapari Suite) have been dated at about 1.76 Ga (Tassinari *et al.*, 1984) and 1.68 - 1.34 Ga (Montalvão and Tassinari, 1984), respectively. In central Suriname, pyroclastic volcanic rocks interbedded in weakly metamorphosed continental sediments showed a 1.66 Ga Rb/Sr age (Priem *et al.*, 1973). Dolerite dykes of the same age or slightly older are also found in Suriname (Hebeda *et al.*, 1973; Norcross *et al.*, 1998) and in Guyana (Snelling and McConnell, 1969). In western Suriname, a 1.2 ± 0.1 Ga widespread mylonitization event (Nickerie Metamorphic Episode) has been determined by Rb/Sr and K/Ar analyses on mica. Locally, mica from rocks of southern Guyana also shows the same event (Snelling and McConnell, 1969). Permo-Triassic dolerite dyke swarm emplacement related to the opening of the Atlantic Ocean is well constrained between 221 Ma and 195 Ma in French Guiana and Suriname (Priem *et al.*, 1968; Deckart *et al.*, 1997).

Ventuari - Tapajós Province (VTP)

The western part of Amazonian Craton was assembled through a succession of magmatic arcs from 2.0 to 1.40 Ga involving the Ventuari-Tapajós, Rio Negro-Juruena and part of Rondonian-San Ignacio provinces. In this way the VTP corresponds to the first magmatic arc, which was accreted to the protocraton consisting of the Central Amazonian and Maroni-Itacaiúnas provinces. The VTP occurs in a prominent NW-SE trend and can be followed from the Ventuari River in southern Venezuela to the Tapajós River in Brazil (Fig. 1). The VTP, as a whole, exhibits a geochronological pattern slightly younger than the Maroni Itacaiúnas Province, with ages ranging from 2.0 Ga to 1.8 Ga (Table 3). The rock-types of the VTP, although not thoroughly documented, differ substantially from those of the MIP. The VTP consists mainly of calc-alkaline granitoid, whereas the MIP includes a large amount of metavolcano-sedimentary sequences and granulitic rocks among others.

Metamorphic Basement

The northern part of VTP is underlain by granite-gneiss having a granodioritic to quartz-dioritic composition; gabbro and amphibolite, which occur within the Ventuari petrotectonic domain (Barrios, 1983). U/Pb zircon ages between 1.85 and 1.83 Ga are available for the Macabana and Minicia gneiss and the Atabapo quartz-diorite, which are in close agreement with Rb/Sr age determinations of 1.83 Ga and Sr initial ratios around 0.7027 (Gaudette and Olszewski, 1981; Tassinari *et al.*, 1996).

The basement of the southern part of VTP, included in the Cuiú-Cuiú Complex (Pessoa *et al.*, 1977) and within the slightly younger Parauari Suite, has almost the same lithological assemblage described above, predominantly with calc-alkaline granodioritic rocks and gneiss of tonalitic composition, metamorphosed in the amphibolite facies. The zircon U/Pb determinations and whole-rock Rb/Sr ages vary from 2.0 to 1.85 Ga (Vignol, 1987; Gaudette *et al.*, 1996; Tassinari, 1996; Iwanuch, 1999). In general, the southern part of the province is older than the northern region, which suggest magmatic arc evolution and the production of new continental crust within the VTP. This began in the S and became progressively younger toward the N. The Sm/Nd crust-formation ages of 2.1 to 2.0 Ga (Sato and Tassinari, 1997) are found throughout the province, indicating the main period of continental accretion in the VTP. $\varepsilon_{Nd(2.0\ Ga)}$ values range from + 2.1 to - 1.6 (Sato and Tassinari, 1997), which suggest a mixing of some subordinate crustal component with predominantly mantle-derived magma. This mixture is due to the fact that external zones of VTP were developed on or adjacent to the Archean Central Amazonian Province.

The southern part of the VTP differs from the northern in having scattered occurrences of greenschist facies metavolcano-sedimentary sequences, which are included in the supracrustal Jacareacanga Suite (Santos *et al.*, 1997). They consist of schist, phyllite, metachert, banded iron formation units, and talc schist. The unit shows a U/Pb detrital zircon age and U/Pb zircon age of 2.1 to 1.92 Ga for the Parauari intrusive granitoid (Santos *et al.*, 1997).

Sedimentary Platform Covers and Associated Magmatism

The southern part of the VTP contains the alkaline to calc-alkaline Iriri acid to intermediate volcanic rocks and associated Maloquinha Granitoid with ages between 1.89 and 1.84 Ga (Santos *et al.*, 1997; Vasquez *et al.*, 1999; Moura *et al.*, 1999), and the acid to intermediate Teles Pires volcano-plutonism dated at *c.* 1.7 - 1.6 Ga (Basei, 1977; Silva *et al.*, 1980; Tassinari, 1996). The age of the volcanism indicates the time that the basins began to subside. These unmetamorphosed volcano-plutonic rocks mainly include rhyolite, rhyodacite, tuff, volcanic conglomerate, quartz-porphyry and dacite. Anorogenic ring granitic bodies with subvolcanic characteristics occur associated with the acid volcanism. In general these rocks are adamelite, granite porphyry, granite, riebeckite-granite, and rapakivi granite, locally with cataclastic textures. Geochemical characteristics suggest an alkaline, calc-alkaline and peralkaline composition for the granitoid (Silva *et al.*, 1980).

Sedimentary platform cover of the Gorotire and Beneficente groups, probably associated with foreland basins and dated at 1.8 - 1.6 Ga and 1.7 - 1.4 Ga, respectively (Santos *et al.*, 1997; Tassinari *et al.*, 1978), overlies these undeformed volcanic rocks that are intruded by 1.6 to 1.3 Ga mafic dykes. These sedimentary sequences, mainly composed of quartz-arenite, argillite, arkose, siltite, chert and carbonate rock such as limestone and dolomite, are typical of shallow marine deposits. The Beneficente Group is tectonically limited by NE-SW trending faults, and it was deposited across the southwestern margin of the Ventuari-Tapajós Province. The sedimentary deposition is coeval with tectonic evolution of the Rio Negro-Juruena Orogeny, which took place along the western side of the VTP between 1.8 and 1.55 Ga.

Rapakivi Granite and Associated Magmatism

The 1.55 Ga El Parguaza and Surucucus anorogenic, intra-plate, rapakivi granite bodies (Tassinari, 1996; Santos *et al.*, 1999) occur in the northern part of the VTP. Likewise, within the transition zone between the VTP and MIP there occur the 1.55 Ga rapakivi granite of the Mucajaí Suite and the associated Repartimento Anorthosite and the Serra da Prata

Charnockite that form part of a Charnockitic-Anorthositic-Rapakivi association, related to the Parguaza event (Fraga and Reis, 1995; Fraga *et al.*, 1997; Santos *et al.*, 1999).

The important anorogenic rapakivi magmatism occurring to the N of the VTP and dated at around 1.55 Ga may be a product of fractionation of magma from the base of the crust, involving material produced by partial melting of upper mantle and the lower-middle part of the continental crust. Although this magmatism occurred within a tectonicaly stable area of the VTP, it is related to orogenic processes of the neighbouring Rio Negro-Juruena Province due to the fact that convergent processes produced chemical changes in the upper mantle that may have led to crustal melting and rapakivi magmatism (Haapala and Rämo, 1995). The large volumes of rapakivi magmatic rock in the area show the importance of the continental accretion in the northwestern part of the Amazonian Craton, at the beginning of the Mesoproterozoic time.

Western Amazonian Craton

The western part of the Amazonian Craton, in like manner to the Grenville Province of Canada, is a multi-orogen region formed between 1.8 and 1.0 Ga where successive magmatism, metamorphism and deformation occurred that regionally affected and reworked precursor provinces, producing new complexes, as well as new juvenile continental crust.

Three major geochronological and tectonic provinces (*sensu* Cordani *et al.*, 1979; Teixeira *et al.*, 1989; Tassinari and Macambira, 1999) occur in the western part of the craton. These are the Rio Negro-Juruena Province (1.8 - 1.55 Ga), the Rondonian/San Ignacio Province (1.55 - 1.3 Ga), and the Sunsas Province (1.3 - 1.0 Ga). Recent advances in the understanding of the evolution of these provinces, based on new geochronological and geological data (Tassinari *et al.*, 1996; Tassinari, 1996; Sato and Tassinari, 1997; Sato, 1998; Van Schmus *et al.*, 1998; Geraldes *et al.*, 1999; Geraldes, 2000; Rizzoto, 1999; Payolla *et al.*, 1998; Pinho *et al.*, 1997; Bettencourt *et al.*, 1997, 1999) amongst others, provide the basis upon which it is possible to subdivided the provinces by orogenies and terranes. The orogenies are defined in terms of their foreland thrust-fold belts, Andean-type magmatic arcs, basement reactivation, transcurrent shearing, thrusting and deformed foredeep sedimentary prisms.

There remain many unanswered questions about the crustal evolution of the southwestern cratonic area, and a major practical obstacle in deciphering the complex evolution is the lack of a comprehensive nomenclature and consensus for describing various geochronological tectonic provinces, tectonic zones, mobile belts, orogens, terranes, domains, blocks, inferred arcs, detailed geological mapping, and precise geochronological data. As a result, conflicting interpretations have been made concerning the boundaries, distribution, evolution, and the real meaning of these provinces. These facts make it critical to unify and separately analyze the different orogens, which might allow temporal correlation of units and provide better constraints for plate tectonic reconstruction. Available information indicates that a variety of different geological environments are represented within the western Amazonian Craton, and consequently some terranes and orogenies can be separated from whole geochronological provinces. With this in mind we now propose the following major preliminary components and their subdivisions, showed in Figure 3:

- Rio Negro - Juruena Province (1.8 - 1.5 Ga)
  - Alto Jauru Greenstone Belt (1.79 - 1.75 Ga)
  - Cachoeirinha Orogen (1.58 - 1.52 Ga)
- Rondonian - San Ignacio Province (1.5 - 1.29 Ga)
  - Rio Alegre Terrane (1.5 Ga)
  - Santa Helena Orogen (1.47 - 1.42 Ga)
  - Rondonian-San Ignacio Orogen (1.4 - 1.29 Ga)
- Sunsas Province (1.3 Ga - 980 Ma)
  - Sunsas Cycle, in Bolivia (1.25 Ga - 900 Ma)
  - Aguapeí Thrust Belt (1.0 Ga - 950 Ma)
  - Nova Brasilândia Terrane (1.11 - 1.0 Ga).
  - Sunsas Orogenesis in Central-Northern Rondônia and Adjacent Areas (1.08 Ga - 980 Ma)

The Proterozoic basement in the western part of the Amazonian Craton, and in particular in the southwestern part, consists of igneous and metamorphic associations. The Rio Negro-Juruena Province basement rocks include several domains of distinctly different rock-types, including several volcano-sedimentary belts, felsic plutonic-gneiss and intrusive granitoid. Two main accretionary events are described for the Rio Negro-Juruena Province. According to Tassinari *et al.* (1996); Van Schmus *et al.* (1999); Geraldes *et al.* (1999) the first comprises the Jamari and Roosevelt terranes of Scandolara *et al.* (1999c) in northern Rondônia; the Alto Jauru greenstone belt of Pinho *et al.* (1997) and Geraldes (2000) in Mato Grosso. These events were defined by U/Pb ages from 1.79 to 1.717 Ga for gneiss and volcanic rocks. The second event, named the Cachoeirinha Orogen (Geraldes *et al.*, 1999) is defined in the same geographical area as the first event and consists of tonalite, granodiorite and granite with ages of *c.* 1.57 - 1.52 Ga (Tassinari *et al.*, 1996; Geraldes, 2000).

Rondonian-San Ignacio events have traditionally been regarded as extending from 1.5 to 1.29 Ga, with a wide geochronological distribution (Fig. 3). New geochronological data are now demonstrating that orogenic events such as the proposed Rio Alegre Terrane (1.5 - 1.49 Ga), Santa Helena Orogeny (1.47 - 1.42 Ga) and Rondonian-San Ignacio Orogeny (1.4 - 1.29 Ga) may be included in the Rondonian-San Ignacio Province.

Moreover it is postulated that the events previously defined between 1.6 Ga - 970 Ma through Rb/Sr isochron ages, within the southwestern part of the craton, need redefinition since Bettencourt *et al.* (1999a) argued that U/Pb zircon ages for the rapakivi suites of the Rondônia area are consistently older than the Rb/Sr isochron ages for the same plutons. The differences being 200 and 150 Ma for plutons older than 1.5 Ga, 100 Ma for those between 1.41 and 1.3 Ga and 4 to 30 Ma for the younger granite with ages situated between 1.08 Ga and 970 Ma. Similar situations were partially recorded in the southwestern Mato Grosso by Van Schmus *et al.* (1998) and Geraldes (2000).

The Sunsas Province is formed by two terranes already described (Sunsas in Bolivia, and Aguapeí in Brazil), the recently-defined Nova Brasilândia Terrane (Rizzoto, 1999a,

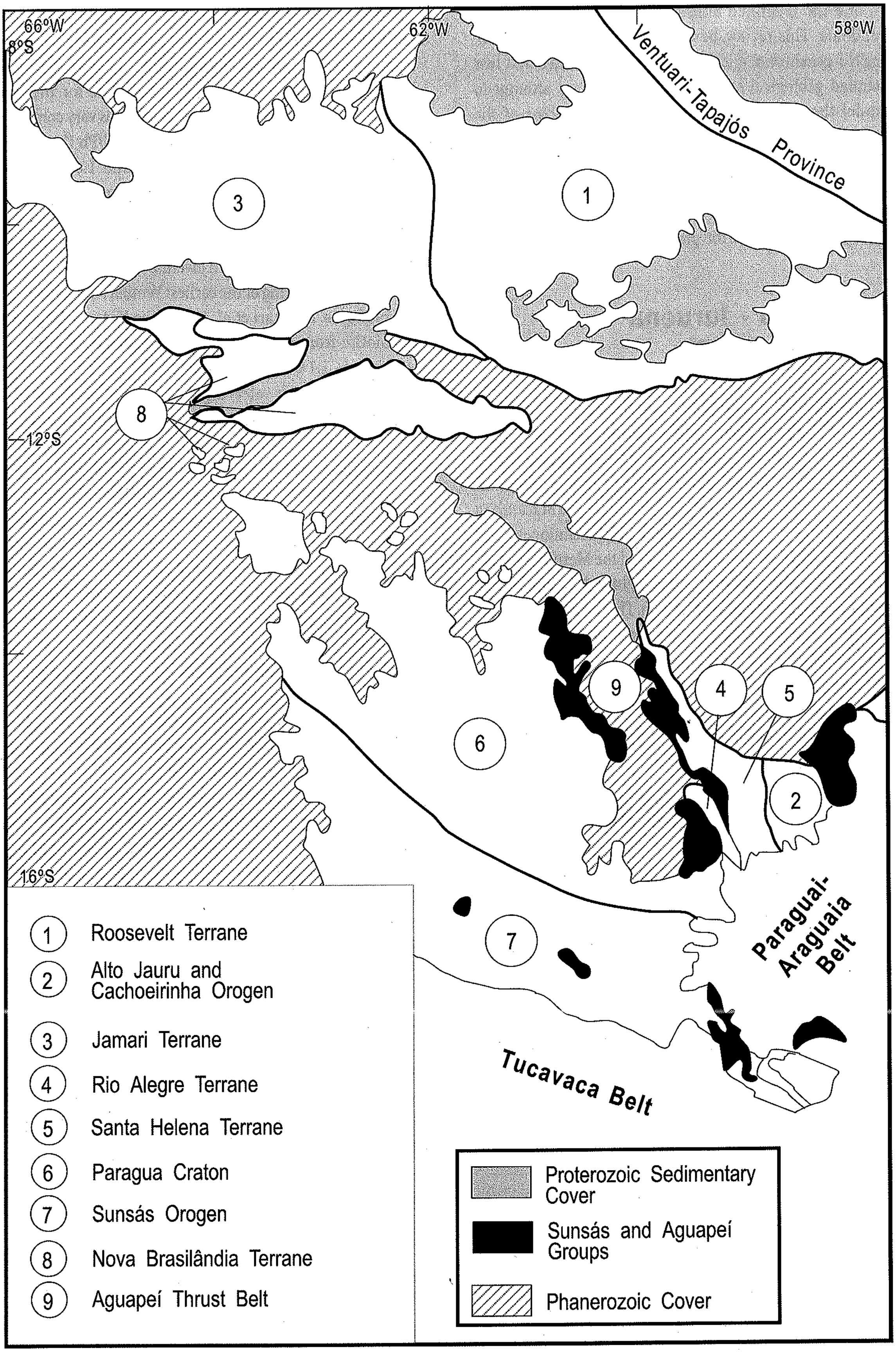


FIGURE 3 - Tectonic map of SW Amazonian Craton showing provinces and orogens.

b), and the redefined Sunsas event in central-northern Rondônia. This review, based mainly on the recent U/Pb, Sm/Nd geochronological data, chemical studies and less detailed geological surveys, is a preliminary attempt to model the Proterozoic evolution of this sector of the Amazonian Craton. It also aims to stimulate further research into the temporal correlation between the tectonic events in the southwestern part of the Amazonian Craton and those of the Laurentian and Baltic shields, thereby providing constraints for plate tectonic reconstruction.

Rio Negro - Juruena Province (RNJP)

The Rio Negro-Juruena Province was defined by Cordani *et al.* (1979) and Tassinari (1981), based on Rb/Sr and K/Ar ages between 1.75 and 1.5 Ga, as a geochronological province consisting of a juvenile mobile belt. Furthermore, Tassinari (1984), Tassinari *et al.* (1996) and Tassinari and Macambira (1999), based on other geochronological techniques, such as Pb/Pb, U/Pb and Sm/Nd, considered the Mesoproterozoic basement of the province as developed by successive magmatic arcs during 1.8 to 1.55 Ga. The basement includes several domains of different rock-types, including volcano-sedimentary belts, felsic plutonic-gneiss and granitoid intrusions. Extensive continental platform molasse or marine sedimentary rocks of Mesoproterozoic, Paleozoic and Mesozoic age fill rift basins within the province.

General Geological Aspects

The Rio Negro - Juruena Province is situated on the western side of the VTP, and its exposures straddle a NW-SE trend approximately 2000 km long and 600 km wide (Fig. 1) in the western part of the Amazonian Craton. The northern region (Uaupés) covers part of Brazil, Venezuela and Colombia and the southern region (only in Brazil) includes the states of Amazonianas, Rondônia and Mato Grosso. Juvenile Paleoproterozoic and Mesoproterozoic crust accreted to the western margin of the Ventuari-Tapajós Province during at least two orogenic events (1.8 - 1.7 Ga and 1.65 - 1.55 Ga) is exposed in the Rio Negro-Juruena Geochronological Province.

Metamorphic Terranes (Basement Rocks)

The basement rocks of the RNJP are composed almost entirely of 1.8 - 1.55 Ga granite-gneiss and granitoid of mainly granodioritic and tonalic composition. Generally the rocks are metamorphosed to the amphibolite facies, although some granulite facies rocks are also present. In the N there mainly occurs biotite-titanite monzogranite (Dall'Agnol and Macambira, 1992), and part of the basement complex extends into Colombia, where it is included in the Mitu Complex (Galvis *et al.*, 1979) and into Venezuela, where they form part of the Casiquiare Petrotectonic Association (Barrios, 1983). On the other hand, in the southern part, granite-migmatite terranes and gneiss of tonalitic composition compose the basement rocks. The general strike of the metamorphic rocks is NW-SE that is crosscut in some areas by NE-SW trending shear zones (Lima *et al.*, 1986).

The geochronological pattern available for the Rio Negro-Juruena Province basement (Table 4) is very complete and coherent, involving Rb/Sr, Pb/Pb and U/Pb (including SHRIMP) ages within 1.8 and 1.7 Ga and 1.65 - 1.5 Ga intervals. Sm/Nd mantle-depleted model ages ranging from 2.0 to 1.7 Ga, which suggest that the protholiths of the basement rocks are composed by mantle-derived magma and also by a mixing between juvenile material and magma produced by recycling of the earliest Ventuari-Tapajós crust. According to Tassinari *et al.* (1996) the K/Ar cooling ages on biotite from the granite-gneissic rocks yielded ages within 1.4 - 1.1 Ga interval. In this way, the older K/Ar ages are interpreted as referring to the uplift and tectonic stabilization of the area, and the younger K/Ar ages may be related to the reheating produced by anorogenic magmatism and a thermal-shearing Nickerie event of Priem *et al.* (1973).

The biotite-titanite monzogranite of the Rio Negro area (N of the RNJP) yielded whole-rock Rb/Sr and Pb/Pb isochron ages of 1.7 Ga and 1.63 Ga, respectively (Tassinari, 1984), and zircon U/Pb ages of 1.7 and 1.52 Ga (Tassinari *et al.*, 1996). Gneiss of tonalitic composition from the Casiquiare and Siapa domains in Venezuela gave a whole-rock Rb/Sr isochron age between 1.78 and 1.62 Ga (Barrios, 1983; Gaudette and Olzewski, 1981). In the southern part of the province, gneiss and granitoid rocks from the Porto Velho-Juruena area yielded SHRIMP U/Pb zircon ages of 1.75 and 1.57 Ga and whole-rock Rb/Sr and Pb/Pb isochron ages of 1.7 Ga (Tassinari *et al.*, 1996).

Younger metamorphic overprints in some regions of the RNJP occur in the southern part of the province as determined by zircon U/Pb ages of 1.42 Ga from gneissic rocks (Payolla *et al.*, 1998), and 1.34 Ga from granulitic rocks (Tassinari *et al.*, 1999). In the northern part of the province, superimposed geological events are shown by a Rb/Sr isochron age of 1.46 Ga obtained from the Uaupés Granitoid (Dall'Agnol and Macambira, 1992), and a Pb/Pb evaporation age of 1.52 Ga defined a two-mica granitoid from the Içana River area (Almeida *et al.*, 1997).

The virtual absence of older ages in the SHRIMP U/Pb zircon analysis; the low values of the initial $^{87}Sr/^{86}Sr$ ratios between 0.702 and 0.706; the μ_1 values around 8.1 and the positive and low negative $\varepsilon_{Nd(1.8\,Ga)}$ values relative to CHUR (+ 4 to - 2), suggest, for most of the Rio Negro-Juruena basement rocks, no contamination from Archean crust. However, these data suggest mixing between juvenile mantle-derived magma with some recycled subordinate older material.

Supracrustal sequences are scattered within the Rio Negro-Juruena Province. They are represented in the southern part of the province, by the Roosevelt metavolcano-sedimentary unit, which is composed by dacite, ryolite, andesite, tuff, volcanic breccia, claystone, sandstone, and banded iron formation units, metamorphosed in the greenschist facies. Zircon from dacite yielded U/Pb age of 1.74 Ga (Santos *et al.*, 1999), whereas a whole-rock Rb/Sr isochron for the volcanic rocks gave an age of 1.56 Ga (Tassinari, 1996). The older age is interpreted as the time of volcanism, and the younger age could be related to the metamorphism.

Small remnants of quartzite of Tunuí Group occur at scattered localities in the northern part of the province. The quarzite beds are crosscut by the 1.52 Ga Uaupés Granitoid (Almeida *et al.*, 1997), which allow us to suppose a time between 1.8 and 1. 52 Ga for the deposition and metamorphism of these sequences. The K/Ar cooling ages of 1.3 and 1.0 Ga obtained on muscovite from the metasediments (Pinheiro *et al.*, 1976) reflects the effect of the mylonitic Nickerie Episode with ages around 1.1 Ga (Priem *et al.*, 1973).

