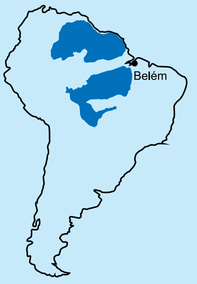
SYMPOSIUM ON MAGMATISM, CRUSTAL EVOLUTION, AND METALLOGENESIS OF THE AMAZONIAN CRATON

ABSTRACTS VOLUME AND FIELD TRIPS GUIDE



- **Workshop on magmatism, crustal evolution, and metallogenesis of Carajás and adjacent provinces**
- **Workshop on A-type granites and related rocks throug time (IGCP 510)**

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Integrated gamma ray/radar imagery of the
Serra dos Carajás Granite pluton
(Paradella et al. 1988)

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SYMPOSIUM ON MAGMATISM, CRUSTAL EVOLUTION, AND METALLOGENESIS OF THE AMAZONIAN CRATON

Workshop on Magmatism, Crustal Evolution, and Metallogenesis of Carajás and adjacent provinces

Workshop on A-type Granites and Related Rocks through Time (IGCP 510 project)

Belém, August 6-9, 2006

Volume Editors

Roberto Dall'Agnol
Lúcia Travassos da Rosa-Costa
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PRESENTATION

The **Center of Geosciences of the Federal University of Pará, Brazil**, is one of the prime earth science institutions conducting research in the **Amazonian region of Brazil**. The Center maintains active undergraduate programs in Geology, Meteorology, Oceanography, and Geophysics, and three graduate programs in Geology-Geochemistry, Geophysics, and Environmental and Atmospheric Sciences. An ambitious six-year project **"Magmatism, Crustal Evolution, and Metallogenesis of Carajás and adjacent provinces"**, related to the **Program of Nucleus of Excellence (PRONEX)** and supported by CNPq/MCT, is being undertaken by the research groups on Granite Petrology, Isotopic Geology, and Metallogenesis of the Center in collaboration with five other Brazilian institutions (Brazilian Geological Survey – CPRM – at Belém, Manaus, and Rio de Janeiro; University of Vale do Rio dos Sinos - Unisinos, Federal University of Amazonas – UFAM, University of São Paulo – USP, Museu Paraense Emilio Goeldi – MPEG).

The symposium is devoted to the geologic evolution of the Amazonian craton and has been planned to mark the completion of this project. The papers related to this subject are assembled in the Workshop 1 **"Magmatism, Crustal Evolution, and Metallogenesis of Carajás and Adjacent Provinces"**. A specific **IGCP 510** (IUGS-UNESCO) workshop 2 on **"A-type Granites and Related Rocks through Time"** is also arranged. Several geologists from Brazil, many of them active in the Amazonian craton, participate in this new IGCP project (2005–2009) and the Amazonian craton will be one of the key areas of IGCP-510.

The symposium received 68 contributions, 44 of them will be presented as oral communications and 24 as posters. 25 are dedicated to topics on magmatism, crustal evolution, and metallogenesis of the Amazonian craton or to related subjects. They are assembled in the workshop 1. Other 43 contributions are devoted to A-type granites and related rocks and are presented in the workshop 2.

Around 150 participants are expected for the symposium. They come from several countries (Australia, Canada, Colombia, Finland, India, Russia, and United States of America), besides Brazil. Representative geologists and scientists from different regions of Brazil will participate actively on the symposium. Most of them come from universities and research institutes, but exploration geologists of several mining companies should also assist the event. Graduate and undergraduate students are also expected.

The symposium will be held in the Sagres Hotel at Belém, Pará State of Brazil, **August 6 to 9, 2006**. A pre-symposium field trip to the Paleoproterozoic, tin-mineralized granites of Pitinga, and a post-symposium field trip to the Archean and Paleoproterozoic granitoids of Carajás province are also proposed to the participants.

The symposium is also a good occasion to visit Belém, and to learn more about its natural, cultural and historical aspects. The Organizing Committee hopes that all people enjoy their stay in Belém and that the symposium will fulfill your expectations. Well come and have a nice time in Belém!

Roberto Dall'Agnol

Coordinator

LIST OF CONTRIBUTIONS

WORKSHOP 1:
MAGMATISM, CRUSTAL EVOLUTION, AND METALLOGENESIS OF CARAJÁS AND ADJACENT PROVINCES

WORKSHOP 2: A-TYPE GRANITES AND RELATED ROCKS THROUGH TIME (IGCP 510 PROJECT)

FIELD TRIPS GUIDE

WORKSHOP 1

MAGMATISM, CRUSTAL EVOLUTION, AND METALLOGENESIS OF CARAJÁS AND ADJACENT PROVINCES

GEOLOGY, ZIRCON GEOCHRONOLOGY AND MINERALIZATION OF PALEOPROTEROZOIC GRANITOIDS FROM THE UATUMÃ-ANAUÁ DOMAIN, CENTRAL PORTION OF THE GUYANA SHIELD, SOUTHEAST RORAIMA, BRAZIL