Sedimentary Platform Cover and Associated Magmatism

In the southern part of the Rio Negro-Juruena Province there are exposed undeformed volcano-sedimentary rocks of Caiabis Group, which can be divided into the Dardanelos and Arinos formations. Mainly volcaniclastic rocks, such as ignimbrite and tuff associated with greywacke, arkose and rhyolitic-rhyodacitic rocks compose the Dardanelos Formation. Samples from the acid volcanic rocks define a Rb/Sr reference isochron age of 1.44 Ga, which was interpreted as the age of the volcanism. Furthermore, the alkaline, tholeiitic and calc-alkaline basalt of the Arinos Formation, which is interlayered in the sedimentary rocks of the Dardanelos Formation, yielded whole-rock K/Ar ages of 1.4 and 1.2 Ga, respectively, for the lower and upper basaltic flows (Tassinari *et al.*, 1978). These geochronological results define the minimum depositional age of the sedimentary sequence. The alkaline basalt flows are associated with the 1.2 Ga Canamã alkali-syenite, which occurs in the northwestern part of the area underlain by the Caiabis Group.

The volcano-sedimentary rocks of the Caiabis Group are related to a rift system that has a NW-SE trend, produced by break-up of stable continental regions, as a reflex of orogenic activities in neighbouring areas, related to the evolution of the Rondonian-San Ignacio and Sunsas provinces. On the other hand, in the northern part of the Rio Negro-Juruena Province, where the volcano-sedimentary sequences are less commom, some volcanic rocks from the Traira River area, interlayered with some sandstone beds, yielded a Rb/Sr isochron age of 1.5 Ga (Pinheiro *et al.*, 1976).

Mafic magmatism associated with dykes swarm, which crosscut sedimentary sequences as well as basement rocks, occurs within three different periods; the older period between 1.4 and 1.35 Ga, and the two other periods ranging from 1.25 to 1.15 Ga, and between 1.0 and 0.95 Ga. These magmatic episodes are related to terminal igneous activity of the orogenies younger than 1.6 Ga. (Bettencourt *et al.*, 1995; Teixeira, 1978; Olszewski *et al.*, 1989; Tassinari, 1996).

Anorogenic Granitoid Magmatism

The anorogenic granitoid magmatism within the southern part of the Rio Negro - Juruena Province is represented by A-type granite and within-plate granite bodies, mainly of syenogranitic and monzogranitic composition, some of them with rapakivi textures, associated with gabbro, syenite, mangerite and charnockite. A rapakivi-granite suite of different age, petrology and geochemistry intruded the basement rocks of the Rio Negro-Juruena Province. These magmatic episodes were accompanied by a few bodies of anorthosite and mangerite, charnockite, mafic dykes and flows, as well as by an alkaline complex. These rocks are included in several granitic suites the ages of which are summarized in Tassinari *et al.* (1996) and Bettencourt *et al.* (1999a). These results showed that the typical anorogenic plutonism was emplaced periodically between 1.6 Ga and 970 Ma.

The rapakivi rocks in the states of Rondônia and Mato Grosso are represented by the Serra da Providência Intrusive Suite, which comprises the granite of Serra da Providência Batholith as well as satellite stocks as described by Leal *et al.* (1976, 1978) in the southeastern part of the Rondônia Tin Province. Gabbro, charnockite and mangerite were included in the suite by Rizzoto *et al.* (1996). This batholith comprises an elongated oval-shaped gabbro-charnockite-mangerite-granite *c.* 140 km long by 40 km wide (Bettencourt *et al.*, 1999a). The four main granitoid units recognized by Rizzoto *et al.* (1996) are porphyritic monzogranite (pyterlite) with subordinate wiborgite, porphyritic monzogranite, equigranular syenogranite and granite porphyre. An U/Pb zircon age reported by Bettencourt *et al.* (1999) yielded 1.606 ± 0.024 Ga for the oldest intrusion, whereas the porphyritic hornblende-biotite monzogranite has an interpreted age of 1.573 ± 0.015 Ga. Piterlite yielded an age of 1.566 ± 0.005 Ga, which is in close agreement with the zircon U/Pb SHRIMP age of 1.588 ± 0.016 Ga reported by Tassinari *et al.* (1996). The associated Ouro Preto Charnockite yielded a zircon U/Pb age of 1.532 ± 0.024 Ga (Van Schmus, personal communication).

The deformation of the Serra da Providência Intrusive Suite together with the surrounding older Rio Negro-Juruena basement probably evolved within a transpressional tectonic regime, which probably occurred during the Rondonian-San Ignacio Orogeny. This may have occurred before the emplacement of the undeformed 1.41 Ga Santo Antonio rapakivi granite (Bettencourt *et al.*, 1999a). Another possibility is that it might be chrono-correlated with the evolution of the Cachoerinha Magmatic Arc at *c.* 1.58 - 1.52 Ga as suggested by Geraldes *et al.* (1999) in the Jauru region in the southeastern part of the Rondônia Tin Province in the State of Mato Grosso.

Orogenies and Terranes in the Southern Rio Negro-Juruena Province

The Rio Negro-Juruena Province is one of the most poorly known provinces in the southwestern part of the Amazonian Craton, apart from the northern part of State of Rondônia and adjacent areas (Jamari and Roosevelt terranes) for which more precise geological and geochronological data are being obtained. This fact makes it difficult to distinguish the different orogens or terranes within this huge province, mainly in the northern part. However in the southern part of the province, in the southwestern region of the State of Mato Grosso, we can

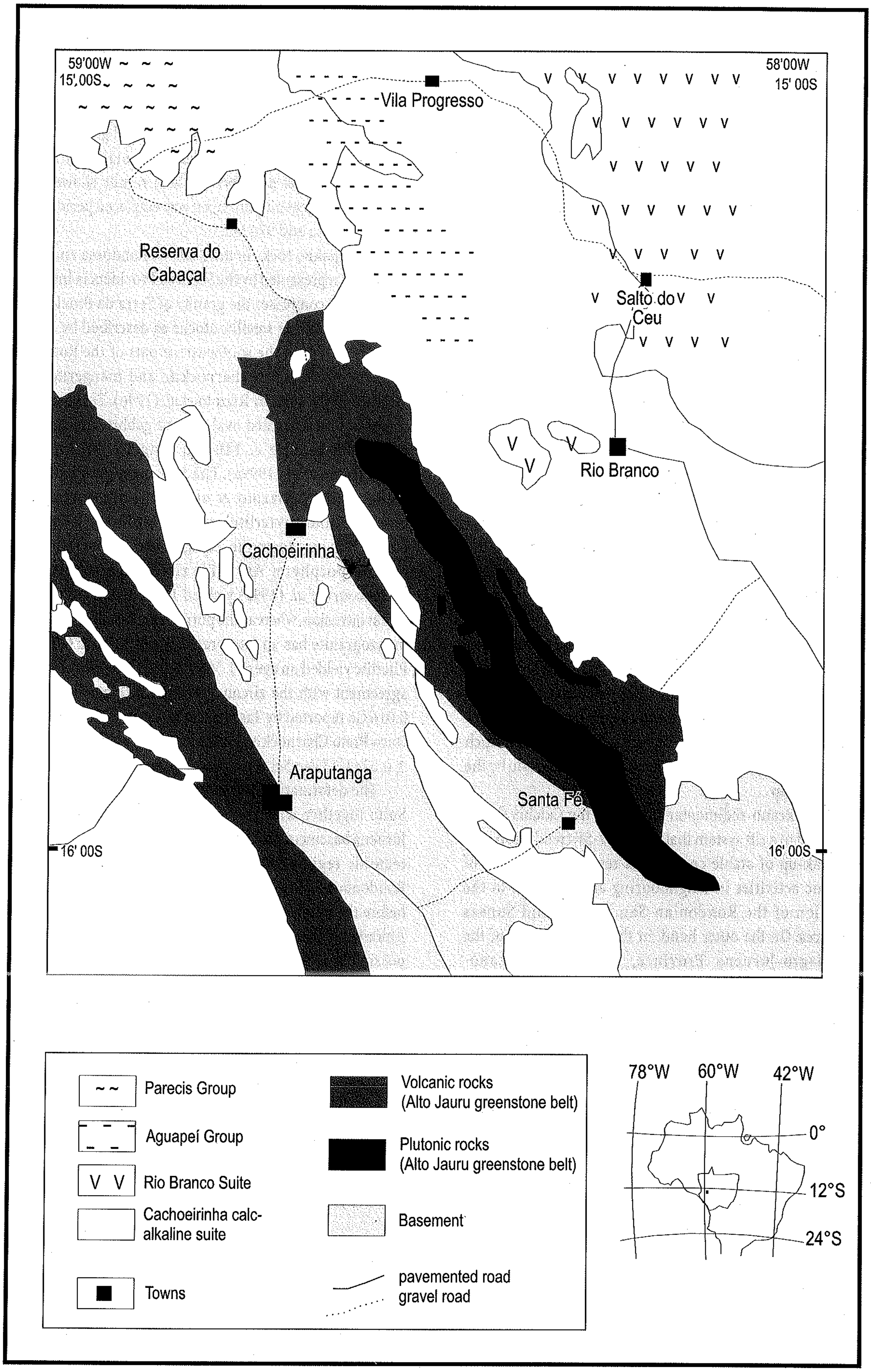


FIGURE 4 - Simplified geological map of the southern estern part of the State of Mato Grosso(SW Amazonian Craton), showing the Cachoeirinha Suite and Alto Jauru Greenstone Belt.

distinguish the Alto Jauru greenstone belt terrane and the Cachoeirinha Orogen which have been recently constrained by precise geochronological data (Geraldes *et al.*, 1999). The following discussion will highlight the main aspects of these two important units of the Rio Negro-Juruena Province.

Alto Jauru Greenstone Belt Terrane

The Jauru region, situated in the southwestern region of the RNJP in the State Mato Grosso, includes metavolcano-sedimentary sequences, interpreted by some authors as greenstone belts sequences. Teixeira *et al.* (1989) and Tassinari *et al.* (1996) considered this as an ancient nucleus preserved within the younger Rondonian-San Ignacio Province. The 1.8 - 1.55 Ga zircon U/Pb ages and 1.9 - 1.75 Ga Sm/Nd mantle depleted model ages obtained by Geraldes *et al.* (1999) on granite and orthogneiss from the basement rocks are in agreement with the RNJP geochronological pattern. The last authors considered the Jauru area as a possible extension of the RNJP.

Volcanic rocks of the Jauru region (Fig 4) were described and named initially by Saes *et al.* (1984) as the Quatro Meninas Volcanic Complex. Monteiro *et al.* (1986) named it the Alto Jauru Greenstone Belt. Three belts of metavolcanic and sedimentary rocks (from E to W named: Cabaçal, Araputanga and Jauru) are separated by granitic-gneiss terranes of tonalitic composition. The belts are intruded by Proterozoic dolerite and granitoid and are covered by Mesoproterozoic clastic sediments of the Aguapeí Group.

Monteiro *et al.* (1986) described the following sequences for the metavolcano-sedimentary unit: the lowest unit (basic volcanics) consists of massive amygdaloidal and variolitic lava and volcanic breccia, which contain lithic clasts of older rocks. Intermediate metavolcanic rocks (andesite lava and tuff, interdigited with felsic lava, tuff and metapelite) locally overlie these. The younger acid metatuff beds consist of dacite-rhyodacite lava, tuff and epiclastic rocks that host the main gold and silver-bearing ore body worked between 1984 and 1990. The acid metatuff beds are overlain by metasediments, which include local quartz-sericite-clorite schist. The interbedding of epiclastic debris is common, together with metachert and, locally, garnetiferous magnetite bands (BIFs). The aforementioned metachert and BIF units are interpreted as chemical metasediments by Pinho *et al.* (1997).

Geochronology and geochemistry of the Alto Jauru Greenstone Belt

Van Schmus *et al.* (1998) and Geraldes (2000) reported U/Pb zircon ages (Table 5) on volcaniclastic rocks (metatuff) yielding 1.767 ± 0.024 Ga, which was interpreted as the crystallization age. The Sm/Nd mantle-depleted model age of 1.87 Ga and the $\varepsilon_{Nd(T)}$ of + 2.4, indicate that the volcanism was derived from mantle-derived magma with little contamination from the supracrustal host rocks.

Plutonic rocks of tonalitic to granitic composition were described in the Jauru region as coeval with the volcanic rocks of the Alto Jauru Greenstone Belt. Ruiz (1992) mapped an area between the Cabaçal and Araputanga volcanic belts and described orthoderived gneiss (São Domingos Granite-gneiss) which is intruded by the Alvorada Granite. Carneiro *et al.* (1992) reported a Rb/Sr isochron age of 1.734 ± 0.226 Ga and initial Sr = 0.7019 for this gneiss, whereas Geraldes (2000) presented a U/Pb zircon age for the same rocks of 1.795 ± 0.01 Ga and a Sm/Nd mantle-depleted age of 1.93 Ga and ε_{Nd} = 2.16.

Ruiz (1992) defined the Aliança Gneiss, which yielded a U/Pb zircon age of 1.747 ± 0.013 Ga (Geraldes, 2000). In addition, Pinho (1996) reported a U/Pb SHRIMP result for volcanic rocks of Alto Jauru greenstone belt which yielded two age groups: the older group of 1.769 ± 0.029 Ga and the younger group of 1.724 ± 0.03 Ga, concordant with the U/Pb isotope dilution dating.

Chemical results for plutonic rocks (tonalite and granodiorite) from the Alto Jauru Greenstone Belt reported by Pinho (1990) indicate a TTG affinity, whereas the results reported by Geraldes (2000) indicated a calc-alkaline trend. In all cases, the authors interpreted these intrusive rocks as being generated in an arc-related environment. Pinho *et al.* (1997) reported chemical results obtained in volcanic rocks from Jauru Belt indicating an ocean floor origin. Different from the ultrabasic-basic rocks observed in the western part of the greenstone belt, the intermediate felsic unit has a predominantly calc-alkaline magmatic affinity. This led the authors to suggest that rocks formed at an ocean-ridge underlie the Jauru Belt (western part), and that the Cabaçal Belt was formed in an arc-related setting.

Metamorphism and Deformation

The metamorphism and deformation described in the rocks of the Alto Jauru Greenstone Belt are quite complex, and probably induced by younger superimposed events. After the crust-forming episode (1.79 - 1.74 Ga), this unit was intruded by a calc-alkaline suite dated at 1.57 - 1.52 Ga that resulted in migmatization and deformation of the rocks of the Alto Jauru Greenstone Belt. Subsequently, the development of the Santa Helena Arc (1.48 - 1.42 Ga) and the Sunsas/Aguapeí events (1.2 Ga - 950 Ma) undoubtedly overprinted the original structures as suggested by the Rb/Sr (1.7 - 1.4 Ga) and K/Ar (1.4 - 1.0 Ga) resetting ages.

Cachoeirinha Orogen

An important rock-forming event occurred between 1.57 - 1.53 Ga in the southwestern part of the border of the Amazonian Craton, and the orogenic products have been considered as part of the Rio Negro-Juruena Province. This event formed arc-related rocks chemically comparable with a calc-alkaline suite, varying from tonalite to granite, that intruded the older basement rocks, represented, locally, by the Alto Jauru Greenstone Belt (1.79 - 1.75 Ga), situated in the same geographic area (Fig. 2). The Cachoeirinha Orogen is bounded to the N by the Cretaceous Parecis sedimentary cover, to the S and E by the Neoproterozoic Paraguai and Araguaia-Tocantins belts and to the W by the Lucialva Lineament, separating the Cachoeirinha related-rocks from those of the younger Santa Helena Magmatic Arc.

The rocks that are now considered as belonging to the Cachoeirinha Orogen, were initially described by Figueiredo *et al.* (1974) and Barros *et al.* (1982) as belonging to the Xingu

Complex. Carneiro *et al.* (1992) suggested that the rocks in the São José do Quatro Marcos area underwent at least two rock-forming episodes. The first episode is represented by grey gneiss (Rb/Sr ages about 1.96 Ga), and the second episode is manifest by pink gneiss and granite with ages from 1.74 to 1.4 Ga (Rb/Sr ages). Granitoid plutons of different composition, with ages ranging from 1.7 to 1.4 Ga, have been separated from the basement (Saes *et al.*, 1984; Leite, 1989; Ruiz, 1992). Tassinari *et al.* (1996) reported U/Pb and Rb/Sr results constraining two major events for the Rio Negro-Juruena Province. They interpreted these as successive magmatic arcs, the older event from 1.8 to 1.7 Ga, and the younger event from 1.6 to 1.5 Ga. The latter event included some reworked material from the older magmatic arc. Recent U/Pb geochronology (Van Schmus *et al.*, 1998; Geraldes *et al.*, 1999; Geraldes, 2000) best constrain these two events in the so-called Jauru region, the first defined as the Alto Jauru Greenstone Belt (1.79 - 1.74 Ga), and the second as the Cachoeirinha Orogeny (1.57 - 1.53 Ga).

Tonalite, granodiorite and granite are the main rock-types related to the Cachoeirinha Orogen. The rocks are grey, equigranular, medium to coarse-grained and with mafic minerals that define the foliation. Plagioclase, quartz, amphibole and biotite comprise the main minerals. Zircon U/Pb ages from the tonalite yielded ages of 1.536 ± 0.011 and 1.549 ± 0.01 Ga, and the Sm/Nd mantle depleted ages are 1.77 Ga with ε_{Nd} = + 0.5 and 1.83 Ga with $\varepsilon_{Nd(T)}$ = + 1.0, respectively (Table 6).

Granodiorite associated with the São Domingos Gneiss is observed in some parts of the Santa Cruz Batolith(Ruiz, 1992). They show lateral variations within the batholiths and display a strong foliation and banding. They are quartz-feldspatic in composition, and occur in felsic layers and in amphibole-enriched mafic layers. The Santa Cruz sample yielded an U/Pb zircon age of 1.587 ± 0.004 Ga (T_{DM} = 2.05 and $\varepsilon_{Nd(T)}$ = - 0.8), and the São Domingos Gneiss presented a zircon U/Pb age of 1.562 ± 0.036 Ga (T_{DM} = 1.79 and $\varepsilon_{Nd(T)}$ = + 0.9).

The gneiss-migmatite rocks associated with the Cachoeirinha Orogen present complex deformation (Ruiz, 1992), which produced irregular folds and discontinuous banding consisting of quartz feldspar-rich and biotite-rich layers. Recrystallized quartz grains with irregular contacts with feldspar and a mozaic fabric are interpreted (Ruiz, 1992) as the result of high-grade metamorphism, and the biotite orientation in bands is due to deformation.

Granitic rocks within the Cachoeirinha Orogen have a widespread geographical distribution over the Jauru region. The Cachoeirinha and Quatro Marcos granites yielded zircon U/Pb ages of 1.522 ± 0.011 Ga (T_{DM} = 1.78 and $\varepsilon_{Nd(t)}$ = + 0.9) and 1.537 ± 0.06 Ga (T_{DM} = 1.75 and $\varepsilon_{Nd(T)}$ = + 0.5), respectively.

Anorogenic plutons of granitic and granodioritic composition are described in the Jauru region. The Água Clara Granodiorite (Saes *et al.*, 1984; Monteiro *et al.*, 1986; Matos *et al.*, 1996) is the largest anorogenic batholith in the Jauru region (600 km^2) and consists mainly of granodiorite with subordinate tonalite and granite (Matos *et al.*, 1996). Geraldes (2000) reported a zircon U/Pb age of 1.485 ± 0.04 Ga, which was interpreted as the crystallization age, and a Sm/Nd mantle-depleted model age of 1.77 Ga and $\varepsilon_{Nd(T)}$ = 1.7, suggesting a Rio Negro-Juruena crust as their magma source. The same interpretation may be considered for the Alvorada and Araputanga granite described by Monteiro *et al.* (1986), which show U/Pb ages of 1.389 ± 0.011 Ga (T_{DM} = 1.77 and $\varepsilon_{Nd(T)}$ = - 1.3) and 1.44 ± 0.06 Ga (T_{DM} = 1.74 and $\varepsilon_{Nd(T)}$ = - 0.4), respectively.

Rondonian - San Ignacio Province (RSIP)

The term Rondonian Province was introduced by Cordani *et al.* (1979), for an important tectono-magmatic event in the 1.45 - 1.25 Ga interval, which developed on the southwestern margin of the Rio Negro-Juruena Province (1.75 - 1.55 Ga). Subsequently, Teixeira and Tassinari (1984), based on more than 200 Rb/Sr and K/Ar determinations, defined the Rondonian Geochronological Province, which was represented by a mobile belt, aged 1.45 - 1.0 Ga. Rocks belonging to this orogen extended from the Ituxi-Abunã region (western part of the State of Rondônia) to the Jauru region (State of Mato Grosso) extending to the San Ignacio-Tunas region in Bolivia, thus including the rocks attributed to the San Ignacio Orogeny by Litherland and Bloomfield (1981). More recently, Tassinari *et al.* (1996) proposed the term Rondonian-San Ignacio Province (1.5 to 1.3 Ga), in order to include rocks belonging to the same event, both in Brazil and Bolivia.

General Geological Aspects

The Rondonian-San Ignacio Geochronological Province lies in the southwestern part of the Amazonian Craton, and it is bounded to the E by the Rio Negro-Juruena Province, and to the S and SW by the Sunsas Province. In several places the boundaries between these provinces are not very well defined, due to the fact that in most areas the effects of younger metamorphic overprinting are very strong.

The 1.55 to 1.3 Ga metamorphic basement, previously ascribed to the Xingu (Leal *et al.*, 1978) and Jamari complexes (Isotta *et al.*, 1978), is composed of granite-gneiss-migmatite terranes and granulitic rocks. In general, these rocks are metamorphosed in the amphibolite or granulite facies. Some Paleoproteorozic granulitic inliers, such as the Lomas Manéches Group in Bolívia (Litherland *et al.*, 1986) are scattered within the province. The Rondonian-San Ignacio Province (RSIP) shows strong NE-SW overprint structures, and is underlain by some regions with a clear ensialic character and others with juvenile magmatic characteristics.

The geochronological pattern for the RSIP basement rocks, include a group of Rb/Sr age determinations between 1.5 and 1.37 Ga, with $^{87}Sr/^{86}Sr$ initial ratios ranging from 0.703 to 0.710 (Amaral, 1974; Teixeira and Tassinari, 1984; Priem *et al.*, 1989; Tassinari, 1996) and zircon U/Pb ages varying from 1.49 to 1.33 Ga (Geraldes *et al.*, 1999). The granitoid plutons of the RSIP yielded two groups of Sm/Nd depleted-mantle model ages. The first and younger group obtained on samples from the Pontes de Lacerda region, around 1.5 Ga, which was considered by Geraldes *et al.* (1999) as being related to the Santa Helena Volcano-Plutonic

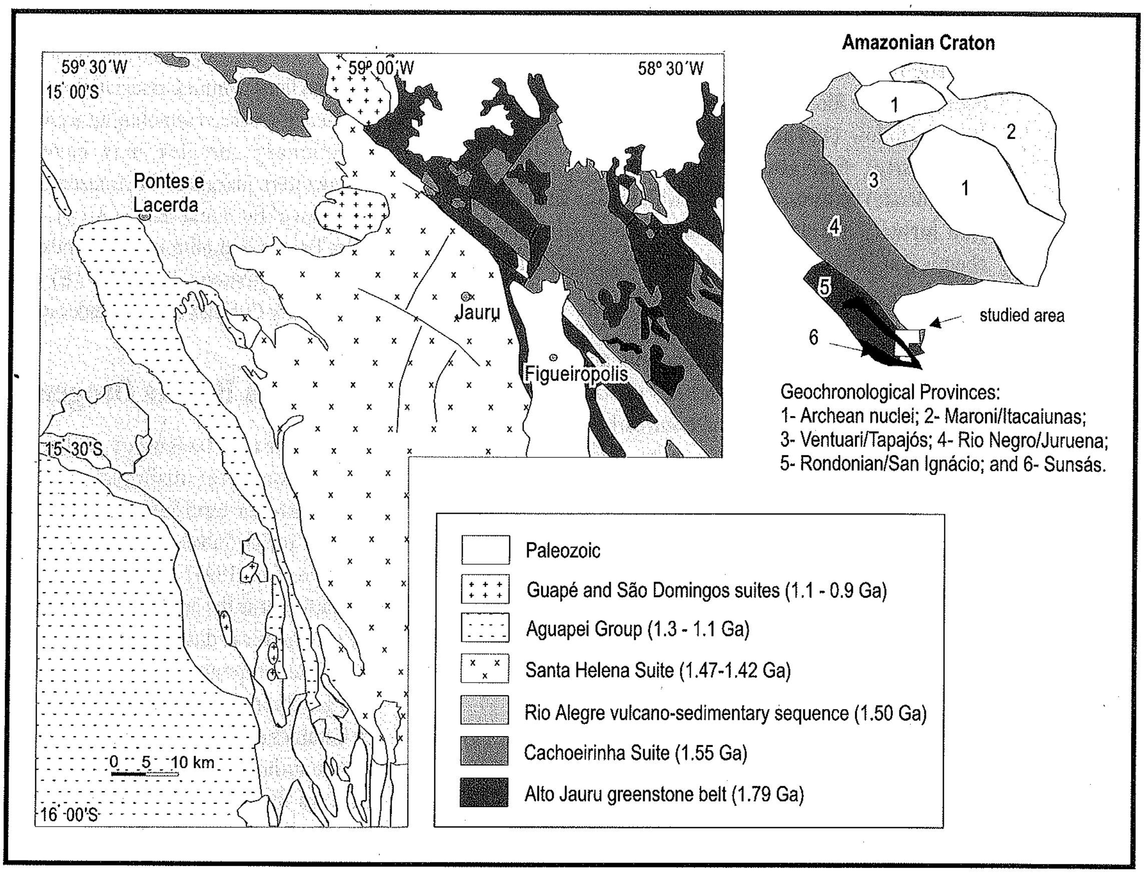


FIGURE 5 - Major geological units of Pontes e Lacerda region (Mato Grosso). The Aguapeí Thrust Belt marks the boundary between Rio Alegre Volcanosedimentary Sequence and the Santa Helena Suite. Santa Helena Suite and Cachoeirinha Suite are separated by the Taquaruçu-Lucialva Lineament.

Arc. The second and older group was composed of samples from the entire Rondonian-San Ignacio Province, with ages ranging from 2.0 to 1.7 Ga. This interval coincides with the estimated mantle-extraction period of the Rio Negro-Juruena Province (Geraldes *et al.*, 1999; Sato and Tassinari, 1997). The older ages indicate the development of crustal reworking within the province.

Metavolcano-sedimentary sequences, represented by the Ascencion Group, in Bolivia, indicate a Rb/Sr metamorphic age of 1.34 Ga (Litherland *et al.*, 1986). The K/Ar cooling ages between 1.35 and 1.3 Ga suggest the beginning of the tectonic quiescence period of the province. Post-orogenic and anorogenic magmatic activity is represented by the Santo Antonio Intrusive Suite (1.406 Ga), the Teotônio Intrusive Suite (1.387 Ga), the Alto Candeias Intrusive Suite (1.346 and 1.338 Ga), the São Lourenço-Caripunas Intrusive Suite (1.31 Ga), the Santa Clara Suite (1.08 Ga), the Costa Marques Group (1.02 Ga) and the Yonger Rondônia Granite (990 Ma), Bettencourt *et al.* (1999). The occurrence of the1.1 Ga undeformed acid volcanism is very scattered within the province. Sedimentary rocks associated with alkaline basalt flows were deposited around 1.1 - 1.0 Ga in the NW-SE continental rift system that corresponds to the age of the basalt that intruded the lower sedimentary sequences of the Guajará Mirim Group.

In this review the term Rondonian-San Ignacio Geochronological Province is maintained, as defined by Tassinari and Macambira (1999), including one or more terranes and/or orogenies, where their respective geological evolution took place within 1.55 to 1.3 Ga period. In this way, recent geological and geochronological studies (Scandollara *et al.*, 1999b; Geraldes *et al.*, 1999) have led to the suggestion that the RSIP could include different terranes and orogenies, which are: (1) The Rio Alegre Terrane; (2) The Santa Helena Orogen; and (3) The Rondonian-San Ignacio Orogen.

The Rio Alegre Terrane

The Rio Alegre Terrane comprises mafic-ultramafic plutonic and volcanic rocks associated with banded iron formation units and chert, which occur in the Rio Alegre Valley in the State of Mato Grosso (Fig. 5). They were initially described by Barros *et al.* (1982), and were correlated to the Rincon del Tigre Complex by Litherland *et al.* (1986). Menezes *et al.* (1993) included these rock-associations in the Pontes e Lacerda Volcano-sedimentary Sequence. Matos (1992) prepared a detailed geological map of this unit and renamed it as the Rio Alegre Volcano-sedimentary Sequence. Pinho (1990) correlated the mafic metavolcanic rocks of the Rio Alegre Valley with the Alto Jauru Greenstone Belt, but this correlation was not confirmed by new isotope data.

This unit occurs in a large area (50 x 200 km) bordered to the E by the Santa Helena Batholith and the Alto Jauru Greenstone Belt. The boundary to the S is covered by the sedimentary rocks of the Pantanal Formation (Quaternary) To the W it is overlain by flat-lying sediments of the Aguapeí Group; and to the N the boundary is not known.

Stratigraphic Units

The magmatic and volcanic metamorphosed rocks observed in the Rio Alegre Valley may be subdivided (Matos, 1992) as follow: (1) The Minouro Formation, consisting of metabasite, fine-grained with local porphyrytic (hornblende) textures, associated with fine-grained banded iron formation units (with magnetite-bearing layers), chemical sediments, chert, and clastic rocks; (2) The Santa Isabel Formation, which consists of metabasalt, metapyroclastic rocks and metariodacite presenting a high degree of oxidation and lateritization, and; (3) the São Fabiano Formation, which includes clastic and chemical metasediments (phylite, quartzite and carbonaceous layers), chert, and metavolcaniclastic rocks, including garnet-kyanite bearing muscovite-biotite schist. Amphibolite and meta-ultrabasic rocks, with nematoblastic textures, are subordinate units interlayered in mica-schist. The intrusive rocks are composed of differentiated complexes including gabbro and serpentinite with cumulate textures, metamorphosed in the greenschist facies.

Lithogeochemistry

Matos (1992) and Matos and Schorscher (1997a, b) based on geochemical studies on metavolcanic and meta-intrusive rocks from the Rio Alegre Terrane, suggested a sub-alkaline signature for these rocks, and a back-arc ocean-floor environment. Mineralogical alterations in these rocks are typical of ocean floor metassomatism including epidotization, carbonatization and sericitization. The geochemical data for the intrusive rocks led the authors to conclude that these resulted from the evolution and differentiation of tholeiitic magma.

Menezes *et al.* (1993) presented REE results for metabasalt from the Santa Isabel Formation showing MORB or immature island arc patterns. The authors suggest a magmatic origin from an enriched-mantle source or from continental margin collision. The existence of ocean-floor related rocks, metamorphosed in the greenschist facies, cut by pyroxenite and amphibolite may be interpreted as a collisional suture. In this way, future research on this unit might take into account the possibility that the rocks of the Rio Alegre Terrane might be an ophiolitic complex.

The major structural features characteristic of the Rio Alegre Terrane is a strong transposition of metasedimentary and metavolcanic rocks. Menezes *et al.* (1993) described this process as the result of an intense mylonitization. The main foliation strike is 30° - 50° NW, and the dip is 20° - 70° (Menezes *et al.*, 1993), indicating strain parallel to the border of the Amazonian Craton. The lineation variation (NW and SE) may have resulted from a progressive deformational event, where initial sub-horizontal foliation (thrusting) changed to a subhorizontal mylonitic foliation formed during strike-slip movement under ductile conditions.

Geochronological and Isotopes Constraints

Magmatic activity of the Rio Alegre Terrane occurred during a short period between 1.509 and 1.494 Ga (Table 7) (Geraldes, 2000). Sm/Nd results obtained on Rio Alegre rocks (T_{DM} from 1.67 to 1.54 Ga and $\varepsilon_{Nd(T)}$ values from + 2.5 to + 4.8, Table 7) suggest a juvenile origin for their magma sources. The Rio Alegre petrotectonic association represents an ocean floor complex associated with clastic and chemical sedimentary rocks, resembling an accretionary complex. This accretionary complex may have collided with the southwestern margin of the Amazonian Craton just after the evolution of the Santa Helena Arc (1.47 - 1.42 Ga) since the Santa Helena Batholith comprehends a region between the Rio Negro Juruena Province (E) and the Rio Alegre Accretionary Complex (W) (Geraldes *et al.*, 2000).

The Santa Helena Orogen

Proterozoic basement rocks, mainly of granitic composition, were initially recognized by Saes *et al.* (1984), who created the term Santa Helena Batholith to include the referred rocks. Subsequently, these rocks were studied by Menezes *et al.* (1993) and Lopes *et al.* (1992), who renamed the batholith as the Santa Helena Granite-Gneiss and, based on geochemical data, classified the associated rocks as intraplate A-type granite. Additional geological, geochemical and geochronological studies on this unit were carried out by Geraldes *et al.* (1997) and Van Schmus *et al.* (1998), which led the authors to propose the term Santa Helena Suite. The authors described igneous and meta-igneous rocks, represented by tonalite, orthogneiss and granite, as a calc-alkaline arc-related suite of 1.48 to 1.42 Ga. The extensive arc-related magmatism together with the new isotope and geochemical results provided a consistent record of this event, and a proposal is now made to elevate the Santa Helena Suite to orogen status.

The Santa Helena Orogen is bordered to the W by both the Rio Alegre volcano-sedimentary sequence and the Aguapeí Thrust Belt (Fig. 5). Limits to the E include several domains of different rock-types, including the Alto Jauru Greenstone Belt (1.79 - 1.75 Ga) and the Cachoeirinha Orogen (1.57 - 1.53 Ga). The northern and southern limits extend beneath the Paleozoic sedimentary cover.

Geochronological Results

The rocks of the Santa Helena Suite consist of granodiorite to granite and tonalite; the tonalite occurring mainly in the western part of the batholith (Lavrinha and Pau-a-Pique tonalite) (Geraldes, 2000). These rocks are leucocratic, grey to green in colour, medium to coarse-grained, and isotropic to slightly foliated. U/Pb zircon data from a hornblende-tonalite yielded an upper intercept (crystallization age) at 1.467 ± 0.025 Ga (Table 1), and the Pau-a-Pique body yielded U/Pb results with an upper intercept age at 1.481 ± 0.047 Ga. The Sm/Nd mantle-depleted model ages for these tonalite bodies are 1.53 Ga ($\varepsilon_{Nd(T)}$ = + 3.8) and 1.5 Ga ($\varepsilon_{Nd(T)}$ = + 4.1) respectively, indicating that in both cases the magma was derived from a source containing a very small, if any, contribution, of older continental crust (Table 8).

Granodiorite and some amphibolite are observed in the northern, central and western parts of the Santa Helena Batholith. The Alto Guaporé Gneiss, the Guaporé and the Triângulo granodiorite are grey in colour, and locally banded (granite-gneiss, biotite-gneiss and magnetite-gneiss). These rocks have zircon U/Pb ages of 1424±15 Ma and 1445±04 Ma, and Sm/Nd model ages (T_{DM}) from1.56 to 1.49 Ga, with $\varepsilon_{Nd(T)}$ values varying from 2.9 to 4.0, indicating that the protolith of this gneiss contained a very small component of older crust.

The granitic rocks have a homogeneous distribution within the batholith. They show restricted compositional and textural variations and are mainly represented by grey to pink, usually equigranular, biotite granite. Previous Rb/Sr results for the Santa Helena Granite-Gneiss and Maraboa Pluton (Geraldes, 1996) yielded, respectively, 1.318 ± 0.024 Ga and 1.275 ± 0.125 Ga. Zircon fractions from Santa Helena Granite-Gneiss yielded an upper intercept (crystallization age) of 1.433 ± 0.06 Ga on the U/Pb concordia diagram. The U/Pb results for the Maraboa Granite, when plotted on a U/Pb concordia diagram yielded an upper intercept (crystallization age) at 1.449 ± 0.007 Ga. Sm/Nd model ages (T_{DM}) for these units are 1.62 Ga ($\varepsilon_{Nd(T)}$ = 3.1) and 1.7 Ga ($\varepsilon_{Nd(T)}$ = 2.5), respectively, indicating that the original granitic magma was derived from a source containing an older Rio Negro-Juruena continental crust component.

Other granitic rocks such as the Alto Guaporé Augen-gneiss, the Cardoso Magnetite-granite, the Santa Elina Granite and the Ellus Granite, were analyzed by the U/Pb technique, and when plotted on concordia diagram, yielded ages of 1.423 ± 15 Ga and 1.444 ± 0.021 Ga. The Sm/Nd model ages (T_{DM}) for these granites range from 1.57 to 1.51 Ga and $\varepsilon_{Nd(T)}$ values vary from + 2.7 to + 3.7, indicating that the parental magmas are composed mainly by mantle-derived material.

Deformation and Metamorphism

The structural analysis of the Santa Helena Batholith shows, according to Menezes *et al.* (1993), a penetrative foliation defined by mafic minerals or elongated k-feldspar and quartz. The regional strike, observed in augen-gneiss, is NNW, and the plunge direction varies from 30°- 60° NE, with the some oscillation to SE. The linear and planar structures of the Santa Helena Pluton are the result of a regional mylonitization, characterized by brecciation and quartz-enrichment at brittle conditions (Menezes *et al.*, 1993). U/Pb ages from zircon collected in centimetric veins sub-concordant with the augen-gneiss foliation yielded a *c.* 1.39 Ga (Geraldes, 2000), defining the deformation between 1.42 Ga (U/Pb age of vein host rock) and 1.39 Ga. This interval is interpreted as the minimum age for Santa Helena metamorphism.

Rock Geochemistry

A more recent geochemical study (Geraldes, 2000) indicates that the rocks vary from quartz monzogabbro and tonalite through granodiorite to granite *sensu latu*. The chemical results indicate a volcanic arc granite (VAG) affinity for the primitive and intermediate rocks, and the granite plots near the boundary of VAG and the within-plate granite (WPG), which is in agreement with the results of Menezes *et al.* (1993) that show that the granitic rocks of the Santa Helena Orogen may be classified as an A-type granitic suite.

Trace element modeling (Bell *et al.*, 1999) suggests that the Santa Helena rocks can be included within two groups: the first group with high Sr content, low Rb/Sr ratios, and relatively steep REE patterns (La/Ybn = 20) in which tonalite and granodiorite dominate. The second group has low Sr, high Rb/Sr ratios and relatively flat REE patterns (La/Ybn = 3.5) with large negative Eu anomalies in which granite dominates. Geraldes *et al.* (1999) reported REE patterns showing a higher fractionation between LREE and HREE in the primitive rocks than in the intermediate and fractionated ones. A positive Eu anomaly was found in the primitive rocks, a light negative Eu anomaly in the intermediate rocks, and a strong Eu negative anomaly in the granite, suggesting that the granitoid plutons were formed during a fractional crystallization.

The Anorogenic Magmatic Activities

The Rio Branco Suite characterizes the anorogenic magmatic activities related to development of the Santa Helena Orogeny. These were formerly described by Oliva (1979) as the Sierra Rio Branco Complex. Barros *et al.* (1982) carried out a detailed study, defining the Rio Branco Group. Subsequently, Leite *et al.* (1986) mapped the Rio Branco region and named these rocks as the Rio Branco Intrusive Suite, which was regarded as a differentiated layered complex. Geraldes *et al.* (1999) considered the anorogenic Rio Branco suite as part of a bimodal igneous suite, comprising coeval mafic and felsic rocks. The units are confined within the volcanic-plutonic rocks of the *c.*1.77 - 1.52 Ga Rio Negro-Juruena Province (Bell *et al.*, 1999).

The felsic part of the Rio Branco Suite includes red to pink granite. The mafic members consist of gabbro, tholeiitic diabase dykes, and porphyritic basalt. Centimetric crystals of alkali-feldspar are bordered by plagioclase (rapakivi texture) in a plagioclase-bearing groundmass. Trace element content (Rb, Y and Nb) indicate a within-plate granite affinity, according to tectonic discrimination diagrams.

U/Pb isotope analyses of zircon from the granite yielded an upper intercept on concordia diagram of 1.423 ± 0.002 Ga, which we interpret as the crystallization age of the felsic rocks. U/Pb analyses of zircon from a gabbro yielded an age of 1.456 ± 0.024 Ga, in agreement with the felsic member ages. The $\varepsilon_{Nd(T)}$ values for mafic rocks range from + 1.24 to + 1.91, suggesting a mantle protholith. The $\varepsilon_{Nd(T)}$ values for felsic rocks are in the range from + 0.16 to - 0.96, which suggest that these rocks had a crustal component in their magma. Sm/Nd mantle-depleted model ages vary from 1.8 to 1.73 Ga for the mafic rocks and from 1.89 to 1.81 Ga for felsic rocks. Similar ages were found in the surrounding basement of the Alto Jauru Greenstone Belt.

The Rondonian-San Ignacio Orogeny

The Rondonian-San Ignacio Orogeny was first proposed by Litherland and Bloomfield (1981), and subsequently defined by Litherland *et al.* (1986, 1989) in Bolivia as the San Ignacio Orogeny. According to these authors, the orogeny is ascribed to the San Ignacio Schist Group (Rb/Sr metamorphic age around 1.344 ± 0.018 Ga). It was accompanied by a significant syn to post-tectonic granitoid magmatism, represented by the potassic calc-alkaline complex (Rb/Sr ages about 1.32 to 1.28 Ga) and by

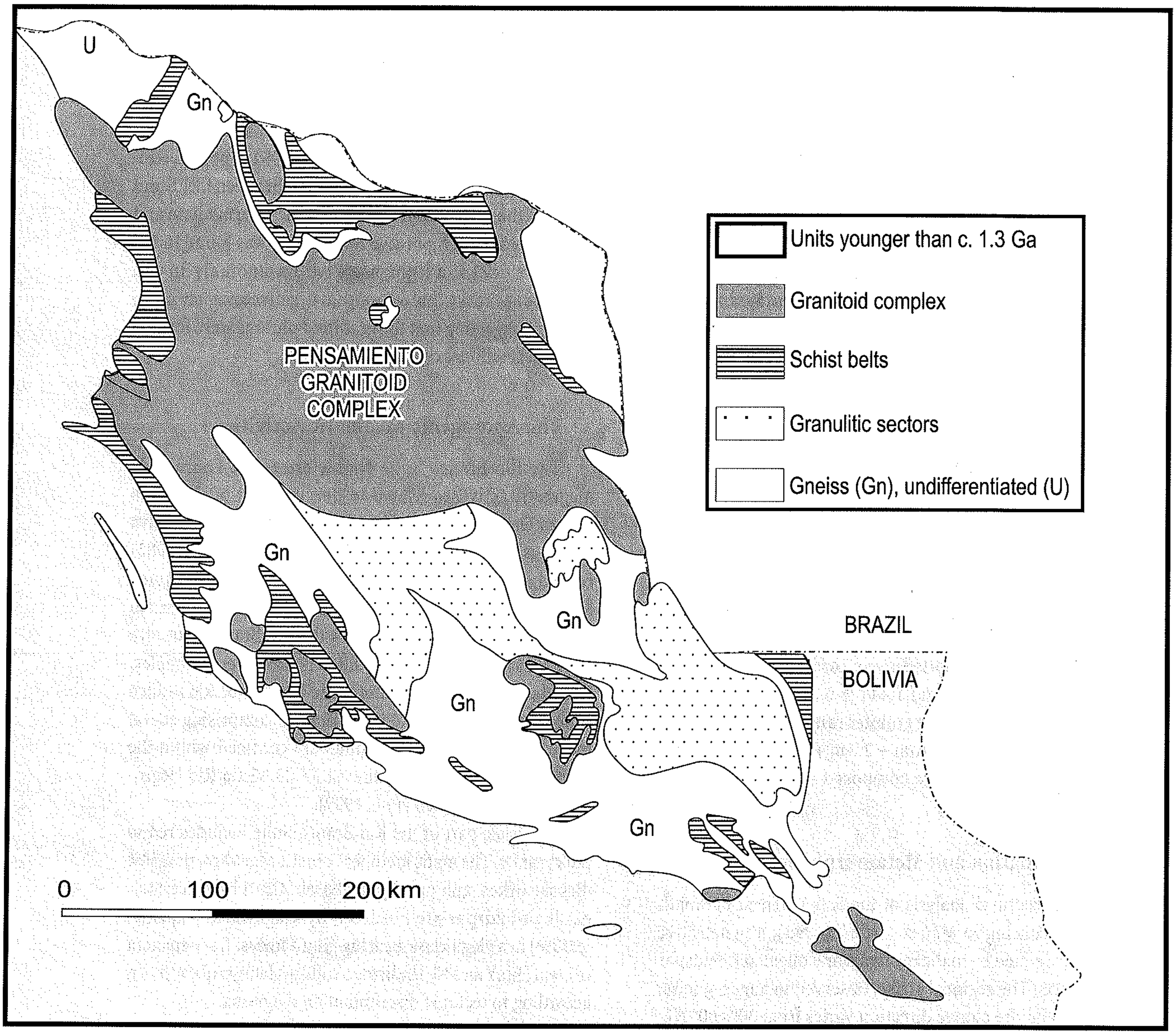


FIGURE 6 - Major geological units of c. 1.3 Ga or older in eastern Bolivia (modified after Litherland et al., *1986).*

the El Tigre Alkaline Complex (1.286 ± 0.046 Ga). In Brazil the correlative event is the Rondonian Episode (Rb/Sr ages from 1.5 to 1.3 Ga) of Teixeira and Tassinari (1984), which led them to propose the term Rondonian-San Ignacio Province which, at this time, unified both cycles. In the State of Mato Grosso, the Santa Helena Orogeny recently defined by Geraldes (2000), occurred within the same interval (1.48 - 1.42 Ga). The difference between both orogenies (Santa Helena and Rondonian-San Ignacio) is that the first has a magmatic arc evolution with a predominant accretion of juvenile material to the crust, whereas the Rondonian-San Ignacio Orogeny is characterized by an ensialic evolution with strong involvement of crustal reworking.

The San Ignacio event is manifest in widespread magmatism in eastern Bolivia, where the *c.* 1.3 Ga orogenic data are preserved in both the Rb/Sr and K/Ar systems. The northern border is not well defined due to the uncertainty of the extension of the Rio Alegre Terrane in the State of Rondônia, which is the eastern limit (Fig. 6). The cover of the Chaco Plain defines the western border. Farther to the S, within the basement rocks of the Sunsas Orogen, the K/Sr systematics are considerably disturbed, and yielded ages strongly reset by the 1.3 - 1.0 Ga Sunsas Orogeny.