Marcelo Esteves Almeida[1,2] & Moacir José Buenano Macambira[3]
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Regional mapping, petrography and zircon geochronology carried out in the Uatumã-Anauá Domain (UAD), central portion of Guyana Shield, Southeastern Roraima State (Brazil), have shown widespread paleoproterozoic calc-alkaline granitic magmatism. These granitoids are distributed into several magmatic associations with different paleoproterozoic (1.97-1.89 Ga) ages, structural and geochemical affinities. In this paper, detailed mapping, petrographic and geochronological studies have distinguished two main subdomains in the UAD. In the northern UAD, the high-K calc-alkaline Martins Pereira (1.97 Ga) and Serra Dourada S-type granites (1.96 Ga) are affected by NE-SW and E-W ductile dextral shear-zones, showing coexistence of magmatic and deformational fabrics related to heterogeneous deformation. Basement inliers (2.03 Ga) crop out to the northeastern part of this area, and are formed by metavolcano-sedimentary sequence (Cauarane Group) and TTG-like calc-alkaline association (Anauá Complex). Xenoliths of meta-diorites (Anauá Complex) and paragneisses (Cauarane Group) reinforce the intrusive character of Martins Pereira Granite. On the other hand, xenoliths of Martins Pereira and biotite-bearing enclaves are found in the younger, undeformed, and SiO_2-rich Igarapé Azul Granite (1.89 Ga). This last and the high-K calc-alkaline Caroebe Granite (1.90-1.89 Ga, Água Branca Suite), including coeval volcanic rocks (1.89 Ga, Jatapu volcanics) and charnockitoids (1.89 Ga, e.g. Santa Maria Enderbite), crop out in the southern UAD. This subdomain is characterized only by local and discrete NE-SW ductile-brittle dextral shear zones. A-type granites such as Moderna (ca. 1.81 Ga) and Mapuera (ca. 1.87 Ga) granites, cross cut both areas of UAD. Furthermore, the geological mapping also identified three main types of metalotects in this region. Gold mineralization is observed in the Martins Pereira-Serra Dourada granitoids (northern UAD), alluvial columbite-tantalite is related to Igarapé Azul granitoids (southern UAD), and amethyst is associated to pegmatites from Moderna A-type granites.

GRANITOGENESIS OF THE PEIXOTO DE AZEVEDO-NOVO MUNDO REGION, ALTA FLORESTA AURIFEROUS PROVINCE (MT): TECTONIC AND METALLOGENETIC IMPLICATIONS

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The Alta Floresta Auriferous Province (MT) is located within the domains of the Ventuari-Tapajós and Rio Negro-Juruena geochronological provinces, in the southern sector of the Amazonian Craton. Within this province, the Peixoto de Azevedo-Novo Mundo region has been one of the main gold producing districts. In this region, the basement is formed of Xingu Complex represented by gneisses, granite-gneisses, schists, meta-ultramafics and amphibolites. Gneisses yield ages of 2,816±4 Ma (Pb-evaporation on zircon) and 1,983±9 Ma (U-Pb on zircon), with T_{DM} of 2.62 Ga, suggesting the occurrence of temporally distinct units, which have not been individualized in the basement of the region. Several generations of granite intrusions have been recognized within this complex, but most of them are still poorly investigated. In this work, on the basis of field relationships, geochemistry and geochronology, three granite suites have been recognized and named Novo Mundo, Nhandu and Peixoto.

In the central and southern part of the Novo Mundo suite, syenogranite and monzonite are the predominant lithotypes, together with later volcanics (e.g. andesite and basalt), whereas monzogranite, granodiorite and syenogranite are dominant in the northern part, in association with multiple thick dikes of gabbro and diorite. In general, these rocks are sub-alkaline to calc-alkaline, slightly peraluminous, with medium to high potassium, and yielded ages of 1,970±3 Ma and 1,964 ±1Ma (Pb-Pb on zircon).

The Nhandu suite is dominated by biotite monzogranite with oval-shaped enclaves of diorite and dikes of micro-granite. Biotite syenogranite and granodiorite are minor in this suite and the latter displays rapakivi texture. These rocks are commonly sub-alkaline, metaluminous to peraluminous and with medium potassium. The age of the Nhandu biotite monzogranite was defined at 1,848±17 Ma (U-Pb on zircon).

The Peixoto suite is mainly represented by isotropic, equigranular to porphyritic biotite monzogranite, hornblende-biotite granodiorite and biotite tonalite of calc-alkaline nature, slightly peraluminous to metaluminous and with medium potassium. An age of 1,792±2 Ma (Pb-evaporation on zircon) was obtained for the biotite monzogranite.