The northern part of the State of Rondônia, and adjacent areas are here understood to be the segment of crust bounded to the S by the Nova Brasilândia Terrane (Sunsas Province) and to the N and E by Cenozoic and Mesoproterozoic sedimentary cover. This region has been subdivided by Scandollara *et al.* (1999b) into the Jamari, Roosevelt and Nova Brasilândia terranes, and the former subdivided in two domains: the Ariquemes/Porto Velho Domain and the Central Rondônia Domain. Up to now, the full extension of the Rondonian-San Ignacio event has not been reliably determined because the region was affected by three orogenic events: Rio Negro-Juruena, Rondonian-San Ignacio and Sunsas-Aguapeí. These overprint effects make it difficult to reconstruct the geological history of older events.

The following major lithological units represent the Rondonian-San Ignacio event (1.47 - 1.3 Ga) in Rondônia: minor remnants of felsic fine-grained syenogranite, gneiss, extensive bimodal rapakivi magmatism and AMCG magmatism in the São Lourenço, Caripunas and Lábrea regions. In addition, the Rondonian episode produced in that area widespread thermal effects and isotope resetting in the older rocks, high-grade metamorphism and sedimentary cover. Noteworthy, are the scarcity of supracrustal rocks and the small amounts of felsic/mafic gneiss suspected to be of igneous origin.

Pre-Rondonian-San Ignacio Basement Rocks

The metamorphic basement in Bolivia mainly comprises older rocks, in general evolved prior to the development of the *c.* 1.4 - 1.28 Ga San Ignacio Orogeny (Litherland *et al.,* 1986). The rocks consist essentially, of schist, gneiss and granulite. All dip steeply, and are of predominantly metasedimentary origin. These rocks are included within the Lomas Maneches Granulite Complex (hyperstene-bearing granulite, cordierite granulite) and Chiquitania Gneiss Complex, and both units have a complex geological history. The granulite and gneiss gave an interpreted Rb/Sr whole-rock regional reference isochron of *c.* 1.9 Ga (Litherland *et al.*, 1986) and Sm/Nd mantle-depleted model ages of *c.* 2.0 - 1.9 Ga (Darbyshire, personal communication.).

In Brazil, within the area affected by the Rondonian-San Ignacio Orogen, there occur some inliers composed of older rocks with ages between 1.77 and 1.47 Ga, which are mostly described in more detail by Payola *et al.* (1998), mainly in the Rondônia Tin Province. The pre-existing basement rocks are composed mostly of tonalitic gneiss and metasedimentary gneiss. These constitute part of remnant older crust referred to the Rio Negro-Juruena event. Granitoid and orthogneiss that represent three intraplate bimodal magmatic events developed over Rio Negro-Juruena crust at 1.57 - 1.56 Ga, 1.54 Ga, and at 1.53 Ga. These are related to the rapakivi Serra da Providência Intrusive Suite and associated rocks. They occurred at 1.42 Ga and are associated with the Rondonian-San Ignacio event. The Sm/Nd mantle-depleted model ages indicate that the parental magma of the granitoid plutons and orthogneiss were derived from a source containing a significant component of older crustal material (Geraldes *et al.*, 1999; Payolla *et al.*, 1998), and/or derived from a mixture of crustal and mantle sources (Payolla *et al.*, 1998).

Payola *et al.* (1998) based on U/Pb and Sm/Nd data defined three age-groups of the pre-existing Rondonian rocks: (1) greyish tonalitic gneiss (1.75 - 1.73 Ga; U/Pb ages and T_{DM} ages 2.2 - 2.06 Ga); (2) granitoid and ortogneiss (1.57 - 1.53 Ga, U/Pb ages with T_{DM} ages of 1.89 - 1.84 Ga) and; (3) fine-grained gneiss (1.42 Ga, U/Pb ages) and T_{DM} ages 1.75 Ga. These geochronological data clearly suggest the involvement of Paleoproterozoic material in the Rondonian-San Ignacio Orogen, showing their predominantly ensialic character.

The available K/Ar ages for Rondônia (Teixeira and Tassinari, 1984) reveal a complex thermal history for the area. K/Ar data on biotite and amphibole from basement rocks show three distinct cooling ages: 1.36 - 1.3 Ga, 1.26 - 1.24 Ga, and 1.1 Ga - 970 Ma. These were interpreted as reflecting the regional cooling related to three tectonic episodes. A zircon U/Pb SHRIMP age of *c.* 1.34 Ga obtained on high-grade granulitic rocks near Ariquemes (northern Rondônia) by Tassinari *et al.* (1999) has demonstrated the presence of this orogenic event in the area. This age is coeval with the emplacement of the Alto Candeias Batholith (1.34 - 1.33 Ga), which occurred in the same area. Despite the interpretation that considered the age of 1.34 Ga as the time of regional metamorphism assigned to the Rondonian-San Ignacio Orogeny, we also consider that the U/Pb age of 1.34 Ga could represent the Alto Candeias thermal event that resulted in the granulitization of the older Rio Negro-Juruena Gneiss. Recent U/Pb monazite age and Sm/Nd garnet-whole-rock isochron age of gneissic rocks of northern Rondônia suggest high-grade metamorphism at 1.33 - 1.31 Ga, which corroborates the SHRIMP results.

Metasedimentary units

The San Ignacio Supergroup crops out in the form of discrete belts throughout the Bolivian Precambrian area. This supergroup is mainly composed of quartzite, feldspatic metapsammitic and micaceous schist or phyllite with subordinate ferruginous, calc-silicate, metavolcanic and graphite-rich units (Litherland *et al.*, 1986). The basin was filled at some stage with arkose and lithic-feldspathic sandstone derived, presumably, from some nearby uplifted basement (Parágua Craton of Litherland *et al.*, 1986). The pelitic units mark a period of quieter deposition in a shallow-water, extending over the entire region. Ferruginous and carbonaceous shale, ironstone and volcanic rocks, which probably represent lower-grade relics of the depositional stage, should not be immediately interpreted as a magmatic arc (Litherland *et al.*, 1986), but could represent a continental margin prism related to the Rondonian-San Ignacio Orogen.

Metamorphism and Deformation

According to Litherland *et al.* (1986), two main phases of penetrative deformation accompanied by low to high-grade metamorphism have been related to the San Ignacio tectonic event. (1) The N to NE trending D_2 event involved upright folding with recumbence to the NE, which was accompanied by widespread migmatization. (2) The essentially NW rending, upright, D_3 folding that was accompanied by the generation of syn-kinematic K-feldspar-bearing granite dated at *c.* 1.35 Ga. Higher-level granophyre complexes and smaller mafic intrusions were also developed. D_3 was followed by phases of essentially non-penetrative deformation, which controlled the emplacement of some late to post-kinematic granitoid plutons and layered alkaline complexes.

Magmatic Units

A summary of the geology of the granitoid plutons of eastern Bolivia has been presented by Litherland *et al.* (1986, 1989). The San Ignacio event was accompanied by extensive syn to late-kinematic granite magmatism, which was designated by Litherland *et al.* (1986) as the Pensamiento Granite Complex. The age of the entire suite is contained within the interval of 1.4 to 1.25 Ga. The syn to late-tectonic magmatism is represented by the dominantly potassic calc-alkaline granite of the Pensamiento Complex which forms a large part of the Parágua Craton of Litherland *et al.* (1986). The terminal magmatic episode is represented by the layered cross-bedded nordmarkite of the El Tigre Alkaline Complex.

The granite series are dominantly potassic calc-alkaline granite, but some are of sub-alkaline composition. The dominant rock-types are monzo and syenogranite, gabbro and diorite. Sub-volcanic granophyre complexes and the layered cross-bedded nordmarkite of the El Tigre Alkaline Complex are observed in the southern zone of Bolivia. Locally, the post-tectonic granite exhibit rapakivi textures (*i.e.*, the Discordancia Granite). The Pensamiento Complex (Litherland *et al.*, 1989) consists of a number of dominantly syenogranite to monzogranite bodies of different ages. The few Rb/Sr isochron ages available for the granitoid plutons range between 1.391 and 1.291 Ga, and the initial Sr isotope composition, varies between 0.7003 and 0.7058 (Table 9). According to Litherland *et al.* (1989) the granitic bodies are syn to post-tectonic. The late to post-tectonic suites are deep level granitoid plutons derived from a mixing between lower crust and mantle sources with a prevailing mantle component. The emplacement took place during a period of stress relaxion, uplift erosion and decline in crustal temperature. The syn-kinematic granite bodies show a mixed crust-mantle isotope signature, which suggests generation mainly from short-lived sialic material.

The magmatic events ascribed to the Rondonian event in northern Rondônia, particularly in the Rondônia Tin Province, comprise intermittent distint bimodal intraplate rapakivi suites, which intruded the *c.* 1.75 - 1.53 Ga Rio Negro/Juruena crust. The episodes are defined by well-constrained U/Pb geochronology between 1.41 and 1.3 Ga (Table 10). This magmatism is represented by the suites as follows: the Santo Antonio-Teotônio (1.406 ± 32 Ga), the Alto Candeias (1.347 to 1.338 Ga) and the São Lourenço-Caripunas (1.314 to 1.309 Ga) rapakivi suites (Bettencourt *et al.*, 1999). The Igarapé Preto Intrusive Suite gave Rb/Sr age of 1.195 ± 0.05 Ga (Tassinari *et al.*, 1984), and could be included in the same event, considering that the U/Pb ages reported for similar rapakivi granite intrusives are consistently older than the Rb/Sr isochron ages of about 100 Ma (Bettencourt *et al.*, 1999).

Charnockite and mafic or ultramafic igneous complexes are associated with the Alto Candeias and São Lourenço-Caripunas suites. Contemporaneous diabase dykes are associated with the Santo Antonio rapakivi granite, whereas charnockitic and syenitic rocks of unknown ages are spatially related to the Alto Candeias rapakivi granites. Diabase, gabbro and anorthosite (Ciriquiqui basic and ultrabasic rocks) with conventional Rb/Sr age of *c.* 1.3 Ga crop out near the São Lourenço-Caripunas Batholith. The São Lourenço-Caripunas rapakivi granite and Ciriquiqui basic and ultrabasic rocks also constitute a large AMCG association. According to Bettencourt *et al.* (1999) there is the possibility that the suite, as defined herein, might consist of several sub-suites, each of which was emplaced over a short time.

Fazenda Reunidas Domain

In the western part of the Rio Alegre Terrane (along the Alegre River and the Aguapeí River), there occur granitoid plutons having a policyclic evolution ascribed to the Fazenda Reunidas Domain. The Aguapeí flat-lying sedimentary rocks bound these rocks to the W. Volcanic rocks of the Rio Alegre Volcano-sedimentary Sequence occur to the E and the Pantanal (Quaternary) sedimentary cover bound these rocks to the S.

In the southern part of Rio Alegre Valley the rocks comprise foliated grey granite denominated the Lajes Granite. Zircon U/Pb results (Table 11) (Geraldes, 2000) revealed a first age group around 1.606 Ga and a second at 1.31 Ga. The Sm/Nd mantle-depleted model age calculated for these rocks is 1.69 Ga, with $\varepsilon_{Nd(1.6\,Ga)} = +3.4$ and $\varepsilon_{Nd(1.3\,Ga)} = 0.0$. The older zircon U/Pb age was interpreted by Geraldes (2000) as the crystallization age, whereas the younger age was considered as isotope resetting in the U/Pb systems due to the superimposed magmatic or metamorphic event.

Tonalitic rocks were observed by Pinho (1990) along the Aguapeí River, near the Santa Barbara Ridge (Fazenda Reunidas Domain). They are associated with amphibolitic and intrusive monzosyenite, which has, in some places, a gradational contact with foliated tonalite, suggesting local melts. Geraldes (2000) reported concordant U/Pb ages for these tonalite bodies close to the contact with the monzosyenite, with values varying from 1.408 to 1.463 Ga. The display of these points along the concordia line suggests an isotopic resetting, probably due to the partial melt of the tonalite resulting in the monzosyenitic liquid with new U/Pb isotopic composition. The $\varepsilon_{Nd(1.4\,Ga)}$ value is + 3.6, which suggests a juvenile magma source for the tonalite. Other associated granitoid rocks presented similar geochronological results such as U/Pb ages of 1.412 ± 0.021 Ga and 1.4 ± 0.021 Ga with respectively ($T_{DM} = 1.58$ Ga and $\varepsilon_{Nd(T)} = 3.6$) and ($T_{DM} = 1.49$ Ga and $\varepsilon_{Nd(T)} = 4.2$).

The policyclic granitoid plutons from the Fazenda Reunidas Domain are younger than those of the Rio Alegre Terrane. However, the correlation between these associations is not well defined, and only further work will allow us to decipher the real tectonic meaning of these rocks.

Sunsas Province (SP)

The Sunsas Province is the youngest tectonic unit of the Amazonian Craton. It is best exposed in the southwestern part of the craton, where it consists of a zone with rocks generated by the erosion of older continental crust; the deposition and subsequent deformation and metamorphism of these sediments and older basement between 1.30 to 1.0 Ga (Litherland *et al.*, 1986). This metamorphic episode is associated with syn-tectonic magmatism. The 1.18 Ga Garzon Granulitic Belt, which occurs in Colombian Andes as a basement tectonic window, described by Kroonenberg *et al.* (1982) along with other Andean inliers (Santa Marta, Medellin, Arequipa/Antofala) (Tosdal, 1996), could be a possible extension of the Sunsas Belt towards the NW. The Tucavaca Belt (Lower Paleozoic) borders the Sunsas Province to the S, to the N by the older Rio Negro-Juruena Province, and to the W it extends under Phanerozoic sedimentary cover.

The start of the Sunsas tectonic evolution, which has been chrono-correlated with the Grenville Orogenic Cycle (1.3 to 1.0 Ga) in Laurentia and Baltica, was marked by an important phase of continental distension (rifting). Basaltic magmatism and the deposition in a continental margin environment of the sediments of Sunsas and Vibosi groups in Bolivia and the Aguapeí Group in Brazil represent this distensive phase. Furthermore, this basin was closed during the development of the Sunsas/Aguapeí Orogenic Belt. During the same orogenic episode there occurred the evolution of the Nova Brasilândia Volcano-plutonic Sedimentary Sequence and syn-tectonic magmatism. These episodes were followed by deformation and alkaline plutonism associated with the final stage of development of the Sunsas Orogen. Uplift and regional cooling occurred after *c.* 920 Ma, when cratonization was gradually achieved.

The Sunsas Geochronological Province may be subdivided into three main lithotectonic segments as follows: (i) the Sunsas Mobile Belt in Bolivia (Litherland and Bloomfield, 1981); (ii) The Aguapeí Thrust Belt in Brazil (Saes and Fragoso Cesar, 1996); and (iii) The Nova Brasilândia Metavolcano- sedimentary Sequence (Rizzoto, 1999).

The Sunsas Mobile Belt in Bolivia

The Sunsas Cycle was marked by an important event involving continental distension that was followed by alkaline plutonism and by the deposition of the Sunsas and Vibosi groups (constrained by Litherland *et al.*, 1986, at about 1.3 Ga - 950 Ma). This probably represents an extension of the same basin of the Aguapeí Group in Brazil (Saes, 1999).

The term Sunsas Orogeny was introduced by Litherland and Bloomfield (1981) to designate a period of sedimentation that included the erosion, deformation and metamorphism and reworking of the basement rocks and magmatism within the interval 1.3 Ga to 950 Ma. These geological events that took place in the southwestern part of the Amazonian Craton form the southern rim of the so-called Parágua Craton of Litherland *et al.* (1986). The deformation and metamorphism resulted in a WNW trending Sunsas Mobile Belt (Litherland *et al.*, 1989). The following summary is totally based on Litherland *et al.* (1986)

The Sunsas Mobile Belt (1.25 Ga - 900 Ma) in Bolivia is represented by reactivated basement, syn and post-tectonic granitoid, and sparse outcrops of metasedimentary rocks. The Sunsas deposits belong to two distinct environments: mobile belt and cratonic. Penetration-deformed beds partially surround the so-called Parágua Craton along its southern and eastern margins.

The geochronological database for this orogeny in Bolivia was summarized by Litherland *et al.* (1986). It is based mainly on Rb/Sr and K/Ar ages, and concludes that the metamorphism, deformation and plutonism of this belt extended from approximately 1.28 Ga to 950 Ma. The metamorphic basement and the San Ignacio Granitoid were reworked at this time as seen by the Sunsas tectono-metamorphic overprint, producing K/Ar age resetting.

The western and southern limits of the Sunsas Mobile Belt are defined by the Rio Negro Front and the Santa Catalina Straight Zone (Fig. 7). Both comprise a NW trending series of lineaments, which on the ground coincide with *en echelon* mylonite belts. Z-shaped folds with limb sliding along short limbs producing minor dextral displacements associated with granulite downgrading. Whilst the Santa Catalina structure is clearly sinistral, the Rio Negro Front appears to show a regional dextral shift. The Granulite Complex to the S shows a sinistral swing.

The southeastern part of the Sunsas Belt can be divided into two tectonic segments. (1) N of Conception; where the San Ignacio structures are preserved to a considerable extent despite Sunsas reworking. (2) The San Diablo Front area, which is described in the southernmost part of the Sunsas Orogen and was interpreted as a suture zone between the Parágua Craton and the San Pablo Terrane (Saes and Fragoso Cesar, 1996; Saes, 1999). According to these authors, the Sunsas Orogen was the result of a collision of the Parágua Craton and the San Pablo Terrane, and the collage zone is represented by the San Pablo Front (Litherland *et al.*, 1986). This collage may be responsible for the metamorphism and magmatism during the Sunsas Cycle, and the granodiorite intrusives observed in San Pablo Terrane are the arc-related result over a SSW dipping subduction zone. There is no geochronological data for San Pablo Granitoid to confirm this hypothesis.

Sedimentation

The sedimentary record of this cycle is represented by the Sunsas and Vibosi groups, dated about 1.35 Ga, that overlie rocks of the San Ignacio Orogen with a marked uncorfomity (Literland *et al.*, 1986). The Sunsas Group is composed of quartzite, sandstone, shale and oligomitic quartz conglomerate, ranging from 1000 to 6000 m in thickness. The group includes three units, which are from the base to the top, the Arco Iris (or Guapama, or El Pucho), Cuatro Carpas (or El Elucion, or Lower Psammitic unit), and Bela Vista (or Cabecera, or Argillaceous unit).

The Arco-Iris unit (in Sierras Huanchaca-Ricardo Franco) comprises oligomitic conglomerate with quartz pebbles in a phyllitic matrix. Clast-supported conglomerate with a quartzitic matrix, poorly sorted siltstone wacke, conglomerate with a ferruginous (hematitic) matrix. Mica-schist, granitoid rocks, black quartz and volcanic rocks mainly form clasts. The Cuatro Carpas unit (in Serrania Huachaca) consists of a varied facies association with channel structures and siltstone and mudflake breccia. Cross-bedding and graded bedding may be result of sorting by current action rather than by turbidity flows. The Lower Psammitic unit (in Sierra Santo Corazon) comprises typical red sandstone, fine to coarse-grained psammitic types, of which the angularity increases with the amount of feldspar (microcline-dominated sub-arkose and arkose). The Argillaceous unit (Sierra Santo Corazon) consists of pelitic rock-types rarely found as massive units. They are normally intercalated with siltstone and psammite in semi-pelitic sequences, which are distinctly rhythmic in parts of Sierra Huanchaca.

Ripple marks, tabular-planar and festooned cross-bedding can be observed in the Arcos Iris, and Cuatro Carpas units. Red mudstone beds, indicating oxidation and dissecation (and hence deposition under subaerial conditions), are typical of shallow marine deposition. The Lower Psammitic unit consists of sandstone with tabular cross-bedding deposited in braided rivers and fine-grained sandstone deposited in eolian dunes. Lithology (mudstone)

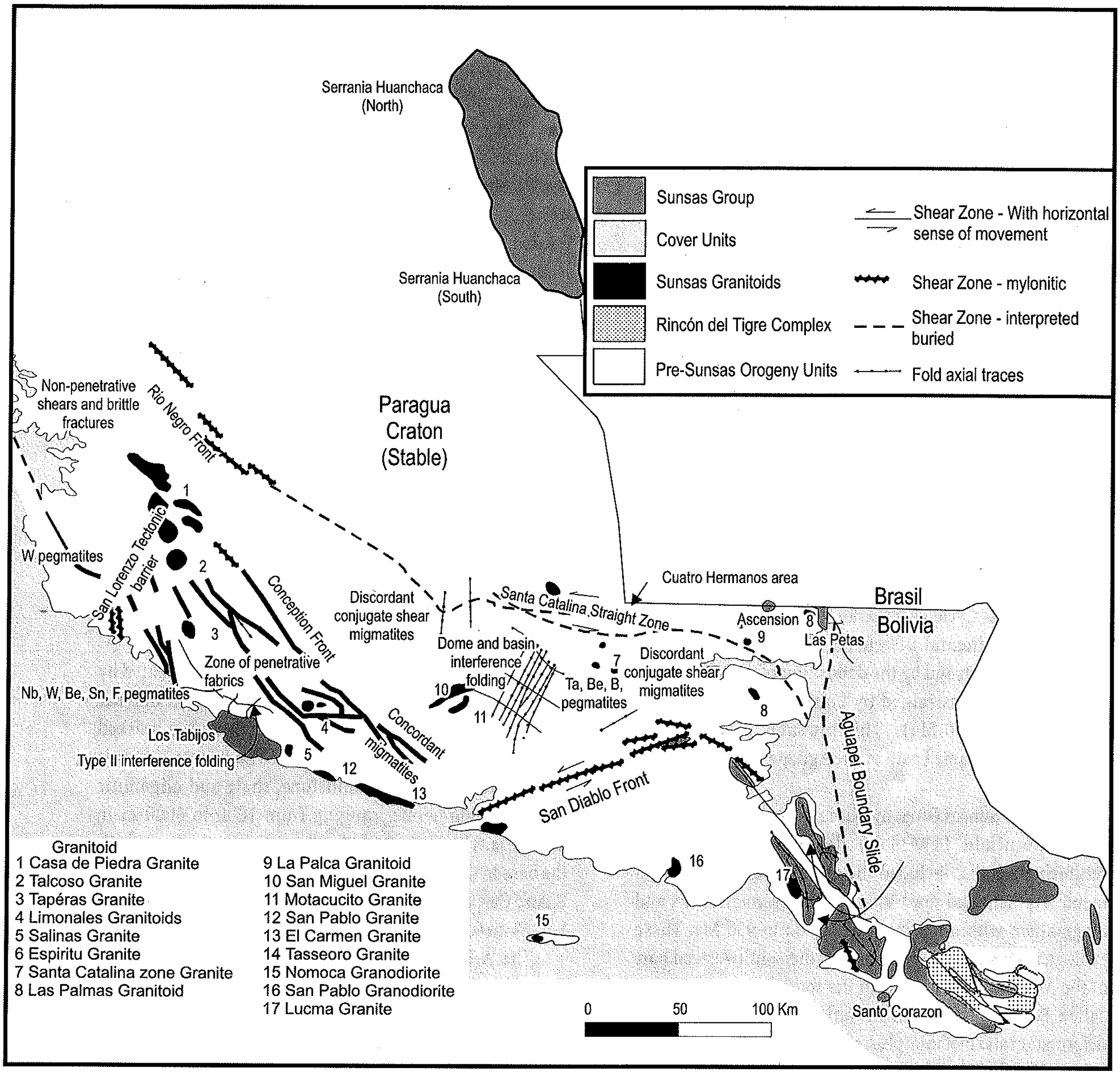


FIGURE 7 - Main units of the c. 1.0 Ga Sunsas Orogeny in eastern Bolivia (modified after Litherland et al.*, 1986).*

and sedimentary structures (rhythmic structures) in the Argillaceous unit are interpreted as result of deposition in deep marine water.