The Novo Mundo suite is interpreted as late to post-tectonic in relation to the development of regional NW-striking sinistral shear zones that host several vein-type gold deposits (e.g. Paraíba, Mineiro, Teto, Sede, Micharia e Domingos). Accordingly, this suite may mark the maximum age for the formation of these structurally controlled deposits. Additionally, the Novo Mundo suite may be temporally and genetically associated with several disseminated gold deposits (e.g. Luizão).

The occurrence of restricted gneisses of Archean age, intruded by late to post tectonic Paleoproterozoic granite suites, with T_{DM} > 2.4 Ga, provide evidence that events of crustal generation may have locally taken place at ages older than previously defined for the Ventuari-Tapajós Province (1,95-1,8 Ga and T_{DM} of 2,2 - 1,9 Ga). Hence, these new dataset may contribute both to improve the limits of this geochronological province and place the ages of 1,970-1,964 Ma as an important temporal mark for gold mineralization in the Alta Floresta Province.

Research funded by CNPq, METAMAT and FAPESP (03/09584-3).

THE SYNTECTONIC PALEOPROTEROZOIC CALC-ALKALINE GRANITOIDS FROM THE MARONI-ITACAIÚNAS PROVINCE, NORTHERN BRAZIL

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Syntectonic granite magmatism was a global-scale process during Paleoproterozoic times. In Amazon craton, the Maroni-Itacaiúnas Province constitutes a large Paleoproterozoic terrain. In central domain of Pará State, between Xingu and Tocantins rivers, granitoids of expanded compositions are abundant and characterized by regional homogeneous foliation striking N60W and WNW-ESE. In outcrops both subvertical and flat-lying rhythmic igneous layering (S_0) testify to laminar flow during magma ascending and chamber filling close to the melt escape threshold. Granites and quartz diorites may be interfingered suggesting magma mingling. These primary surfaces pass laterally to high temperature secondary foliation (S_1) developed on incompletely consolidated magma between the rigid percolation threshold and the particle locking threshold. The development of these structures was controlled by progressive deformation under decreasing temperature regime, so that one can ascertain the syntectonic emplacement of these granitoids during regional shortening stresses. Corrosion of biotite and amphibole on faces parallel to the secondary foliation gave rise to symplectites which indicate that magma emplacement and crystallization were synchronous to coaxial flattening. Aplite veins would translate shallow-level emplacement and would have been formed through stress-controlled segregation near the particle locking threshold. In strongly recrystallized rocks low-plunge lineations indicate late strike-slip components. Sigma porphyroclasts found in mylonites point to sinistral movement whereas late displacement of aplite veins indicates destral shear sense. Syenogranites, monzogranites and granodiorites predominate and are followed by tonalites, syenogranites and scarce quartz diorites. A wide facies variation is identified on the basis of the biotite and amphibole abundances. Primary magnetite and sphene indicate crystallization under relatively high oxygen fugacity conditions. These rocks have low FeO/MgO ratios, relatively high $CaO/(Na_2O+K_2O)$ ratios and low incompatible element contents. Rare-earth elements patterns are moderate to strongly fractioned. These rocks are calc-alkaline, weakly peraluminous and their chemical signature is comparable to that of the I-type granitoids. The origin of magmas would have involved partial melting of both mantle and lower continental sources. Pb-Pb zircon (evaporation) dating of a granite yielded an age of 2076±6 Ma considered as the crystallization age. Sm-Nd data yielded Nd model ages between 2.25 and 2.35 Ga, and $\varepsilon Nd_{(t)}$ values ranging from +0.83 to -0.6. One analysis furnished a Nd model age of 2.57 Ga and an $\varepsilon Nd_{(t)}$ value of -4.12. Structural and petrological evolution of the studied granites is similar to that observed in other paleoproterozoic terrains which are related to magmatic arc environments developed during soft amalgamation of continental plates.

REFINING OF THE TIMING OF OROGENETIC EVENTS IN NORTHERN RONDÔNIA, SW-AMAZONIAN CRATON, DURING GEONS 17-12: IMPLICATIONS FOR UNDERSTANDING THE EVOLUTION OF THE PROTEROZOIC LITHOSPHERE

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New SHRIMP U-Pb zircon geochronological analyses have refined the timing of magmatism and metamorphism during the geons 17-12, in northern Rondônia state. There were two short-lived calc-alkaline plutonic episodes from 1761 to 1745 Ma, 1736 Ma to 1728 Ma and volcanic episodes at 1751-1740 Ma, related to soft-collision/accretion driven by subduction of oceanic crust, assigned to the Juruena Orogeny, and synchronous with the deposition of volcano-sedimentary and sedimentary sequences (Mutum-Paraná, Roosevelt, and Beneficente Groups), after ca.1751 Ma. A younger magmatic episode, 1688 to 1681 Ma and 1665 to 1661 Ma, resulted in partial melting of previous lithosphere and generation of sheet-like and small intrusive bodies of garnet-bearing granite. These data do not allow unequivocal correlation to a collisional regime. Coeval basin sediments deposited between 1.66 and 1.57 Ga - protoliths of the Rio Preto and Machadinho paragneiss belt - have experienced high-T, low-P metamorphism at 1545 Ma (U-Pb monazite), and zircon overgrowths at 1590 Ma and 1524 Ma, related to the Serra da Providência Intrusive Suite (SPIS: 1.60 - 1.53 Ga). These magmatic and sedimentary episodes represent temporal correlatives to the Lomas Maneches granitoid suite (1689-1663 Ma), and paragneisses from the Chiquitania Complex and San Ignacio Group, of eastern Bolivia, deposited after 1690 Ma; metamorphic imprints on these rocks at 1333 and 1310 Ma are documented. Felsic rocks were intruded at ca. 1637 Ma, accompanied by metamorphism and deformation between 1637 to 1617 Ma. Subsequent mangerite-charnockite-granite (MCG) and associated mafic rocks of the (SPIS), define a north-northwest array subparallel to the Mesoproterozoic proto-margin. These rocks were emplaced during extension (transpressive/transtensive strain), while convergence and transpression along the presumed orogen margin continued (Cachoeirinha orogen ~1.58-1.52 Ga), farther southeast. Lower crustal delamination following mafic underplating and partial melting of the deep crust, possibly in a broad back-arc setting or collisional mantle suture is invoked. We confirm the widespread nature of the Rio Crespo Intrusive Suite (RCIS), composed of pink or greenish, fine- to medium-grained, quartz-feldspathic banded gneisses, metamorphosed at amphibolite or granulite facies conditions between 1350 and 1310 Ma. In addition, we propose to attribute orogeny status to this suite, thereby creating the "Rio Crespo Orogeny", including events between 1520 and 1460 Ma. This orogeny is preliminarly interpreted as resulting from subduction along a juvenile continental margin arc, correlated to the Rio Alegre Orogen (1509-1494 Ma), in Mato Grosso. From 1.42 and 1.24 Ga northern Rondônia was under the effect of the Rondonian/San Ignacio Orogeny (1550 -1.320 Ma) and Nova Brasilândia Orogeny (1.25-1.11 Ga), resulting in distal inboard AMCG and mafic magmatism, mainly represented by four intrusive suites. Temporal equivalents are the metagabbros from the Colorado Metamorphic Suite (1352 Ma), farther southeast, and the Pensamiento granites (1400 - 1320 Ma), in eastern Bolívia. In northern Rondônia the 1.41-1.24 Ga magmatism appears to be associated with NNW- SSE transpressional/transtensional strain. A different approach is that they represent early back-arc rift products or some other variety of intracratonic rifting.

MAGMATISM AND CRUSTAL EVOLUTION OF THE CARAJÁS PROVINCE, AMAZONIAN CRATON

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The Carajás Metallogenic Province (CMP) is the more important Archean province of the Amazonian craton identified so far. It is divided in two major tectonic domains, the Rio Maria Granite-Greenstone Terrain (RMGGT) and the Carajás Basin (CB). Geophysical evidence suggests that the limit between both domains coincides with a regional ~EW trending discontinuity situated to the north of Sapucaia and south of Canaã dos Carajás. It is admitted the existence of a Transition Domain originally similar to the RMGGT but intensely affected by the magmatic and tectonic events recorded in the CB. There are important differences between the RMGGT and the CB: (1) The supracrustal sequences of these domains differ in age (2.97 to 2.9 Ga in the RMGGT vs. ca. 2.76 Ga in the CB) and petrologic characteristics. (2) The rocks exposed in the RMGGT were formed in between 2.98 and 2.86 Ga and the main shear event identified in it occurred around 2.87 Ga. In the CB, the main stratigraphic units formed in the period of 2.76 to 2.70 Ga and the last Archean deformational and metamorphic events have been dated at 2.58 to 2.50 Ga. The tectonic stabilization of the RMGGT preceded that of the CB. (3) The Archean granitoids of the RMGGT are similar to those found in classical Archean terranes and yielded ages between 2.98 and 2.86 Ga. In the CB, the common occurrence of 2.75 Ga to 2.57 Ga old, subalkaline A-type granites represent an important difference between this tectonic domain and the RMGGT. (4) In the RMGGT, a back-arc setting was admitted for the evolution of the mafic-ultramafic sequences of the greenstone belts (2.97 Ga). It evolved to an island magmatic arc, during the generation of the 2.87 Ga granitoids. In the CB, two models are proposed: the first model admits that the supracrustal sequences were related to a continental rift tectonic setting; the second assume a continental margin setting, which evolution was related to the subduction of an oceanic crust, followed by a continent-continent collision. Nd isotope data from the Paleoproterozoic granites of the CB favor an ensialic evolution. The main granite groups distinguished in the CMP include six Archaean groups (3.0 to 2.57 Ga) and one Paleoproterozoic group (1.88 to 1.86 Ga). The older Archean granitoid groups occur in the RMGGT: (1) Older tonalitic-trondhjemitic series (TTG; 2.98 to 2.93 Ga); (2) The Rio Maria Granodiorite and associated rocks (sanukitoid series; ~2.87 Ga); (3) Younger tonalitic-trondhjemitic series (TTG; ~2.87 Ga); (4) Potassic leucogranites of calc-alkaline affinity (~2.93 to 2.86 Ga). The groups (5) and (6) occur only in the Carajás Basin and in the Transition domain. They are represented, respectively, by the granitoids of the Plaquê Suite (~2.73 Ga), and the subalkaline foliated granites (~2.75 Ga). The group (7) corresponds to the ~1.88 Ga anorogenic, A-type granites and occurs indistinctly in all tectonic domains of the province. The Mesoarchean magmatism of the RMGGT is similar to that recorded in classical granite-greenstone terranes. The Neoarchean magmatism of the CB is very peculiar reflecting its distinct tectonic evolution. The dominance in it of subalkaline granites with A-type geochemical signature is remarkable. The anorogenic Paleoproteorozoic A-type magmatism is found in different tectonic domains. It is associated with an extensional tectonic setting and is probably related to mafic underplating in the lower crust inducing the melting of crustal protoliths.