The Vibosi Group is a sequence about 2000 m thick of sandstone and arkose. Litherland *et al.* (1986) correlated the Vibosi Group with the Upper Psammitic unit and, consequently, included the Vibosi Group in the Sunsas Cycle. The basal Santa Isabel Formation (1100 m) is composed of medium-grained arkose. These beds are overlapped by the San Marcos Formation (750 m) with interbedded purple sub-arkose and fine-grained reddish-brown quartz sandstone. The Santo Columbo Formation (450 m), at the top of the sequence, comprises fine-grained, grey, and locally cross-bedded quartz sandstone.

The Magmatism

The Sunsas Cycle magmatic activity in Bolivia occurred between 1.005 Ga to 993 Ma (considering Rb/Sr isochron age) and is represented by the Rincon del Tigre Igneous Complex and several kinds of granitoid and migmatite. The Rincon del Tigre Igneous Complex occurs over an area of about 720 km^2, being a layered, thick, differentiated, mafic/ultramafic sill discovered by Hess (1960), which cuts sedimentary rocks of the Sunsas and Vibosi groups. The complex is subdivided in three units: lower ultramafic unit, middle mafic unit and upper felsic unit (granophyre). Darbyshire (1979) reported a Rb/Sr age of 992 ± 86 Ma for these rocks.

According to Litherland *et al.* (1986) the Sunsas Ganitoid includes both syn to late-kinematic bodies related to shear zones and late to post-kinematic types with little or no signs of deformation. The syn to late-kynematic types, may be foliated locally and consist mainly of medium to coarse-grained biotite or biotite muscovite syenogranite. The granitoid may show gradational contacts with nebulitic Sunsas gneiss-migmatite rocks. The main plutonic bodies of the Sunsas Province are: Espiritu Granite, Santa Catalina Zone Granite, Las Palmas Granitoid, La Palca Granitoid, San

Miguel Granite, Motacucito Granite, San Pablo Granite, El Carmen Granite, and Nomoca Granodiorite (Table 12).

The late to post-tectonic bodies are aligned within the Sunsas Orogen across the San Diablo Shear Zone and are represented by the Casa de Piedra, Talcoso, Tapeva, Salinas and Tasseoro granite bodies, and also by the San Pablo Granodiorite, and Luma Granite in the southeast fringe. They are circular or oval in plan view with intrusive contacts and little or no signs of internal foliation. They are dominantly medium to coarse-grained biotite monzogranite. Additionally, marginal swarms of crosscutting pegmatite and aplite veins are observed in the country rocks. The observed field features indicate that the granite emplacement occurred at a higher crustal level. The age determinations are still fragmentary, and only the Casa de Piedra Granite was dated by Rb/Sr at 1.005 ± 0.012 Ga. According to Teixeira and Tassinari (1984) this age is in good agreement with those already observed for the Young Rondônia Granite and Costa Marques Group in Brazil.

The Sunsas Migmatite occurs along sets of vertical conjugate shears. The migmatite is poorly developed in granoblastic granulite and on the Concepcion Front. These rocks are concordant with a new penetrative D_3 shear zone fabric. As a whole the paragneiss was migmatized in the upper amphibolite facies affecting the Rondonian-San Ignacio basement.

The Aguapeí Thrust Belt

The Aguapeí Thrust Belt occurs in the southwestern part of the Amazonian Craton in Brazil and comprises a sedimentary group deformed in a cratogenic environment. This unit partially covers the vulcano-plutonic basement ascribed to Rio Negro-Juruena and Rondonian-San Ignacio Province. The sedimentary sequence was described as Aguapeí unit (Fig. 8) by Figueiredo *et al.* (1974). Souza and Hildred (1980), Saes *et al.* (1992) and Menezes *et al.* (1993) who proposed the elevation of this unit to group status describing three formations: Fortuna, Vale da Promissão, and Morro Cristalina. Litherland *et al.* (1986, 1989) suggested the correlation between Aguapeí and Sunsas groups, indicating the link between Sunsas and Aguapeí basins and the contemporaneity of the respective metamorphic episodes.

The development of the Sunsas-Aguapeí sedimentary basin was controlled by the Jauru Terrane to the E in Brazil, and by the Parágua Craton of Litherland *et al.* (1986) to the W in Bolivia. The southern limit is unknown, and the basin probably extends northwards, encompassing the sedimentary rocks deposited in the Pacaás Novos, Uopiane, São Lourenço and Pimenta Bueno grabens. Deformational features were described by Saes *et al.* (1992); Menezes *et al.* (1993) and Geraldes (1996), suggesting the existence of a *c.* 950 Ma linear NNW mobile belt with different levels of deformation. Deformation included thrusting, folding and the development of shear zones correlated with the Grenville collage that resulted in the formation of the Rodinia supercontinent.

Sedimentary Units

The location of the Aguapeí Group in southwestern part of the Amazonian Craton is shown in Figure 8. In Bolivia the sedimentary rocks are observed at Serrania de Huanchaca and Santo Corazon (Litherland *et al.*, 1989), and in Brazil in the Ricardo Franco, São Vicente, Santa Barbara and Rio Branco ranges. According to Souza and Hildred (1980) and Saes *et al.* (1992), the Aguapeí Group includes three formations: a sandstone and conglomerate unit (Fortuna Formation); an intermediate pelitic unit (Vale da Promissão Formation) and an upper sandstone unit (Morro Cristalino Formation).

The sequence of the Aguapeí Group (in Brazil) and Sunsas Group (in Bolivia) record a complete cratonic oscillation, with a (1) transgressive phase with tide-dominated deposition of sandstone and conglomerate; (2) a marine progradation phase allowing the psammitic deposition in an oceanic, current-dominated environment; (3) an upper unit recording a marine regression with deposition of fluvial sandstone beds.

The above-described evolution allows the interpretation of the Sunsas-Aguapeí Basin as a depression originated by crustal extension within the Amazonian protocraton. Both the immature nature and anomalous thickness of the Santo Corazon area suggest the NNW trend of older basement structures which acted as paleosutures for rifting that originated the Sunsas-Aguapeí Basin. The Aguapeí Thrust Belt is characterized by a deformational event that thrust and folded the sedimentary rocks of the Aguapeí Group (Saes, 1999).

The K/Ar dating of hydrothermal seriates in veins in gold deposits associated with the Aguapeí sequence showed ages in the range 960 to 840 Ma, which may indicate the time of the hydrothermal sericitization. Pb/Pb dating in galena yielded model ages in the range 1.0 Ga to 800 Ma for the Onça Deposit, in agreement with K/Ar ages reported by Geraldes *et al.* (1997). These geochronological results suggest minimum ages for the Aguapeí Group.

Magmatism

The Guapé Intrusive Suite was first described by Barros *et al.* (1982), and also studied by Saes *et al.* (1984) and Menezes *et al.* (1993). The first-cited authors reported a Rb/Sr (whole-rock isochron) age of 950 ± 40 Ma. The last-cited authors carried out chemical studies and described bimodal anorogenic characteristics for this unit. Geraldes (2000) reported a T_{DM} age of 1.29 Ga and $\varepsilon_{Nd(950\,Ma)}$ value of + 1.27, suggesting a contribution of juvenile and crustal material for the magma genesis. The same author also reported two U/Pb zircon ages for the São Domingos Suite of 939 ± 19 Ma (T_{DM} = 2.21 and $\varepsilon_{Nd(T)}$ = - 7.1) and 914 ± 14 Ma (T_{DM} = 2.21 and $\varepsilon_{Nd(T)}$ = 7.6). This unit was interpreted as a shear-controlled S-type granitoid generated at the end of the Aguapeí thrust event. Sato and Tassinari (1997) found rocks with T_{DM} ages of *c.* 1.15 Ga in the area.

The Nova Brasilândia Terrane

The summary given below draws on published work and almost totally on Rizzoto (1999), Rizzoto *et al.* (1999a, b), to whom the reader is referred for detailed descriptions. The name Nova Brasilândia Metavolcano-sedimentary Sequence was introduced by Silva *et al.* (1992) for a group of supracrustal rocks. These rocks consist of amphibolite facies metamorphites as represented by mica-quartz schist, biotite paragneiss, calc-silicate rocks, and amphibolite that occur in the Nova Brasilândia d'Oeste and Alta Floresta d'Oeste regions (southeastern Rondônia), formerly recognized and named the Comemoração Epimetamorphites by Leal *et al.* (1978). More recently, and well documented by Rizzoto (1999) the entire sequence was redefined as a distinct tectonic unit the limits of which extend to northeastern and southeastern regions of the State of Rondônia.

Based on recent geological studies and U/Pb (SHRIMP) geochronological data, Rizzoto (1999) proposed the name Nova Brasilândia Group to embrace the main lithostratigraphical unit composed by dominantly mafic rocks (metagabbro, metadiabase and amphibolite) and by a metaplutonic-sedimentary sequence (biotite-feldspar quartz gneiss, mica schist and calc-silicate rock). These rocks are intruded by several high-level late-tectonic A-type granite plutons. However, the formal name Nova Brasilândia Terrane was proposed by Scandolara *et al.* (1999c) to replace the terms previously applied to these rocks.

Supracrustal rocks

In the type area the Nova Brasilândia Group was subdivided by Rizzoto (1999) into the Migrantinópolis Formation and Rio Branco Formation. The Migrantinópolis Formation consists of psammo-pellitic supracrustal rocks derived from deep-sea sediments, which consist of siliceous-clastic-carbonaceous turbiditic sediments that are intruded by subordinate sills, stocks and dykes of metagabbro-norite, amphibolite and metabasalt. The absolute age of supracrustal rocks remains unknown, but detrital zircon from a banded paragneiss indicate a U/Pb SHRIMP zircon age of 1.215 ± 0.02 Ga, which is interpreted as the maximum age of the deposition of the sediments. Inherited zircon having variable ages from 2.09 Ga to 1.417 Ga and Sm/Nd model ages for the banded paragneiss yielded values from 1.91 to 1.63 Ga, $\varepsilon_{Nd\,(T)}$ = - 3.8. These data support the assumption that a continental crust source was present on the northern flank of the Nova Brasilândia Group probably ascribed to granitoid plutons of the Serra da Providencia Intrusive Suite (1.57 to 1.53 Ga) and metadacite of the Roosevelt Sequence (1.75 Ga).

Sills and stocks of mafic meta-igneous rocks, metagabbro, metadiabase represent the Rio Branco Formation in addition to amphibolite interlayered with minor amounts of marl-turbidite (calc-silicate gneiss) and rare terrigenous silicic-clastic metaturbidite (quartz-feldspar gneiss and fine-grained mica-schist).

The 1.11 ± 0.01 Ga age for a metamorphosed (amphibolite facies) subophitic metagabbro is based on four zircon fractions, which was interpreted as the age of metamorphism that affected the sequence (Rizzoto, 1999). The metabasic rocks are characterized by $\varepsilon_{Nd(T)}$ varying from 3.1 to 5.0, which indicate a mantle source for these rocks, suggesting a juvenile-magma accretion to the continental crust at this time (Table 13). These data match the values and the interpretation previously advanced by Sato and Tassinari (1997). The geochemical and isotope data define the metabasic rocks as enriched mantle basalt of the tholeiitic series (P-MORB) and probably these sequences (turbidite and mafic magmatism) represent a passive rift environment.

Granitic Magmatism

The granitic intrusions in the Nova Brasilândia region took place in two distinct pulses at 1.098 ± 0.01 Ga and 995 ± 15 Ma, related to Rio Branco Granite and the Rio Pardo Granite Suite (Rizzoto *et al.*, 1999a, b). The Rio Branco Granite is mainly composed of a number of small syn-tectonic bodies interlayered with metabasite and calc-silicate gneiss. Monzogranite bodies have been strongly deformed and are controlled by the main transcurrent regional fault system. Samples of biotite monzonite gneiss have a U/Pb zircon crystallization age of 1.098 ± 0.01 Ga, which overlap with peak-metamorphic age and deformation of the Nova Brasilândia Group. The $\varepsilon_{Nd(T)}$ values of - 0.4 and the Sm/Nd model age (T_{DM}) of *c.* 1.63 Ga indicate that the original magma was derived from a source with an older crustal component and slight participation of mantle material (Table 13).

The Rio Pardo Granite Suite represents the younger tardi to post-tectonic granite pulse, which indicates the final pulse of the Sunsas Orogeny in the area. It is represented by oval shaped, epizonal plutons, locally grading into foliated charnockite. The granite intrusives are dominantly hypersolvus syenogranite and subordinate subsolvus monzonite showing rapakivi textures. A metamorphic, granoblastic texture is superimposed and the rock exhibits a protomylonitic texture. The granite intrusives are metaluminous, peraluminous, sub-alkaline A-types granite intrusives and have age counterparts in the Younger Rondônia Granite in northern Rondônia. Contemporaneous foliated coarse-grained grey to greenish charnockite bodies also occur.

Four zircon fractions of one porphyritic monzonite gave an upper intercept crystallization age of 995 ± 15 Ma. The Sm/Nd model age around 1.5 Ga and $\varepsilon_{Nd(T)}$ = + 0.5 suggest that the granitoid plutons were derived from the recrystallization of an older continental crust with a short crustal life together with significant juvenile contribution. Five samples yielded a Rb/Sr isochron age of 1.003 ± 0.022 Ga and $^{87}Sr/^{86}Sr_{initial}$ = 0.7038 ± 0.0002 (MSDW = 0.3031), which is in close agreement with the new radiometric results.

Deformation and Metamorphism

It was postulated by Rizzoto *et al.* (1999a, b) that the Nova Brasilândia Group evolved during two periods of complex distension and convergent tectonic regimes. The model must consider two phases of deformation, as follows:

- An extensional tectonic setting: involving intracontinental rifting evolving to a progressive continental margin with the production of coeval 1.15 Ga mantle-derived tholeiitic melts (P-MORB type) represented by sills. The mafic rocks clearly precede the deformation and metamorphism that affected the foliated granitic rocks in the area.
- Later, during the compressional tectonic regime: the rocks of the Nova Brasilândia Group were affected by a severe transpressive regional metamorphic event in the upper amphibolite facies, under high-temperature and low pressure conditions, represented by the Rio Branco Transpressive Belt. A well-developed foliation and schistosity including widespread formation of mylonite accompanied this event by the development of transcurrent shear-zones.

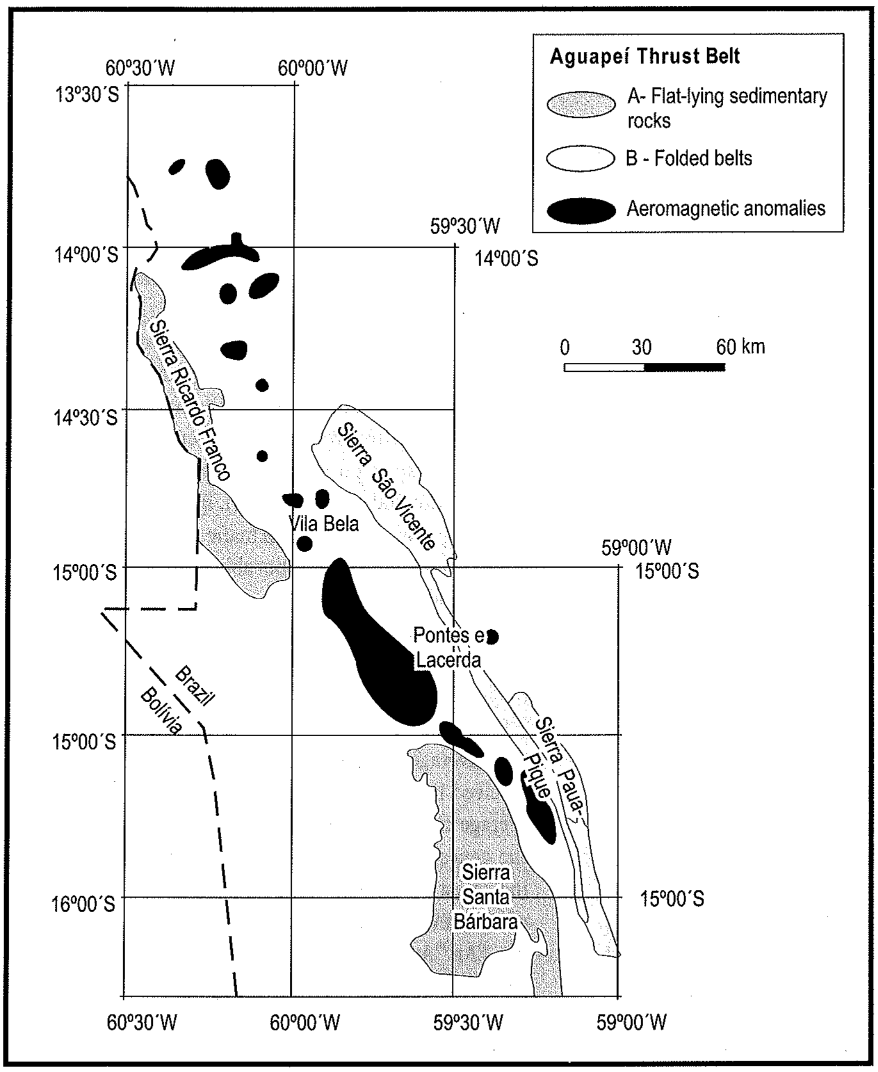
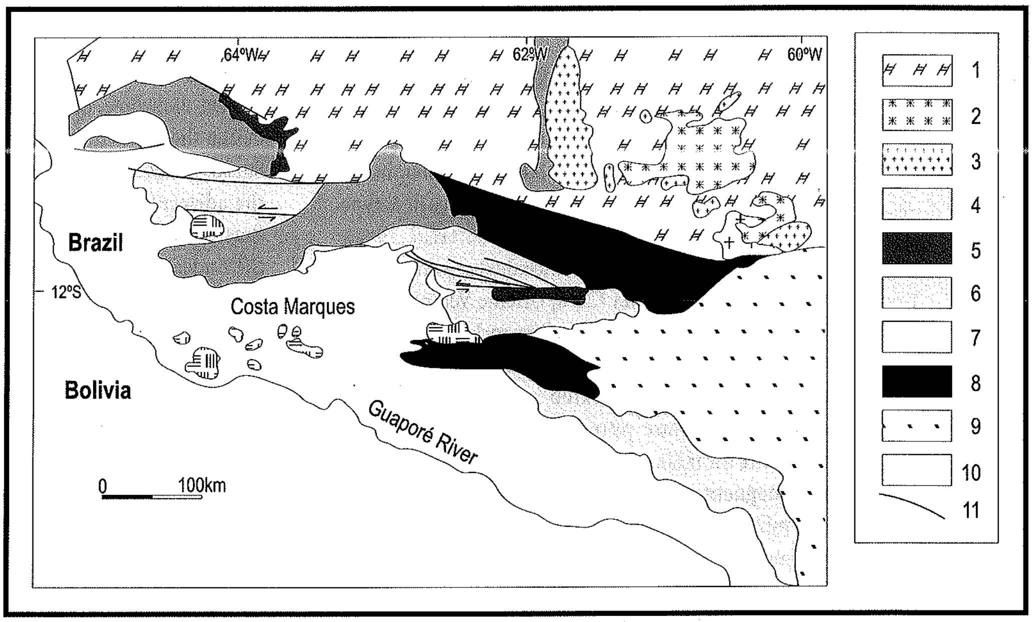


FIGURE 8 - Geographic distribuition of the Aguapeí Group morphostructures. The aeromagnetic anomalies delineate the cancealed Rio Alegre Terrane boundary (modified after Menezes et al.*, 1993 and Saes, 1999).*

FIGURE 9 - Major units of the Nova Brasilândia Group. 1 - Jamari Terrane; 2 - Roosevelt Terrane; 3 - Serra da Providência Intrusive Suite; 4 - Nova Brasilândia Volcano-sedimentary Sequence; 5 - Mafic rocks; 6 - Undeformed Sunsas Sedimentary Cover; (Tardi to post tectonic granitoids); 8 - Paleozoic Cover; 9 - Mesozoic Cover; 10 - Recent Cover; and 11 - Fault.



During this episode the mass transport was from SW toward NE. The anatectic syn-tectonic leucogranite resulting from partial melting of metaturbiditic sediments yielded a U/Pb age of 1.1 ± 0.008 Ga, which was interpreted by Rizzoto (1999) as dating the regional metamorphism in the area. This metamorphic episode also produced intense migmatization of the metaturbidite beds and recrystallization of the metabasic rocks.

Sunsas Effects in Northern Rondônia and Adjacent Areas

The effects of the Sunsas Orogeny in northern region of Rondônia (Fig. 10) and adjacent areas (states of Mato Grosso and Amazonianas, Brazil) occurred during the period between 1.15 Ga to 970 Ma. It includes a metamorphic overprint and deformation from 1.156 to 1.1 Ga and the emplacement of rapakivi granite intrusives, mafic dykes and granitic plutons between 1.08 Ga to 970 Ma in the older Rio Negro-Juruena and Rondonian-San Ignacio geochronological provinces. This superimposed metamorphic episode was previously recognized by Amaral (1974) as an autonomous reactivation on the ancient craton that he called the Rondoniense Reactivation (1.05 Ga - 900 Ma). These effects partially coincide in time with the Sunsas Orogenesis in Bolivia, the Aguapeí Thrust Belt and Nova Brasilândia Terrane, both in Brazil.

The Sunsas precursors in the region encompass the voluminous Rio Negro-Juruena (1.8 - 1.55 Ga) overprinted crust, mostly composed of paragneiss tonalitic gneiss, granitoid, migmatite and basic granulite, and rocks related to the Rondonian-San Ignacio event (1.41 - 1.39 Ga), already within the Rondonian-San Ignacio Province. These rocks show mainly bimodal mafic-felsic rapakivi magmatism with minor felsic gneiss. Sedimentary precursors are possibly represented by shallow marine sediments of the Beneficiente Group and by the Prosperança Formation.

The magmatism at 1.08 Ga - 997 Ma in northern Rondônia is composed of rapakivi granite and associated mafic rocks, including the Santa Clara Intrusive Suite (1.8 - 1.07 Ga) and Younger Rondônia Granite (1.0 Ga - 970 Ma). The granite bodies are mainly sub-alkaline, metaluminous to peraluminous, and show geochemical features of A-type within-plate granite (Leite Jr., 1996; Bettencourt *et al.*, 1997).

The Santa Clara Intrusive Suite includes the granite from the following massifs: Santa Clara, Oriente Velho, Oriente Novo, and Manteiga (Fig. 14). The older rock association is composed of porphyritic quartz-monzonite, monzonite and syenogranite with subordinated amounts of quartz-monzonite and minor pyterlite. Biotite and minor hornblende are the main mafic minerals and zircon, apatite, ilmenite, magnetite, allanite, fluorite and sphene are the essential minerals. A younger association includes syenite, trachyte and peraluminous and peralkaline granite.

The Younger Rondônia Granite intrusives were subdivided by Leite Jr. (1996) and Bettencourt *et al.* (1999) into two distinct suites. The first suite is composed of metaluminous to marginally peraluminous subsolvus and sub-alkaline types with minor associated quartz-syenite, quartz-monzonite, monzonite. The second suite, of restricted occurrence, shows a hypersolvus character as well as alkaline affinities. The field relationships suggest that the alkaline rocks are younger than the sub-alkaline types. The geographical distribution and the ages of the granitoid are shown in Figure 10 and Table 14, respectively.