THE PRONEX NUCLEUS: MAGMATISM, CRUSTAL EVOLUTION AND METALLOGENESIS OF CARAJÁS AND ADJACENT PROVINCES, AMAZONIAN CRATON

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The Pronex Nucleus was created in October, 2000, for an initially four years project, later extended to a six year project. The Pronex was conceived as an ambitious Brazilian program turned to give support and to strengthen multi-institutional groups of research of recognized dynamic action in key scientific areas. The Center of Geosciences of the Federal University of Pará (UFPA), represented by the groups of research on granitoid petrology and metallogenesis and the isotope geology laboratory (Pará-Iso), associated with geologists of the Serviço Geológico Nacional (CPRM), Vale do Rio dos Sinos University (Unisinos-RS), Federal University of Amazonas (UFAM), Museu Paraense Emilio Goeldi (MPEG), and São Paulo University (USP) created this Pronex nucleus. It was articulated to develop a research project on "Magmatism, crustal evolution, and metallogenesis of Carajás and adjacent provinces of the Amazonian craton". The integration between different institutions was extremely positive, reinforcing previous cooperation projects and creating new issues. International cooperation was also stimulated by the Nucleus: The active participation in the IGCP 426 and 510 projects, implying cooperation with Helsinki University and ISTO (Orléans, France); the research projects on the Guiana Shield involving UFPA, CPRM, BRGM and French universities; the projects on the Tapajós Gold province with the leadership of USP and participation of USGS, UFPA, and CPRM; the SHRIMP geochronological studies in cooperation with Australian universities; these are all good examples. The Pronex Nucleus is ending this year his project and the present symposium was in large part conceived to divulgate the main results achieved. In this period, the Nucleus gave a relevant contribution to the improvement of the geosciences in the Amazonian region: 15 doctors and 40 masters were formed in graduate programs, and 120 undergraduate students were introduced to scientific research. The main scientific results have been published in international and national journals, some special volumes were edited and special symposium, events, and local meetings were organized. The main goals of the Pronex Nucleus research project were: (1) To define the major magmatic events in the Carajás and adjacent provinces, characterizing the magmatic series involved, their origin and tectonic settings. (2) To establish the relationships between magmatic events and associated mineralizations, trying to define their age, origin and nature of fluids involved. (3) To clarify the relationships between the Archean Carajás province and the neighboring provinces and the crustal evolution of the eastern Amazonian craton. The first objective was satisfactorily attained not only in the Carajás province but also in the São Luís craton, Amapá Block, Araguaia and Goiás belts, Tapajós province, and Pitinga and Central and SE Roraima regions. The second objective was developed partially integrated with a DNPM/ADIMB project and the more relevant results were achieved in the Tapajós, Carajás and Pitinga provinces, with some significant contributions also in the São Luís craton, Amapá Block, and Araguaia Belt. The third goal was also accomplished: Archean and Paleoproterozoic crustal domains were defined in the Bacajás, Xingu-Iriri and Amapá regions; the limits between the Amazonian craton and the Brasiliano Araguaia belt were confirmed; the contrasts between the Carajás and Tapajós provinces were demonstrated. We hope that the present symposium and the subsequent volume to be published will be able to show clearly the whole contribution of the Pronex Nucleus.

GEOLOGIC AND ISOTOPIC CONSTRAINTS ON FLUID SOURCES FOR THE IGARAPÉ BAHIA Cu-Au DEPOSIT, CARAJÁS MINERAL PROVINCE, BRAZIL

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The Igarapé Bahia Cu-Au deposit, in the Carajás Province, is hosted by low-grade metamorphic rocks of the Archean (~ 2.75 Ga) volcano-sedimentary Itacaiúnas Supergroup. The deposit is surrounded and partly overlain by greenschist facies metarenites of the Águas Claras Formation (> 2.65 Ga) and is crosscut by undeformed mafic dikes (≤ 2.65 Ga). The orebody at Igarapé Bahia is a fragmental rock layer situated at the contact between a lower basaltic unit, with associated quartz-magnetite BIF and hyaloclastite, and an upper turbiditic pile. The fragmental rock contains mainly basalt and BIF clasts derived from the footwall unit set in a fine-grained matrix consisting of magnetite, chlorite, siderite and disseminated to massive chalcopyrite. Amphibole, quartz, gold and minerals containing Co, Mo, U, W, F, P, Mn, Sn, Ag, B, Cl and LREE are also present. Metamorphism produced slightly foliated structures in most Igarapé Bahia rocks. Clasts in the fragmental layer are usually foliated in the same direction of the foliation of the matrix. Chalcopyrite grains in the matrix are normally anhedral and elongated, suggesting metamorphic deformation / remobilization. Crosscutting relationships demonstrate that the fragmental rock Cu-Au mineralization neither transects the Águas Claras metarenites nor the mafic dikes, being consequently coeval or very close in age to the ~ 2.75 Ga Itacaiúnas host rocks.

Fluid inclusions trapped in a quartz cavity in the fragmental layer indicate that highly saline aqueous fluids (≤ 45 wt% NaCl + $CaCl_2$ eq), coexisting with carbonic ($CO_2 \pm CH_4$) and low-salinity aqueous carbonic fluids, were involved in ore formation. A temperature near 400°C for mineralization was estimated from stable isotope geothermometry and gangue mineral parageneses.

Most stable isotope determinations in ore-related minerals do not clearly discriminate between possible sources for the ore. Carbon isotopes in carbonates ($\delta^{13}C_{PDB}$ - 6 to - 13‰), for instance, indicate they derive from organic and possibly also from deep-seated, magmatic carbon; oxygen results in carbonates ($\delta^{18}O_{SMOW}$ 4 to 20‰) point to a $\delta^{18}O$-rich, magmatic or sedimentary source; sulphur isotopes in chalcopyrite ($\delta^{34}S_{CDT}$ -1.1 to 5.6‰ with an outlier at – 10.8‰) indicate that most sulphur is magmatic or leached from magmatic rocks, whereas some contribution of oxidized and of reduced, biogenic sulphur is also evident; oxygen isotopic ratios in quartz and magnetite yield enriched $\delta^{18}O$ compositions for the ore-forming fluids ($\delta^{18}O_{SMOW}$ 6.5 to 10.3‰), which may reflect a magmatic input or interaction with $\delta^{18}O$-rich, possibly sedimentary, rocks. Differently from the mentioned examples, boron isotopic data provide unambiguous evidence regarding source. Results obtained in tourmaline that occurs disseminated in the fragmental rock matrix ($\delta^{11}B$ 12 to 26‰) imply a marine evaporitic source for boron and consequently for the highly saline mineralizing fluids of Igarapé Bahia.

These $\delta^{11}B$ data combined with the absence of granites in or near the deposit area reinforce the role of non-magmatic brines in the genesis of the fragmental rock-hosted ore of Igarapé Bahia. Taking into account geologic constraints, magmatic fluids, if present, could only be related to the ~2.75 Ga old, Estrela-type granites of the Carajás Province or other coeval intrusives.

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OXYGEN ISOTOPES OF IGNEOUS ZIRCONS AND THE TECTONIC EVOLUTION OF THE ORIENTAL BORBOREMA PROVINCE, NE BRAZIL

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This study was performed with the objective of testing the hypothesis of terrane accretion in the Borborema province (BP) through the study of oxygen isotope composition of zircon from Neoproterozoic granitoids from five suspect terranes of the Borborema province: Seridó, Transverse Zone (Cachoeirinha-Salgueiro - CS, Alto Pajeú – AP, and Alto Moxotó - AM belts) and Pernambuco-Alagoas domains. Except for one pluton, all are magmatic epidote-bearing granitoids.

Values of $\delta^{18}O$ (zircon) differ for the three domains, but are similar for different plutons of the same domain. The São Rafael pluton in the Seridó domain presents average $\delta^{18}O$ (zircon) value of 5.98 ± 0.16‰ (1 std dev; n = 10), slightly higher than values of $\delta^{18}O$ (zircon) in equilibrium with mantle-derived rocks. The determined values correspond to calculated whole rock $\delta^{18}O$ values = 7.5 to 8.1‰ (Ferreira et al., 2003).