The sub-alkaline suite consists of at least three distinct intrusive granite phases. Early intrusive bodies are composed mainly of coarse pyterlitic to porphyritic biotite syenogranite, late intrusive syenogranite and alkali-feldspar granite. The most recent intrusive rocks are rare, and are comprise mainly of (topaz), lithium-mica albite granite, and (topaz) quartz-feldspar porphyry. Primary tin and associated metal deposits are spatially related to granite of the two latter phases. The alkaline suite is composed of alkali-feldspar granite and peralkaline granite, alkali-feldspar syenite, trachyte and microsyenite and sub-alkaline quartz-feldspar porphyry and hybrid rocks (quartz microsyenite and quartz syenite). Biotite and more rarely sodic amphibole are the main mafic silicate minerals in the granite, but augite and/or hornblende are common in the syenite and microsyenite.

The Younger Rondônia Granite shows $\varepsilon_{Nd(T)}$ values of + 0.33 to - 3.25, T_{DM} between 1.66 to 1.73 Ga, initial Sr in the range of 0.707 to 0.709, $\delta^{18}O = +81$ to 9.5 ‰ and has $^{206}Pb/^{204}Pb$ of 17.7 - 20.6 and $^{208}Pb/^{204}Pb$ of 37.3 - 43.2, indicating time-averaged Th/Pb > 4. Older crustal rocks are clearly involved in granite genesis. A source characterized by an average crustal to elevated Th/U ratio also contributed to the genesis of these granite intrusives. Oxygen isotopes indicate a calc-alkaline magma component or assimilation of high-level crustal material (Bettencourt *et al.*, 1999).

$^{40}Ar/^{39}Ar$ plateau ages on hornblende foliated granitic gneiss and augengneiss from the Ariquemes region (RNJP) provided by Bettencourt *et al.* (1996) defined ages of 1.156 ± 0.036 Ga and 1.149 ± 0.035 Ga, respectively. These data suggest a Sunsas metamorphic overprint. The progressively slightly younger dates obtained on the biotite, 1.001 ± 0.033 Ga and 912.8 ± 30.5 Ma, and more feldspar (antiphertite slow cooling rates during metamorphism and are consistent with K/Ar ages observed in the Younger Rondônia Granite (1.08 - 1.0 Ga).

On the whole, the $^{40}Ar/^{39}Ar$ dates of 1.15 Ga - 950 Ma define the approximate period of regional cooling of the Sunsas Orogeny in the area. This interval is also recorded in the adjacent Rondonian-San Ignacio Province, the Nova Brasilândia Terrane and in the Garzon-Santa Marta inliers in the Andean Belt in Colombia (Krooneberg, 1982). Regional metamorphic cooling at 1.1 Ga, or slightly after, is indicated over large areas of Grenville Province (Anderson *et al.*, 1999).

Tectonic setting

The now recognized 1.15 to 1.1 Ga evolutionary stage in the southwestern sector of the Amazonian Craton is coherent, and is demonstrated by proto-ocean mafic rocks and typical rift-related supracrustal rocks recognized in the Nova Brasilândia Terrane (Rizzoto *et al.*, 1999a). The 1.08 Ga - 970 Ma stage as represented by extensive rapakivi magmatism, mafic flows and plutonism, in like manner to the Grenville Province, is widely recognized and attributed to collisional orogenesis between Laurentia and Amazoniania. Sadowski and Bettencourt (1996) proposed that the spatial organization of Grenville-Sunsas age structure in the southwestern part of the Amazonian Craton is compatible with

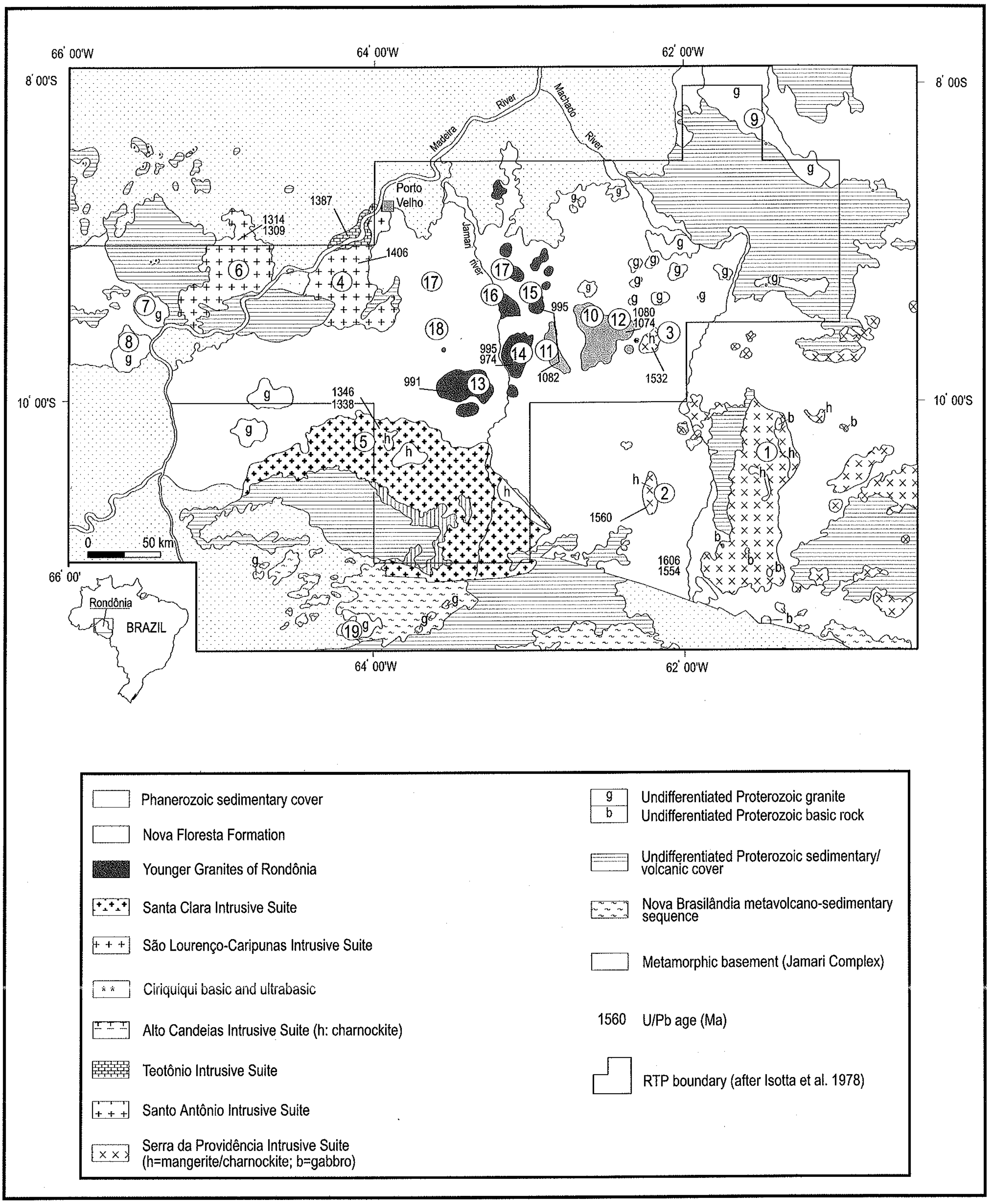


FIGURE 10 - Simplified geological map of the Rondônia Tin Province and adjacent areas, showing a distribuition of 1.6 Ga to 970 Ma rapakivi granite suites: 1 - Serra da Providência Batholith; 2 - Ouro Preto Charnockite; 3 - União Massif; 4 - Santo Antonio Batholith; 5 - Alto Candeias Batholith; 6 - São Lourenço-Caripunas Batholith; 7 - São Simão Massif; 8 - Abunã Massif; 9 - Igarapé Preto Massif; 10. Santa Clara Massif; 11. Manteiga Massif; 12. Oriente Novo Massif; 13 - Massangana Massif; 14 - São Carlos Massif; 15 - Pedra Branca Massif; 16 - Caritianas Massif; 17 - Santa Barbara Massif; 18 - Bom Futuro and Palanqueta hills; 19 - Costa Marques Group. Modified after Leal et al. *(1978), Schobbenhaus* et al. *(1981) and Bettencourt* et al. *(1999).*

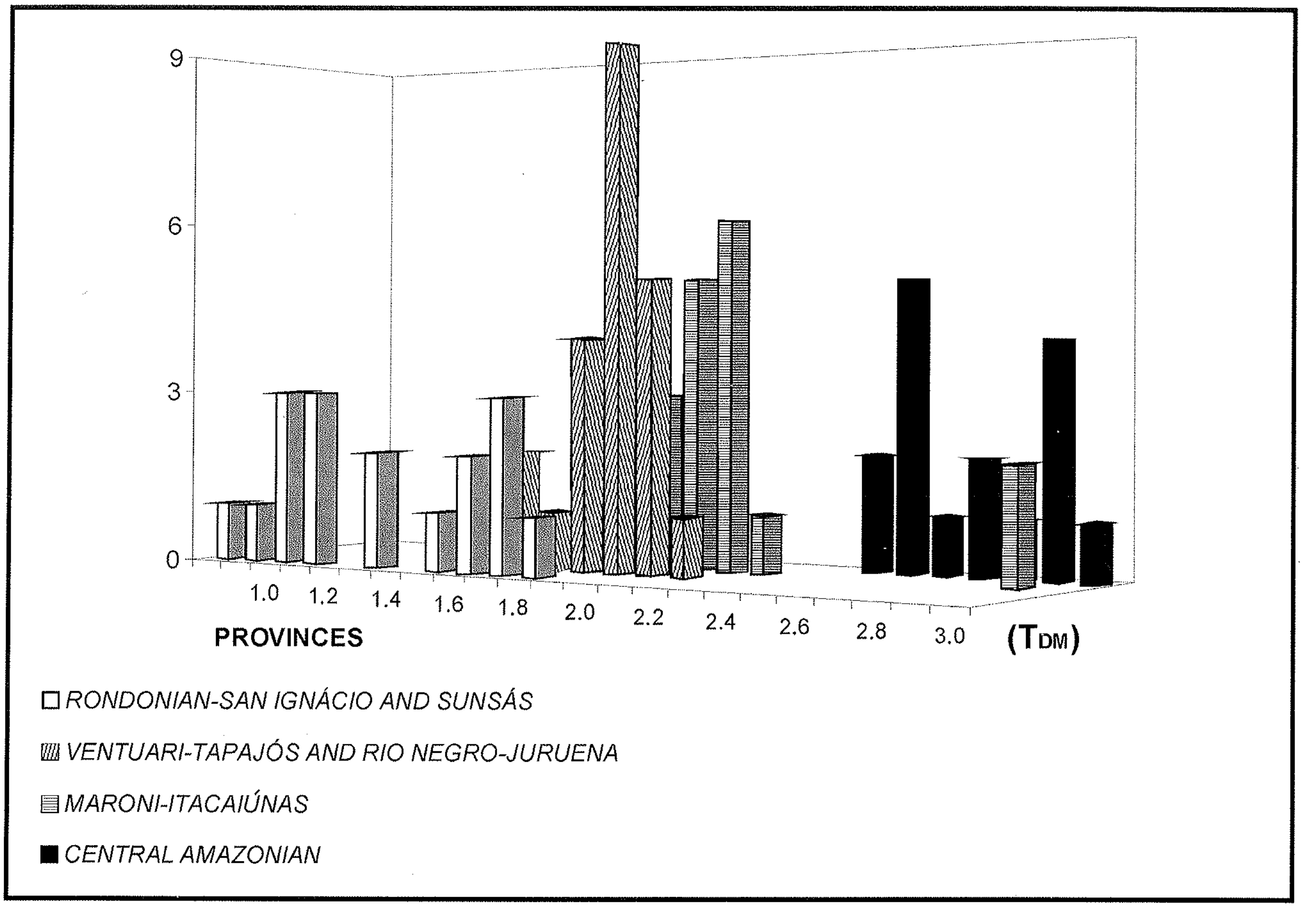


FIGURE 11 - Hystogram showing major accretionary events in the Amazonianian Craton according to depleted mantle Sm/Nd model ages.

a transpressional left-lateral component of collision, as mentioned by Hoffman (1992) and proposed locally by Gower (1996) in Canada. Following the collision, extensive strike-slip faults were accompanied by the intrusion of anorogenic granite and alkaline basalt that also resulted in the collapse of older cratonic sedimentary cover.

However a major extension-related underplating model as proposed by McLelland (1989) in terms of the thermal insulation below supercontinents, might also account from the proposed tectonic settings. It seems clear that a metamorphic event occurred in northern Rondônia between 1.156 Ga and 1.149 Ga, as indicated by the hornblende Ar/Ar data. This range of ages contrast with the time-span for the metamorphism of the Nova Brasilândia Terrane dated at 1.1 ± 0.008 Ga by Rizzoto (1999). As is the case in much of the Grenville Province these events, according to Gower (1996), show metamorphism between 1.01 Ga and 990 Ma. However, we predict that the northern Rondônia area could have been involved in a yet younger metamorphic event between 1.08 Ga to 970 Ma, but evidence for this remains to be confirmed.

Final considerations

Although the geochronological data for the Amazonian Craton is far from complete, the available geological and geochronological data show that the crustal evolution of the craton involved the significant addition of juvenile material during the Archean and Proterozoic, as well as the reworking of older continental crust. In this way we can estimate that about 30% of the continental crust of the entire cratonic area was derived from the mantle during the Archean and about 70% in the Proterozoic.

The distribution of the geochronological provinces of the Amazonian Craton suggests that the Archean protocraton was initially composed of independent microcontinents (Carajás-Iricoumé, Roraima, Imataca blocks, and the West Congo Craton, in Africa), which were amalgamated by Paleoproteorozic orogenic belts, between 2.2 and 1.95 Ga. The amalgamation of the Archean blocks that occurred at same time that juvenile Paleo-Mesoproterozoic continental crust began to be accreted to their western margins.

In this way, the Ventuari-Tapajós, Rio Negro-Juruena and part of the Rondonian-San Ignacio (Santa Helena Orogen) provinces represent a vast area of juvenile continental crust. These provinces were accreted to the protocraton between 1.95 and 1.45 Ga by successive magmatic arcs. It is likely that these arcs were the result of the subduction of oceanic lithosphere at the onset of the collision between a continental mass, composed at that time by the Central Amazonian and Maroni-Itacaiúnas provinces against another continental mass. This continental mass is now probably part of Rondonian-San Ignacio and Sunsas provinces and Laurentia-Baltica (Sadowski and Bettencourt, 1996; Tassinari *et al.*, 1996).

Between 1.4 and 1.0 Ga, as reported by Sadowski and Bettencourt (1996), the orogenic evolution of the Rondonian-San Ignacio and Sunsas Orogenies took place in ensialic environments, due to continental collision between the Amazonian Craton and Laurentia. Major mantle-crust differentiation in the Amazonian Craton took place at 3.1 - 2.8 Ga (CAP); 2.8 - 2.5 Ga (CAP); 2.2 - 2.0 Ga (MIP); 2.0 - 1.9 Ga (VTP and RNJP); 1.9 - 1.7 Ga, 1.6 - 1.5 Ga and 1.48 - 1.42 Ga (RSIP) and near 1.1 Ga (SP), as shown in Table 14. In Table 15 is shown the distribution of the Sm/Nd mantle-depleted model ages for the whole of the Amazonian Craton. These episodes, together with the 2.0 Ga to 900 Ma anorogenic magmatism related to rifting and continental breakup (basic-alkaline magmatism, A-type granitoid plutons, bimodal magmatism and the deposition of platform sediments, with decreasing ages from the NE towards the SW) are consistent with the hypothesis of lateral crustal growth during the Paleoproterozoic and Mesoproterozoic in the Amazonian Craton.

The Amazonian Craton in a Global Context

The 2.2 - 1.9 Ga geological evolution of the northeastern part of the Amazonian Craton is correlated with the West African Craton, whereas the southwestern part has a 1.75 Ga - 950 Ma tectonic history more compatible with Laurentia and Baltica. In this way, the main geological events that occurred in the Amazonian Craton can be chrono-correlated with cratonic areas.

The Northeastern Amazonian Craton

Various tectonic models have been proposed for the geodynamic evolution of the Maroni-Itacaiúnas Province and its relationship with the other domains of the Amazonian Craton. According to these models the Archean relics of the Imataca Complex are related to subduction with roughly N-S plate movements. Following minor Archean events, the major tectonothermal event occurred around 2.1 - 2.0 Ga (Transamazonian event) that is also related to subduction as manifest in the agglomeration of a succession of island arcs and back-arc basins thus explaining the production of juvenile material. These N-S oriented subduction processes led to formation of a mass of subducted sheets intruded by granitoid (granite greenstones terranes) responsible for the granulitic and amphibolitic metamorphism, as well as for the main orientation of the Central Guiana Granulitic Belt.

Ledru *et al.* (1994) and Vanderhaeghe *et al.* (1998) presented a model for the Transamazonian evolution of the Maroni-Itacaiúnas Province in northern French Guiana, where comparison with the crustal evolution of the West African Craton is emphasized. Two main stages of evolution have been defined. The first event corresponds to an early Transamazonian (*i.e.*, 2.2 - 2.14 Ga) major period of juvenile crust generation, characterized by oceanic crust subduction and continental accretion (formation of the granite-greenstones complexes).

The second stage is characterized by collision tectonics and crustal anatexis at about 2.09 - 2.08 Ga. This model is supported by detailed geochemistry, structural geology and geochronological studies, but the extension of this view to the whole MIP would be premature as it does not take into account the relationship with high-grade belts and reworked Archean nuclei. Delor *et al.* (1998) presented a model for the same region in which mantle plume processes are emphasized for the formation of juvenile crust, and the importance of modern collisional hypotheses for tectonic evolution are minimized.

For the entire Maroni-Itacaiúnas Province it is possible to define two main rock-forming events, the older event occurring between 2.26 and 2.11 Ga, and the younger event occurring between 2.0 and 1.86 Ga. The first period is characterized by the development of the granite-greenstone terranes, whereas the interval between 2.0 and 1.86 Ga is related to the formation of the Central Guyana Granulitic Belt and the gneiss-migmatite terranes. Within the period between 2.26 and 1.9 Ga there predominated continental accretion by mantle-derived material. During the period from 1.9 to1.86 Ga the crustal reworking processes appear to have been the most important of geological events.

In the West African Craton the Transamazonian Orogenic Cycle, also named the Ebournean Orogeny, comprises large granite-gneiss terranes and 2.25 - 1.95 Ga volcanic and sedimentary sequences. Between 2.1 and 2.0 Ga these sequences were affected by the Ebournean Orogeny. The emplacement of the granitoid plutons took place during three different periods: 2.18 - 2.17 Ga; 2.12 - 2.08 Ga and 2.0 - 1.95 Ga (Oberthur *et al.*, 1994), which were chrono-correlated with the granitoid plutons in French Guiana (Milesi *et al.*, 1995). In the West African Craton there are two volcanic episodes, the older episode dated at 2.19 - 2.17 Ga is characterized by tholeiitic magma. The younger episode, characterized by volcanism, occurred at 2.08 Ga and is composed of bimodal volcanic rocks (Delor *et al.*, 1992; Oberthur *et al.*, 1994; Milesi *et al.*, 1995). The age of the volcanism within the metavolcano-sedimentary sequences of the Maroni-Itacaiúnas Province is poorly constrained, but the available data, especially from French Guiana, suggest an age around 1.1 Ga (Gruau *et al.*, 1985).

The southwestern Amazonian Craton

A tentative time chart of events based on the new U/Pb and smaller amounts of Rb/Sr ages is shown in Figure 12. It also shows the relationships between sedimentation, calc-alkaline and rapakivi magmatism, mafic intrusions, thermal-metamorphic imprints and deformation among the orogens and terranes of the southwestern sector of the Amazonian Craton. Since Baltica, Laurentia and Amazoniania seem to have belonged to the same margin of a super-continent, in our discussion we will compare and contrast some of the evolutionary aspects of the orogens.

Events between 1.79 - 1.53 Ga

Little is known about the environment that might define the transition from Ventuari-Tapajós and Rio Negro-Juruena orogenic events. Likewise, the evidence that can be obtained for the precursors and detrital materials, limited to recent detrital U/Pb zircon ages at 1.9 - 1.7 Ga for metasedimentary gneiss from the Rondônia Tin Province provided by Payolla *et al.* (1998).

Data show that at least two main orogenic events occurred between 1.80 and 1.70 Ga and between 1.57 and 1.53 Ga within the Rio Negro-Juruena geochronological province. Calc-alkaline arc-related plutonism and volcanism point to two groups of magmatic rocks providing strong evidence for subduction related juvenile crust growth along more than 2000 km flanking the closest western margin of the Ventuari-Tapajós Province.

The first calc-alkaline magmatism is interpreted as recording the time of accretion of the island arc rocks to the proto-Amazonian Craton over a subduction zone dipping NW. The rocks were derived from mantle protholith magma with ages ranging from 2.0 to 1.7 Ga, probably by the recycling of the earliest Ventuari/Tapajós crust (2.0 - 1.8 Ga).

Gower (1996) provides a summary of correlatable events in Laurentia where crust of similar age, restricted to the pre-Makkovikian-pre-Labradorian (1.79 - 1.71 Ga) rocks is found in the Mealy Montains Terrane, Goose Bay area. In the Makkovik Province and in the Ketilidian Mobile Belt of southern Greenland, rapakivi granite and calc-alkaline crust have been dated at 1.74 Ga and 1.75 Ga, respectively.

The orogenetic events extending from 1.79 to 1.75 Ga in the southwestern part of the Amazonian Craton partially overlap in time with events in the Baltic Shield. These events include the Gothian-Kongsberian orogenesis (1.75 - 1.55 Ga) and the intermittent 1.85 - 1.65 Ga Trans-Scadinavian Igneous Belt (TIB-1: *c.* 1.81 - 1.77 Ga and TIB-2: *c.* 1.72 - 1.69 Ga) magmatic episodes as well as with the early rapakivi magmatism in the western part of the shield (Finland and Russia) (Larsen and Berglund, 1992; Wikström, 1996, *apud* Åhäll and Gower, 1997 and Sudblad and Ahl, 1997).

Events between 1.7 - 1.6 Ga

To date there is no unequivocal evidence as to whether subduction was continuous from 1.79 Ga. However, tectono-magmatic events within the interval 1.7 - 1.6 Ga are not yet recorded or reliably demonstrated in the southwestern part of the Amazonian Craton. Moreover, after the accretion of the 1.79 - 1.7 Ga calc-alkaline plutonic and volcanic rocks underlying the Alto Jauru Greenstone Belt (southwestern Mato Grosso), the Juruena region, and the Jamari and Roosevelt terranes, there seems to have occurred a long period of stabilization between 1.7 and 1.6 Ga.

According to Åhäll *et al.* (1996) and Åhäll and Gower (1997) magmatic activity in Baltica between 1.69 and 1.58 Ga produced calc-alkaline juvenile crust (1.69 - 1.65 Ga), alkaline-calcic late TIB granitoid (TIB-3: 1.68 - 1.65 Ga), and coeval calc-alkaline rocks. Farther to the E, in Finland, Estonia and Latvia, rapakivi magmatism produced the Wiborg-Estonia Group (1.65 - 1.62 Ga) as well as massifs temporally linked with calc-alkaline and alkaline-calcic Gothian magmatism (Rämo and Haapala, 1995; Laitakari *et al.*, 1996; Rämo *et al.*, 1996).

In Laurentia calc-alkaline magmatism extended from 1.68 to 1.65 Ga which led Gower (1996) to suggest southward subduction related crustal growth under the early Labradorian Arc. In Baltica the progressive eastward shift of magma composition from calc-alkaline to alkaline-calcic and finally through rapakivi granites strongly support eastward subduction (Åhäll and Gower, 1997). Gothian subduction continued in Baltica producing continental margin calc-alkaline magmatism and arc-accretion between 1.62 and 1.59 Ga, whereas no such activity has been recognized in eastern Laurentia (Gower, 1996).

Events between 1.58 - 1.52 Ga

Calc-alkaline juvenile crust from the Cachoeirinha arc-system (1.57 - 1.53 Ga) seems to be a complex crustal collage and may represent the root of a juvenile magmatic arc. The onset of the associated Cachoeirinha Granite (1.522 ± 0.011 Ga), the Quatro Marcos Granite (1.533 ± 0.006 Ga) and probably the Serra da Providência Intrusive Suite (1.575 - 1.52 Ga) farther N, temporally linked to the calc-alkaline and alkaline-calcic magmatism, might be expressions of the eastern Cachoeirinha subduction.

The Serra da Providência Intrusive Suite started to emplace outboard, farther N, more likely in an anorogenic setting, into increasingly more stable continental crust of the Rio Negro/Juruena juvenile arc system (1.75 - 1.72 Ga). The speculation that was offered by Bettencourt *et al.* (1999) was that the Serra da Providência Intrusive Suite could not be clearly linked to either extension at the end of the Rio Negro-Juruena Orogeny or to the development of a neighbouring orogeny between 1.6 and 1.5 Ga is now believed to be more likely related to the Cachoeirinha Orogeny.

In Baltica, continent-continent collision occurred at *c.* 1.58 Ga, and eastward subduction was renewed (Åhäll and Gower, 1997). Evidence is given by calc-alkaline *c.* 1.55 Ga mafic-ultramafic tonalitic intrusions (northern Telemark) and *c.* 1.53 - 1.5 Ga rapakivi magmatism in central Sweden. These events are correlatable with the onset of the Cachoeirinha Orogen in southwestern Mato Grosso, and in Finland, by the Aland Riga Group (1.58 - 1.54 Ga) and the *c.* 1.56 - 1.54 Ga Salmi Group rapakivi plutons (Laitakari *et al.*, 1996; Rämö and Haapala, 1995). There is no indication of metamorphic or magmatic activity during the period 1.6 - 1.55 Ga in Laurentia and, for this reason, there might have occurred the development of a passive continental margin basin (Gower, 1996; Åhäll and Gower, 1997).

Events at c. 1.5 Ga

The Rio Alegre rocks may be interpreted as having originated at a mid-ocean ridge at *c.* 1.5 Ga (U/Pb zircon ages) that underwent metasomatism under seawater (cloritization and epidotization). Metamorphism under greenschist to lower amphibolite facies (biotite zone to garnet-kyanite zone) and transposition until mylonitization (NW foliation) were associated with the accretionary process of the proto-Amazonian Craton during Mesoproterozoic times. The geochemical data on the intrusive rocks suggest an evolution as a result of differentiation of tholeiitic magma. Sm/Nd mantle-depleted model ages on volcanic and intrusive rocks vary from 1.87 to 1.77 Ga and $\varepsilon_{Nd(T)}$ values from + 2.0 to + 2.8, suggesting a mantle-derived magma (Geraldes *et al.*, 1999).

Geological relationships allow us to suggest that the tectono-metamorphic evolution of the Rio Alegre Terrane might represent the suture zone recording the end of the ocean plate subduction which gave origin to the Santa Helena Magmatic Arc. According to this hypothesis the Santa

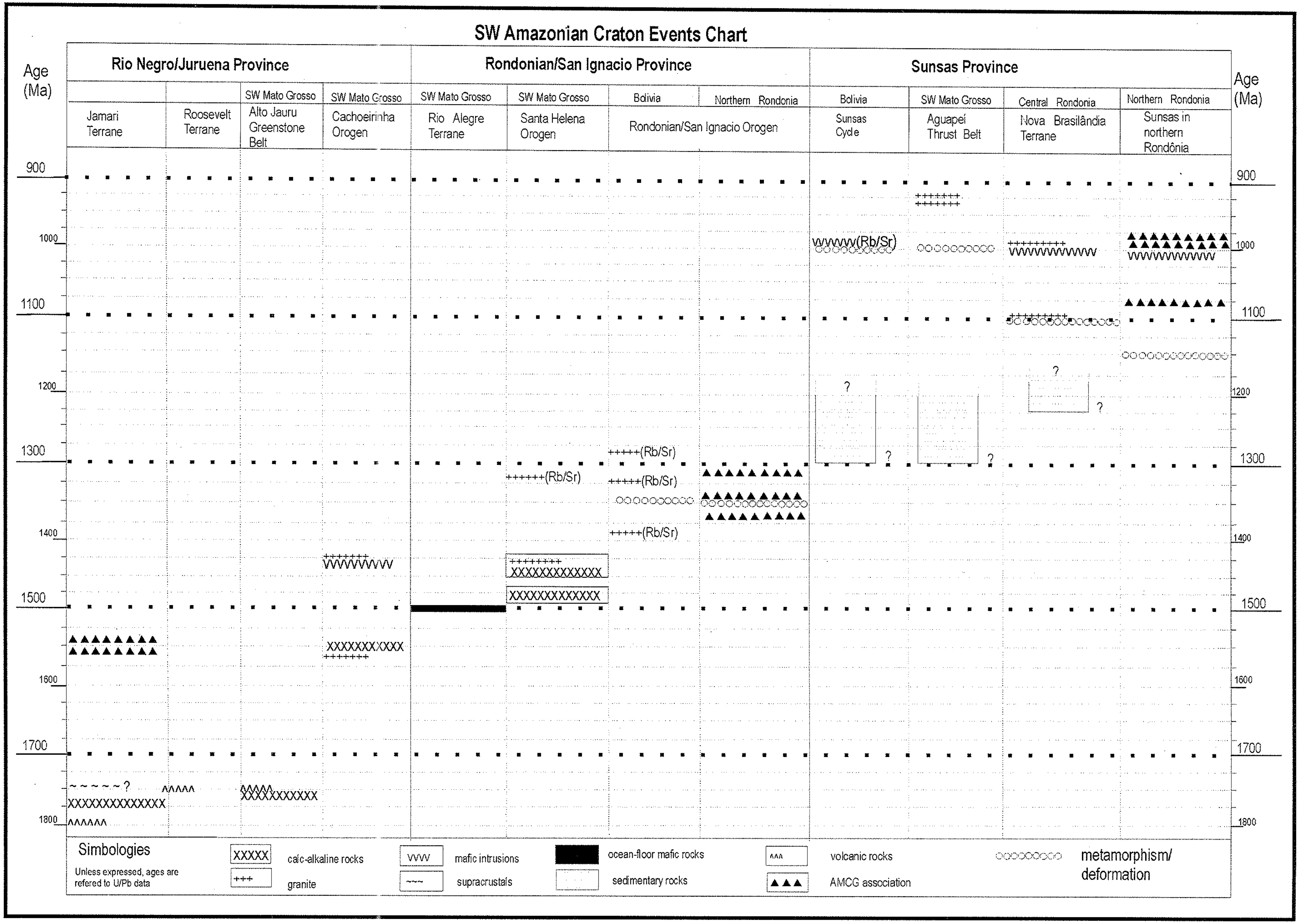


FIGURE 12 - A tentative time-correlation chart showing the orogenic events of the SW Amazonian Craton.

Helena Suite (U/Pb ages of 1.47 - 1.42 Ga and T_{DM} between 1.7 and 1.5 Ga) would have formed as a result of the ocean crust subduction, represented partially by the Rio Alegre Terrane. Detailed research on the Rio Alegre rocks should consider the possibility of an ophiolitic character for its genesis.

Sadowski and Bettencourt (1996) suggested that Amazoniania was also joined to Laurentia-Baltica at 1.6 Ga, and separated from it during Mesoproterozoic rifting known in Grenville Province as the Pinwarian Orogeny (1.51 - 1.45 Ga) that began a Wilson Cycle which probably ended with the formation of Rodinia (Gower and Tucker, 1994). This extensional event may be represented in the Amazonian Craton by the Rio Alegre Terrane, which leads one to suppose a possible link between Laurentia and Amazoniania pre-1.4 Ga.

Events between 1.45 - 1.3 Ga

A Mesoproterozoic history within this period is now classified into two stages: Santa Helena Orogen (1.48 - 1.42 Ga) and the Rondonian-San Ignacio Orogen (1.41 - 1.3 Ga). The Santa Helena Orogen (1.48 - 1.42 Ga) could be divided into a syn-accretion stage and a syn-collisional stage. The syn-accretion stage occurred at 1.48 Ga and generated calc-alkaline igneous and meta-igneous rocks including orthogneiss, tonalite and granite emplaced between *c.* 1.47 and 1.44 Ga. The syn-collision stage occurred between *c.* 1.42 and 1.4 Ga and consisted of period of mylonitization and migmatization at *c.* 1.42 to 1.4 Ga. There followed by a pulse of undeformed granite intrusion at 1.47 Ga. These were products of cratonic manifestation associated with the development of the Santa Helena Arc.

Orogenesis continued until the formation of the Alto Jauru Greenstone Belt, and the final bimodal phase of the Rio Branco Suite farther to the E between *c.* 1.456 and 1.423 Ga, which might be considered as back-arc granitoid magmatism outboard from the subduction zone.

According to Geraldes *et al.* (1997, 1999) and Van Schmus *et al.* (1998) the rocks are components of a *c.* 1.45 Ga, NW trending volcano-plutonic arc, that developed over an eastward dipping subduction zone along the western margin of a continent. This arc consisted of 1.8 to 1.7 Ga units of the Alto Jauru Greenstone Belt and the 1.57 - 1.53 Ga Cachoeirinha Orogen. The Sm/Nd data suggest that part of the orogen represented juvenile crust and may also have included a significant contribution from older crust.

The accretion of the Santa Helena Arc (*c.* 1.45 Ga) in the southwestern part of the Mato Grosso was followed in northern Rondônia by a prolonged period of voluminous anorogenic rapakivi plutonism, metamorphism, thermal effects and sedimentation. Geological rifting between 1.42 - 1.41 Ga to produce back-arc basins did not lead to crustal separation. The intrusions were not accompanied by continental margin processes, which suggest an intracratonic environment. Four distinct intraplate rapakivi magmatic age groups intruding the Rio Negro-Juruena (1.75 - 1.53 Ga) crust are revealed by the following intrusive suites: Santo Antônio (1.406 Ga), Teotônio (1.387 Ga), Alto Candeias (1.346 and 1.338 Ga), São Lourenço/Caripunas (1.314 and 1.309 Ga) and probably the Igarapé Preto Intrusive Suite (Rb/Sr age 1.195 Ga). Farther to the NW the Canama and Guariba alkaline plutons probably belong to this period.

In spite of contradictory opinions, it is reasonable to suppose that the 1.41 - 1.3 Ga intermitent intraplate bimodal magmatism accompanied by sedimentation in rift-related settings (Palmeiral and Prosperança sediments) could be regarded as the distal manifestation inboard of rifting and environmentally related to the development of the Santa Helena and San Ignacio orogenies.

The anorogenic episodes have age correlation in eastern Laurentia represented by the Michael Gabbro (1.426 Ga); Mealy dykes (1.38 Ga, Rb/Sr age); AMCG plutons of the Nain Plutonic Suite (1.35 - 1.29 Ga); the alkaline and peralkaline Red Wine Intrusive Suite (1.33 Ga), the genetically related Letitia Lake Formation and the mafic volcanism represented by the Seal Lake Group (1.25 - 1.23 Ga); and dyke emplacement which ended the Elsonian event (Gower, 1996). Coeval anorogenic magmatism was also on-going in Baltica, the eastern proto-margin of Amazoniania, at 1.41 Ga and 1.38 - 1.36 Ga expressed in the southwestern Scandinavian Domain by gabbro-anortosite-granite plutons and dolerite associations (Åhäll and Conelly, 1996).

Events between 1.29 - 1.19 Ga

Events between 1.29 - 1.25 Ga in the southwestern part of the Amazonian Craton are geochronologically poorly known, apart from the initial period of sedimentation. This period refers to the Sunsas and Aguapeí cycles, constrained at 1.215 ± 0.02 Ga (U/Pb SHRIMP detrital zircon maximum age for deposition of the sediments of the Nova Brasilândia Group) by Rizzoto *et al.*, (1999c).

This period overlaps with the Elsonian event (1.46 - 1.23 Ga) on the northern margin of the eastern part of the Grenville Province. It consists of mafic volcanism and dyke emplacement at 1.25 and 1.23 Ga, with the termination of anorogenic events in eastern Laurentia at 1.23 Ga. It coincides with the opening of the Elzevirian Orogenic Cycle (1.29 - 1.19 Ga; Rivers, 1997), with the sedimentation in the Sunsas-Aguapeí Basin, and with the deposition of sediments of the Nova Brasilândia Group.

Events between 1.19 - 1.089 Ga

This was a time of prevailing rifting activity leading to an extensional tectonic environment which permitted substantial sedimentation at *c.* 1.215 ± 0.02 Ga, emplacement of mafic magmatism during the initial extension stage and syn to late-kinematic granitoid emplacement in the compressional stage. Saes and Fragoso Cesar (1996) have considered the Sunsas Belt as resulting from a passive continental margin, and including deep marine turbidite sediments that have undergone subduction under the overthrusted plate. This has been named the San Pablo Terrane which supercedes the term San Pablo Granitoid (Litherland *et al.*, 1986) and it is related to a Sunsas Cycle calc-alkaline magmatic arc (Saes and Fragoso Cesar, 1996). The Aguapeí Aulacogen considered as an interior rift (Saes *et al.*, 1992; Saes, 1999) is represented by shallow marine shelf sediments, and represents the correlatable basin. Relevant units occur in the Nova Brasilândia Terrane and which are linked to the rifting stage include mantle-derived tholeiitic sills, stocks, gabbro and diabase dykes, emplaced at 1.15 Ga. This attests to widespread juvenile accretion (Rizzoto, 1999; Sato and Tassinari, 1997). A U/Pb zircon age of a metagabbro at 1.1 ± 0.015 Ga dates a metamorphic event of the mafic rocks, which is contemporaneous with turbidite beds and the emplacement pre-date the age of the metamorphism.

The Nova Brasilândia units provide an unequivocal link with the correlatable Sunsas Belt and the Aguapeí Thrust, and certainly represent the northwestern extension of the latter. The clastic rocks of the Sunsas-Aguapeí and Nova Brasilândia units represent a foreland assemblage partially backthrusted onto the Amazonian Craton. Suture rocks of coeval age were found in the Central Andes of Colombia and might be hidden below the Cisandine sediments of Bolivia (Sadowski and Bettencourt, 1996).

Granitoid plutons dated at 1.11 ± 0.008 Ga (anatetic leucogranite) as well the first 1.098 ± 0.01 Ga granitoid pulse associated with the compressive stage of the Nova Brasilândia Group are described. Isotope data for these rocks indicate derivation from an older crustal source (Rizzoto, 1999). A metamorphic event between 1.15 - 1.14 Ga (Ar/Ar age in hornblende and biotite) was defined by Bettencourt *et al.* (1996) in northern Rondônia (Jamari area), and another peak at 1.1 Ga (U/Pb SHRIMP zircon) was suggested by Rizzoto (1999) in the Nova Brasilândia Group. These favour the idea of dominance of two metamorphic pulses in the southwestern part to the Amazonian Craton during this interval.

The Sunsas Cycle was conventionally delimited by Litherland *et al.* (1986) between 1.35 - 1.0 Ga. Throughout much of the Grenville Province, the period between 1.3 - 1.0 Ga has been subdivided into the Elzeverian (1.23 - 1.18 Ga), Adirondian (1.18 - 1.08 Ga) and Grenville cycles (1.08 Ga - 970 Ma; Gower, 1996). More recently the Grenville Cycle was subdivided by Rivers (1997) into Elzeverian Orogenic Cycle (1.29 - 1.19 Ga) and the Grenville Orogeny, which comprises the terminal continent-continent collision and the respective pulses, which are the Sawinigan (1.19 - 1.14 Ga), Ottawan (1.08 - 1.02 Ga) and Rigolet (1.0 Ga - 980 Ma).

It seems that the events between 1.19 Ga - 980 Ma recorded in the southwestern part of the Amazonian Craton could be more appropriately compared to the Sveconorwegian (1.17 Ga - 950 Ma) and Adirondian (*c.* 1.18 - 1.08 Ga) extensively documented all over the Grenville Province and in southern Greenland (Gower, 1996). The Adirondian was accompanied by the emplacement of voluminous AMCG suites (1.17 and 1.12 Ga) and partly by compressional tectonic regime (Gower, 1996; Emslie and Hunt, 1990). This magmatic event overlaps with the time of emplacement of the mafic-felsic magmatism (1.15 and 1.098 Ga) and tectonics recorded in the Nova Brasilândia Terrane.

The remaining doubt is whether the 1.15 and 1.098 Ga mafic-felsic magmatism might suggest emplacement inboard of a continental margin over a northward dipping subduction zone and subsequent back-arc rifting or simply an expression of an intracontinental rifting and a proto-ocean expansion. Under these considerations it follows that the concept of the Sunsas Orogeny in the Amazonian Craton needs urgent re-evaluation, as already considered in respect to the Grenville Cycle in eastern Laurentia (Gower, 1996; Rivers, 1997).

Late Sunsas Events (1.08 Ga - 970 Ma)

Cratonic magmatism within this interval is characterized by the substantial addition of within-plate A-type felsic alkalic and mafic rocks dominantly in the Nova Brasilândia Terrane, Rondônia Tin Province, Bolivia and in scattered places in southwestern part of Mato Grosso. These rocks are represented by the Santa Clara Intrusive Suite (1.08 - 1.07 Ga); the Younger Rondônia Granite (1.0 Ga - 970 Ma); the associated Nova Floresta Formation consisting of alkali basalt and mafic dykes (K/Ar *c.* 1.0 Ga - 900 Ma); the Rio Pardo Granite Suite (995 ± 15 Ma), accompanied by foliated charnockite; the Costa Marques Group (Rb/Sr *c.* 1.018 Ga); the Guapé Intrusive Suite (Rb/Sr 950 ± 40 Ma); the late kinematic Sunsas Granitoid; the mafic-ultramafic Rincon del Tigre Complex (Rb/Sr 993 ± 139 Ma); and a number of pegmatites and basic rocks.

The magmatism is dominated by older sub-alkaline rapakivi granite intruded by younger alkaline rocks and deep source mafic magma. There also occurred the deposition of intracontinental rift sedimentary sequences, represented by the Palmeiral Formation, the Prosperança Formation; the Pacaás Novos, Uopiane and São Lourenço components, and the Sunsas Group (Leite Jr. *et al.*, 1996; Scandolara and Amorim, 1999) which indirectly attest to an extensional tectonic regime and rifting related to the final stage of the Sunsas Orogeny.

The rapakivi granite and associated mafic rocks in the Nova Brasilândia Terrane were most probably formed in a back-arc extension inboard from an active continental margin magmatic arc. The plutons in the Rondônia Tin Province developed in the foreland of the Sunsas Orogen probably involved extension and crustal thickening at *c.* 1.0 Ga followed by granite plutonism in the 990 - 960 Ma interval. This magmatism, deformation and thermal effects (high-grade ductile deformation and metamorphism which calls for re-evaluation) have been interpreted by Sadowski and Bettencourt (1996) as reflecting collisional tectonism, more precisely, continent-continent collision of left lateral transpressional character between Laurentia/Baltica and Amazoniania. The associated transtensional regime responsible for this magmatism also resulted in the collapse of the older cratonic sedimentary cover into the Uopiane, Pacaás Novos grabens in Brazil.

Magmatism associated with the same event in Laurentia has been widely attributed to collisional orogenesis between Laurentia and Amazoniania (Gower, 1996). According to Rivers (1997) the continent-continent Grenville Orogeny took place between *c.* 1.19 Ga and 980 Ma and comprised three distinct pulses of crustal shortening at *c.* 1.19 - 1.14 Ga, 1.08 - 1.02 Ga, and 1.0 Ga - 850 Ma, separated by periods of extension. The last pulse caused northwesterly propagation of the orogen into its foreland. The periods of crustal extension during the Grenville Orogeny were coeval with emplacement of mafic magma and anorthosite complexes implying that large quantities of mantle magma and heat had access to the base of the previously thickened orogenic crust. All these models are compatible with the late Sunsas geological evolution. Corrigan and Hanmer (1997) interpreted the within-plate AMCG-type plutonism in the Grenville Orogen, between 1.08 Ga and 850 Ma, to have formed in response to the delamination of the subcontinental lithosphere, injection of mantle magma and concomitant extension, following crustal thickening.

Also important is the intervening deformation and metamorphism, the latter still unequivocally demonstrated. In the correlatable Grenville Province and Sveconorwegian Orogen (Baltica) tectonic deformation and emplacement of AMCG plutons within the interval 1.1 Ga to 920 Ma are commonly accompanied by high-grade ductile deformation, amphibolite and high-pressure granulite down to greenschist facies metamorphism (Gower, 1996; Corrigan and Hanmer, 1997; Andersson *et al.*, 1999; Larsen, 2000). However the younger Ar/Ar dates on biotite and feldspar recorded in the Rondônia Tin Province by Bettencourt *et al.* (1996) of *c.* 1.001 Ga and 912 Ma, show slow metamorphic cooling rates that are consistent with the K/Ar ages observed in the Younger Rondônia Granite (1.08 Ga - 970 Ma). These ages are readily interpreted as related to cooling as rapakivi magmatism waned during crystallization as stability of the Sunsas Orogen was reached.

Events between 970 - 920 Ma (Terminal Acivities of the Sunsas Orogen)

The terminal magmatism related to the Sunsas Orogen are the bimodal Guapé Intrusive Suite (Rb/Sr *c.* 950 ± 40 Ma) and the S-type São Domingos Intrusive Suite, dated at 930 ± 19 Ma and 917 ± 5 Ma (U/Pb zircon) by Geraldes (2000). They are related, respectively, to extension and to the Aguapeí thrusting. Post-collisional time-correlatable igneous episodes in the Grenville Province, represented by several granitoid plutons and aplite dykes occurred between *c.* 966 - 956 Ma, following crustal thickening (Tucker and Gower, 1994; Gower, 1996; Wasteneys *et al.*, 1997). In the Sveconorwegian Orogen (1.1 Ga - 900 Ma) (southwestern Sweden and south-southwestern Norway) synchronous post-collisional bimodal rift-related AMCG intrusions and dolerite are recorded at *c.* 966 and 956 Ma. Minor syn-tectonic calc-alkaline magmatism is dated at *c* 1.04 Ga (Bingen *et al.*, 1998; Larsen, 2000). Also marking the end of the tectonic activity, there is the Rogaland AMCG Complex and other norite-anorthosite complexes and related hybrid rocks, which appear to lack Grenville correlatives, (Åhäll and Schöberg, 1996) are recorded in southwestern Sweden.

Table 1 - Summary of the isotopic ages referred to the rocks of the Central Amazonian Province.