Plutons of two belts of the Transverse Zone domain have high $\delta^{18}O$ (zircon) values between 8.7 and 10‰. High-K calc-alkalic granitoids from the CS belt have $\delta^{18}O$ (zircon) values varying from 8.71 to 9.74‰, with average value of 9.29 ± 0.34‰ (n=10), while calc-alkalic granodiorites have an average value of 10.01 ± 0.2‰ (n= 11). These values correspond to calculated magmatic whole rock values of 10.7 to 11.0‰ (for SiO_2 contents varying from ~63 to 68%) for the high-K calc-alkalic plutons, and 11.6 to 11.7‰ (SiO_2 from 65-67%) for the calc-alkalic ones. High-K calc-alkalic granitoids from the AP belt present slightly lower $\delta^{18}O$ (zircon) values, averaging 9.13 ± 0.09 (n = 8), corresponding to calculated whole rock $\delta^{18}O$ value of 10.9‰. These data suggest that an important high $\delta^{18}O$ component from sediments and/or altered ocean crust was present in the source rock of these plutons (e.g. Emas pluton, Ferreira et al., 2003). Exceptions for these high values are plutons of the AM belt, which show slightly lower $\delta^{18}O$ (zircon) values: the high-K calc-alkalic Remédios pluton has average value of 8.30 ± 0.12 (n = 3), while the shoshonitic Betânia pluton shows average value of 7.38 ± 0.18‰ (n = 5).

Values of $\delta^{18}O$ (zircon) for the peraluminous Batateiras granitoid, in the Pernambuco-Alagoas domain, are intermediate between those for the Seridó and the Transverse Zone domains, averaging 6.88 ±0.13 (n=2), implying a calculated whole rock $\delta^{18}O$ value of 8.6‰. These data suggest that a high $\delta^{18}O$ component from sediments was involved in the source rock for these leucocratic granitoids.

The São Rafael pluton in the Seridó domain presents more negative εNd(0.6Ga) values (average -19.6) than the other plutons in the other domains, and oldest t_{DM} ages (2.4 to 3.2 Ga). Plutons in the Transverse Zone, which presents higher $\delta^{18}O$ (zircon) values, have younger t_{DM} ages, 1.3 to 1.8Ga (average 1.4), compatible with a significant high $\delta^{18}O$ component from altered ocean crust, as discussed by Ferreira et al (2003). The exception of $\delta^{18}O$ (zircon) values observed for plutons of the Alto Moxotó belt in the Transverse Zone repeats for Nd isotopes as they present more negative εNd (avg -12.4) and older t_{DM} 1.89 Ga. The studied pluton of the Pernambuco-Alagoas domain, which have intermediate $\delta^{18}O$(zircon) values presents variable εNd values from -4.3 to -17 and Nd model ages, from 1.5 to 2.0 Ga, indicating a substantial supracrustal input in the source region of the magma.

These results show that plutons with the highest $\delta^{18}O$ (zircon) values present less negative εNd values, and youngest t_{DM} (0.6Ga) ages, implying important differences in magma source, and are compatible with higher supracrustal input with time. The granitoids in the Transverse Zone seem to represent a mixture of Neoproterozoic mantle-derived material with magma derived from melting of Paleoproterozoic high $\delta^{18}O$ continental crust, which yield intermediate Nd model ages, of ca. 1.4 Ga. The only exceptions for the data in this domain are the plutons of the Alto Moxotó belt that present lower (by ca. 2‰) $\delta^{18}O$ (zircon) values, more negative εNd and an older t_{DM} age than those in the other studied belts of the Transverse Zone domain.

Lower $\delta^{18}O$ values for the São Rafael pluton in the Seridó domain coupled with Nd isotopic data indicate that magma formed by remelting of Paleoproterozoic lower continental crust. Data for the Batateira pluton in the Pernambuco-Alagoas domain seems to represent melting of Paleoproterozoic lower crust with some input of supracrustal high $\delta^{18}O$ rocks buried to the base of the crust.

These results show that the three domains have different crustal evolution histories, and do not favor assembly of terranes in the Transverse Zone domain. On going radiogenic and oxygen isotope analysis of a larger number of granitic plutons from the different belts will help gain a better understanding of the crustal evolution and anatomy of the domains and belts of the Borborema province. *Ref.: Ferreira et al. 2003, CMP, 145(2):205-216.*

AGE AND ISOTOPIC CHARACTERISTICS (Pb AND S) OF THE Fe OXIDE-Cu-Au-U-REE IGARAPÉ BAHIA ORE DEPOSIT, CARAJÁS MINERAL PROVINCE, PARÁ STATE, BRAZIL

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The Fe oxide-Cu-Au-U-REE Igarapé Bahia ore deposit is located in the Carajás Mineral Province, southeastern of the Amazonian craton, northern Brazil. This deposit occurs in the northern part of this province, is hosted by the Archean Igarapé Bahia Group (2.75 Ga) and comprises four ore bodies known as Acampamento Sul, Acampamento Norte, Furo 30, and Alemão. Owned by the Companhia Vale do Rio Doce (CVRD), mining operations started in the late 1980 with most efforts being directed to produce gold from the 40-100 m-thick lateritic-gossanic crust that was developed above the primary sulfide-rich ores. Ore reserves are estimated at 219 Mt with average grades of 1.4% Cu and 0.86 g/t Au. About 140 t of gold have been produced from the supergene-enriched zone, which is now practically exhausted.