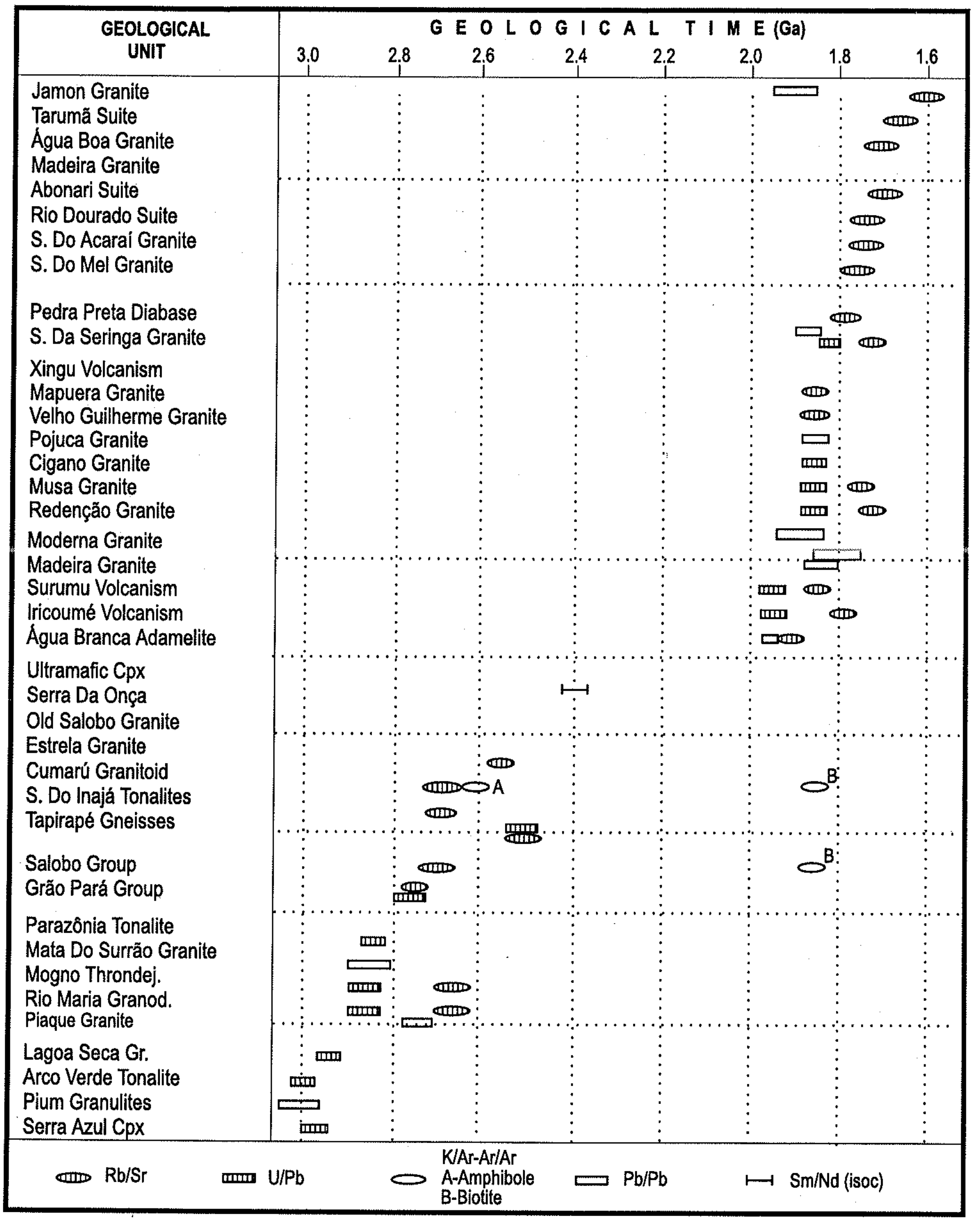


Table 2 - Summary of the isotopic ages referred to the rocks of the Maroni-Itacaiúnas Province.

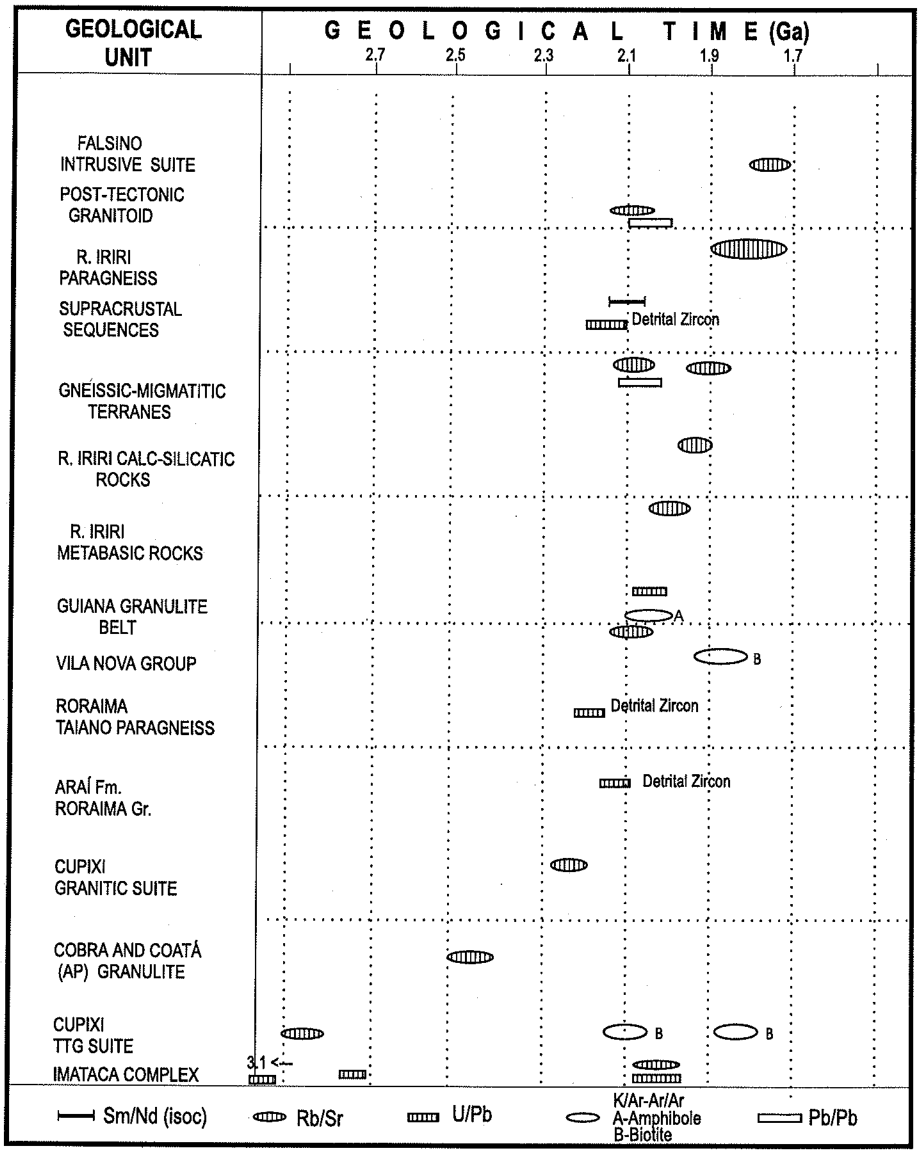


Table 3 - Summary of the isotope ages referred to the rocks of the Ventuari/Tapajós Province.

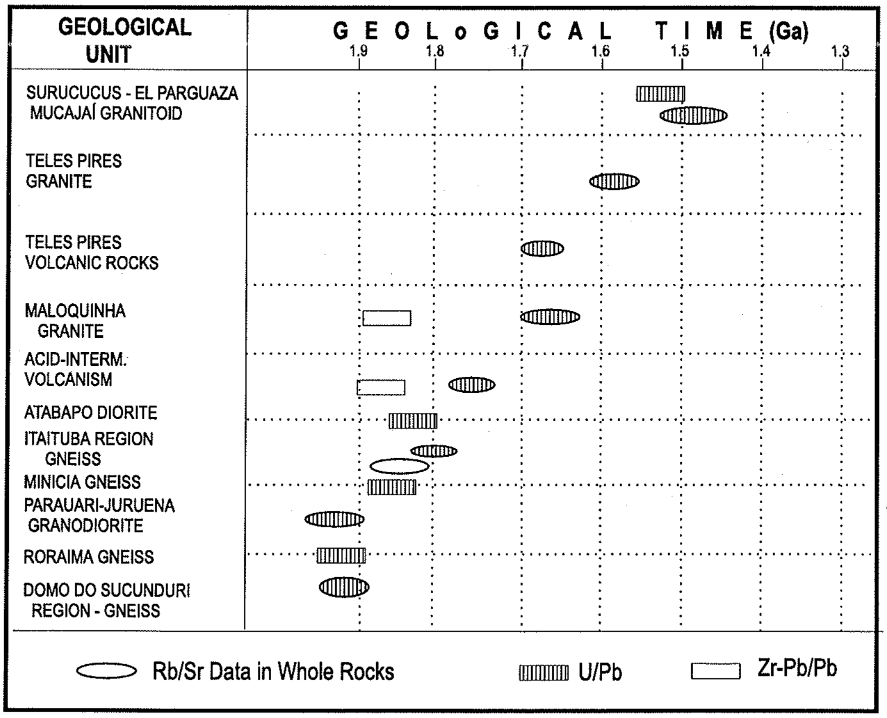


Table 4 - Summary of the isotopic ages referred to the rocks of the Rio Negro/Juruena Province.

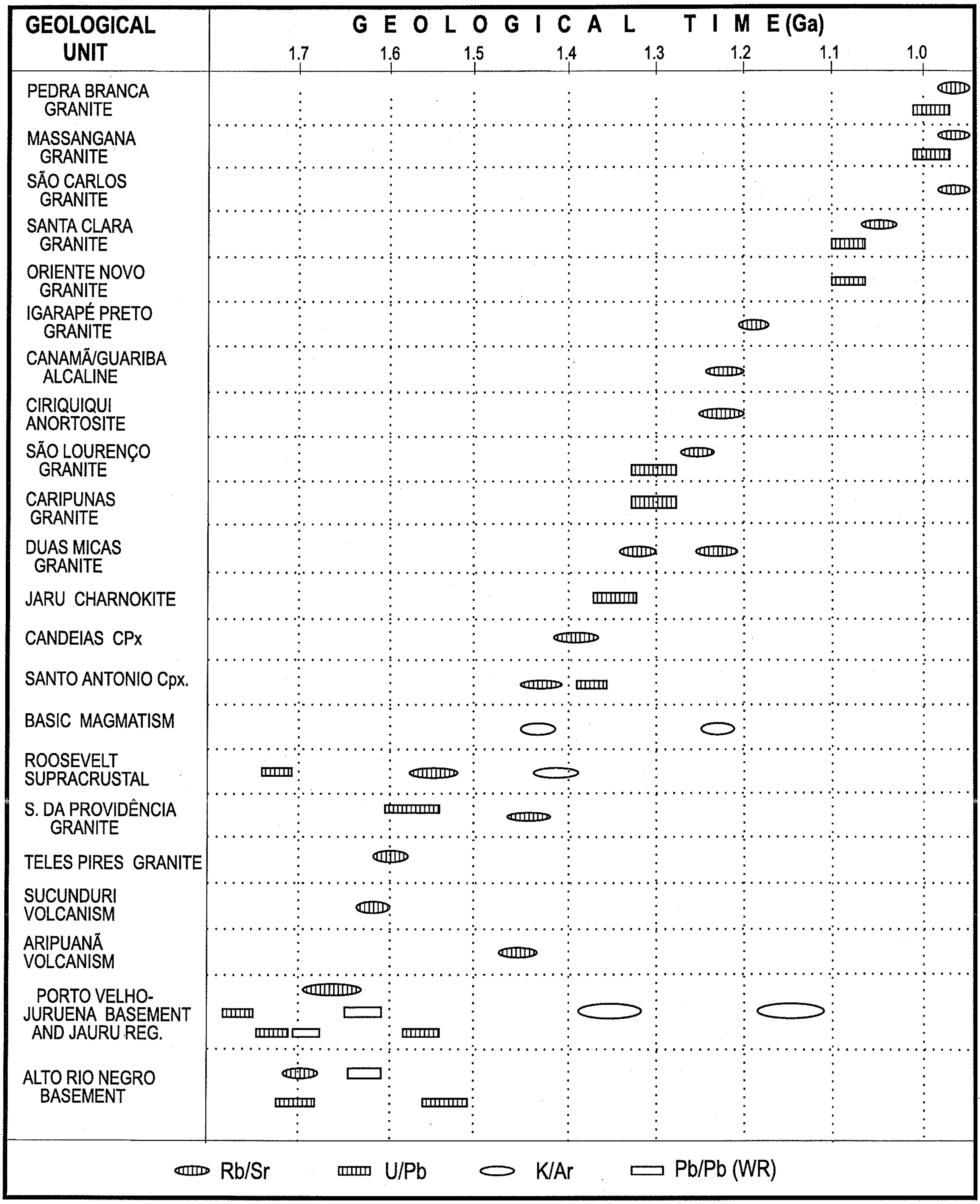


Table 5 - U/Pb and Sm/Nd properties of the Alto Jauru greenstone belt (after Geraldes, 2000).

NUMBER	ROCK DESCRIPTION	U/Pb AGE (Ma)*	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(T)$	T_{DM}
97-131	Cabaçal volcanism	1767±24	-17.7	2.8	1868 Ma
97-133	Pink Gneiss	1795±10	-18.1	2.2	1926 Ma
97-147	São Domingos Gneiss	1746±20	-11.9	2,0	1773 Ma

Table 6 - U/Pb and Sm/Nd properties of the Cachoeirinha calc-alkaline suite (after Geraldes, 2000).

DESCRIPTION	U/Pb (Ma)*	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(T)}$	T_{DM}	f
Quatro Marcos Tonalite	1536 ± 11	- 14.2	+ 0.5	1.77	-0.38
Cachoeirinha Tonalite	1549 ± 10	- 14.7	+ 1.0	1.83	-0.40
São Domingos Gneiss	1562 ± 36	- 20.2	+ 0.9	1.79	-0.53
Quatro Marcos Granite	1522 ± 12	- 19.6	+ 0.9	1.78	-0.54
Cachoeirinha Granite	1537 ± 06	- 22.2	+ 0.5	1.75	-0.60
Santa Cruz Granite	1587 ± 04	- 15.0	- 0.8	2.05	-0.36
Água Clara Granodiorite	1485 ± 04	- 5.0	+ 1.7	1.77	-0.50
Araputanga Granite	1440 ± 06	- 20.2	- 0.2	1.74	-0.56
Alvorada Granite (1)	1389 ± 03	- 20.3	- 1.3	1.77	-0.54

*U/Pb zircon ages were made by isotopic dissolution in monocrystal

Table 7 - U/Pb and Sm/Nd properties of the Rio Alegre volcano-sedimentary sequence (after Geraldes, 2000).

NUMBER	ROCK DESCRIPTION	U/Pb AGE (Ma)	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(T)}$	T_{DM}
97-122	Metadiorito	1509 ± 10	-2.7	4.3	1.54
97-124	Metadacite	1503 ± 14	-2.4	4.8	1.48
97-134	Metadiorite	1494 ± 11	-11.3	2,5	1.67

Table 8 - U/Pb and Sm/Nd properties of the Santa Helena Suite (after Geraldes, 2000).

SAMPLE	LITHOLOGY	U/Pb (Ma)	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(T)}$	T_{DM}	f
97-113	Lavrinha tonalite	1464 ± 25	-13,1	+ 3,8	1,53	-0,45
97-140	Pau-a-Pique tonalite	1481 ± 47	-4,9	+ 4,1	1,50	-0,25
97-108	Guaporé granodiorite	1435 ± 22	-11,8	+ 3,4	1,54	-0,42
97-106	Alto Guaporé gneiss	1424 ± 15	-8,6	+ 4,0	1,49	-0,35
97-102	Triangulo gneiss	1445 ± 04	-15,4	+ 2,9	1,56	-0,51
97-115	Santa Helena granite-gneiss	1433 ± 06	-8,9	+ 3,1	1,62	-0,32
97-141	Maraboa granite	1449 ± 07	-7,1	+ 2,6	1,70	-0,26
97-105	Alto Guaporé augen-gneiss	1424 ± 11	-12,8	+ 2,8	1,57	-0,44
97-120	Cardoso magnetite-granite	1423 ± 15	-11,7	+ 3,6	1,52	-0,33
97-135	Santa Elina granite	1436 ± 06	-10,2	+ 2,7	1,55	-0,38
97-168	Ellus Farm granite	1437 ± 12	-11,1	+ 3,7	1,52	-0,40
97-169	Ellus Mine granite	1444 ± 21	-10,8	+ 3,6	1,51	-0,39

Table 9 - Rb/Sr results of the San Ignacio major units (after Litherland et al., *1986).*

STAGE		GRANITOIDS		Rb/Sr AGES (Ma)	$^{87}Sr/^{86}Sr$ INITIAL	K/Ar AGES (Ma)
Syn to Late kinematic		San Rafael		1291 ± 49	0.7003 ± 0.0007	
		San Ramon San Andres Ascension Ibaimini San Javier Marimonos El Puente Refugio Santo Rosario San Pedro Santo Corazon Correreca Tauca Cocalito				
	Pensamiento Complex	Poerto Alegre				
		La Junta		1375 ± 80	0.7052 ± 0.0031	
		Guarayos				1043± 22 (biotite)
		San Martin Compamento				
		Florida				1244 ± 27 1380 ± 19 (biotite)
		Piso Firme		1325 ± 45	0.7044 ± 0.0026	
		Cerro Grande Granophiric Suite	San Simon de Guarayos			
			Cerro Branco			
			Cerro Grande			
Late to Post kinematic		San Cristobal				1296 ± 18 (biotite)
		Porvenir				
		Padre Eterno				1326 ± 19 1268 ± 2 (muscov.)
		Tres Picos				143 ± 14 (biotite)
		Orobayaya		1283 ± 33	0.7058 ± 0.0031	
		Diamantina		1391 ± 70	0.7004 ± 0.0033	
		Discordância				
		El Tigre Alkaline Complex		1286 ± 46		

Table 10 - U/Pb and Sm/Nd properties of the of Rondônia Tin Province granitoid rocks (after Bettencourt et al., *1999a).*

EPISODES	RAPAKIVI SUITES	U-Pb AGES (Ma)	Rb-Sr AGES (Ma)	K-AR AGES (Ma)	TECTONIC SETTING
12	Santo Antônio Intrusive Suite	1406±32	1305 (3)		Extensional regime
	Teotônio Intrusive Suite	1387±16	1270 (4)		related to
2	Alto Candeias Intrusive Suite		1358±74 (5)		Rondonian-San Ignacio
	Alto Candeias Batholith	1346±05			Orogenic Cycle or to
		1346±05			opening of the
		1338±05			Grenville Ocean.
3	São Lourenço-Caripunas	1314±13	1268±15 (6)		
	Intrusive Suite	1312±3			
		1309±24			
	Igarapé Preto Intrusive Suite		1195±50 (1)	1195 (7)	
	Ciriquiqui basic and ultrabasic		1300 (7)		

Table 11 - U/Pb and Sm/Nd properties of the Fazenda Reunidas Domain major units (after Geraldes, 2000).

LITHOLOGY	U/Pb (Ma)	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(T)}$	T_{DM}	f
Tonalitic Gneiss	1384 ± 40	-4.7	3.6	1.52	-0.24
Carrapato Microgranite	1400 ± 24	-11.2	4.2	1.49	-0.42
Rio Alegre Granodiorite	1412 ± 21	-5.1	3.6	1.58	-0.24
Lajes Granito	1360	-14,8	0.0	1.69	-0.44
Lajes Granito	1606	-14,8	3.4	1.69	-0.44

Table 12 - Rb/Sr results of the Sunsas granitoid (after Litherland et al., *1986).*

STAGE	GRANITOIDS	Rb/Sr	$^{86}Sr/^{87}Sr$	K/Ar (Ma)
Pos	Casa de Piedra Granite	1005 ± 12		958 ± 27 (bio)
				911 ± 20 (musc)
Pos	Talcoso			986 ± 27
Pos	Taperas			
Tardi	Limonales			
Tardi	Salinas			
Syn	Espiritu			
Syn	Santa Catalina Zone			
Syn	Las Palmas			
Syn	La Placa			
Syn	San Miguel			
Syn	Motacucito			
Syn	San Pablo			
Syn	El Carmen	972 ± 21		
Pos	Tasseoro			
Pos	Nomoca			991 ± 27
Syn	San Pablo			546 ± 16
Pos	Lucma			
Pos	Rincon del Tigre Complex	993 ± 139		

Table 13 - U/Pb and Sm/Nd properties of the Nova Brasilândia group major units (after Rizzoto, 1999).

SAMPLE	LITHOLOGY	U/Pb (Ma)	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(T)}$	T_{DM}
GR-05	Metagabbro	1110 ± 15	+ 4.8	+ 4,3	-
GR-10	Metaturbidite	-	+ 1.0	+ 3.1	-
GR-10A	Biotite Monzogabbro	1098 ± 10	- 10.3	- 0.4	1,63
GR-18	Metagabbro	-	+ 2.3	+ 5.0	-
GR-20	Anatetic leucogranite	1110 ± 08	-12.6	-1.5	1,66
GR-20A	Metaturbidite	-	- 15.3	- 3.9	1,85
GR-20A$_1$	Metaturbidite	-	-14.9	- 3,8	1,85
GR-20C	Calc-silicated gneiss	-	- 15.2	- 4.3	1,91
GR-23	Porphire Monzogranite	995 ± 15	- 10.6	+ 0.5	1,50

Table 14 - Granitoids of Rondônia Tin Province major units U/Pb and Sm/Nd results (after Bettencourt et al., *1999a).*

EPISODES	RAPAKIVI SUITES	U-Pb AGES (Ma)	Rb-Sr AGES (Ma)	K-Ar AGES (Ma)	TECTONIC SETTING
1	Santa Clara Intrusive Suite		1052±21 (5)	1035 (8)	Extentional regime related to collisional stage of Sunsas-Aguapei Orogenic Cycle.
	Manteiga Massif	1082±05			
	Santa Clara Massif	1081±50 1074±21			
	Oriente Novo Massif	1080±27 1074±08			
	Costa Marque Group		1018±76 (9)		
2	Younger Granite of Rondônia		956±09 (6)		
	Pedra Branca Massif	995±05		950 (8)	
	São Carlos Massif	995±73 974±06			
	Massangana Massif	991±14		1000 (7)	
	Nova Floresta Formation				

Table 15 - Precambrian geological history of the Amazonian Craton.

MAJOR EPISODES OF CRUST FORMATION	MAIN EVENTS OF ACCRETION OF JUVENILE CRUST	DIVERGENT TECTONISM WITHIN-PLATE MAGMATISM	SEDIMENTS AND ASSOCIATED MAGMATISM IN CONTINENTAL RIFT SYSTEMS
1.28-1.1Ga SP	1.1 Ga SP	1.05- 0.9Ga RSIP	1.1 - 1.0Ga RSIP
1.5 -1.3Ga RSIP	1.48-1.42Ga RSIP	1.45 - 1.2Ga RNJP	1.45 - 1.2Ga RNJP
1.8 -1.55Ga RNJP	1.8-1.7 and 1.57-1.53 Ga RNJP	1.75 - 1.5Ga VTP-RNJ	1.65 - 1.4Ga RNJP
1.95 - 1.8Ga VTP	1.95 - 1.8Ga VTP	1.85 - 1.8Ga CAP	1.90 - 1.6Ga CAP-VTP
2.25 - 2.0Ga MIP	2.1 - 1.95Ga 2.25 - 2.1Ga MIP		1.95 - 1.8Ga CAP
2.9 - 2.7Ga CAP	2.98 – 2.87 Ga CAP	2.6 - 2.3Ga CAP	
3.1 - 3.0Ga CAP	>3.0 Ga (?) CAP		

CAP - Central Amazonian Province
VTP - Ventuari-Tapajós Province
RSIP - Rondonian-San Ignácio Province
MIP - Maroni-Itacaiúnas Province
RNJP - Rio Negro-Juruena Province
SP - Sunsás Province

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