The Igarapé Bahia Group occurs as a small window within the overlying Águas Claras Formation. This group consists of mafic metavolcanic, metapyroclastic and metasedimentary rocks, in addition to banded iron-formations and hydrothermal breccias. The Águas Claras Formation overlies discordantly the Igarapé Bahia Group and represents a slightly metamorphosed siliciclastic sequence composed dominantly of quartz sandstones intercalated with conglomeratic, and less commonly, pelitic beds. Mafic dikes cut all these lithological varieties. The Igarapé Bahia Group rocks were affected by hydrothermal metamorphism of low greenschist facies conditions reaching temperatures up to 400° C. The Cu-Au mineralization is best developed in the breccias that lie between the mafic metavolcanic and metapyroclastic/metasedimentary units. Chalcopyrite, pyrite, bornite and chalcocite are the main sulfides, and are associated with Fe-rich chlorite, magnetite, siderite, and subordinate amounts of tourmaline, fluorite, REE-bearing minerals and calcite. In trace amounts occur monazite, REE-carbonates, ferberite, hessite and uraninite, in addition to native gold and silver.

Dating of chalcopyrite from the hydrothermal breccias and metavolcanic, metapyroclastic and dike rocks by the Pb-Pb method yielded ages of 2772±46, 2756±24, 2754±36 and 2777±22 Ma, respectively. A similar age of 2744±12 Ma on gold by Pb-Pb evaporation-ionization method from the hydrothermal breccia, mafic metavolcanic rocks and gossan was also obtained, which is considered to be the age of the mineralization and therefore contemporaneous with the formation of the volcano-sedimentary sequences of the Igarapé Bahia Group (2745-2747 Ma). These geochronological data support a genetic link between the volcanic processes and the Igarapé Bahia Cu-Au mineralization. Pb-Pb analyses on chalcopyrite leachates from the hydrothermal breccias reveal ages of 2385±122 and 2417±120 Ma, suggesting remobilization most likely due to regional tectonic reactivations related with the development of the Carajás and Cinzento strike-slip fault systems. Pb isotopic analyses show highly radiogenic samples that are indicative of magmas derived from sources in the upper crust enriched in U and Th. $\delta^{34}S$ values (–2.1 to +4.2 per mil) are consistent with derivation of sulfides from magmatic fluids, but a submarine environment similar to that of Archean VMS mineralization in which evaporites have been deposited can not be ruled out.

AN OVERVIEW OF THE AMAZONIAN CRATON EVOLUTION: INSIGHTS FOR PALEOCONTINENTAL RECONSTRUCTION

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Supercontinent assemblages developed at several times in the Earth history and major tectonic events (accretionary and collisional processes) of the Amazonian craton may be correlated to these continental amalgamations. Based on geologic, structural and paleomagnetic evidence paleocontinental reconstructions have been proposed for Archaean to younger times taking into account paleomagnetic data, orogenic belts match, crustal provinces match, fossil assemblages and glaciogenic sequences. This work deals with the continental growth of the Amazonian craton and the relationship of these accretionary processes with supercontinent amalgamations throughout geologic time. The oldest highly speculative continent (Ur) had joined five Achaean cratonic areas (Kaapvaal, Western Dhawar, Bhandara, Singhhum and Pilbara cratons) where 3.0-2.8 Ga shallow-water supracrustals assemblages are observed. Coeval sediments of Agua Clara formation intercalated with 1.97-1.92 Ga volcanic rocks may suggest the participation of the Achaean rocks of the Carajás region in the Ur landmass.

Supercontinental 2.45 Ga Kenorland amalgamation is indicated by paleomagnetic data including Laurentia (Superior and Wyoming cratons), Baltica (Karelia craton), Australia (Yilgarn craton), and Kalahari and Kaapvaal cratons as recorded by glaciogenic and paleoweathering layers. The lack of such sedimentary rocks suggests that Amazonian craton was not part of the Kenorland supercontinent. From 1.83 Ga to 1.25 Ga two supercontinents including Amazonian craton were proposed: Columbia and Hudsonland. They take into account paleomagnetic and tectonic data indicating that NE portion of the Amazonian craton (Maroni/Itacaiunas province) had connection with West Africa and Kalahari cratons at that time. Paleomagnetic data also indicate Amazonia (Nova Brasilandia) and Laurentia (Llano segment) connection at 1.2 Ga.

Reconstructions of the Rodinia supercontinent (AUSWUS, SWEAT and AUSMEX) show Amazonia joined to Laurentia-Baltica as result of 1.1 Ga to 1.0 Ga fusion based on the Sunsas-Aguapei belts, Greenville and Sveconorueguian belts, respectively. The Sunsas-Aguapei orogen is interpreted by several authors as the last thermo-tectonic event in Amazonian craton, which is coeval to the Rodinia amalgamation. The large Late Mesoproterozoic landmass included also Siberia, East Antartica, West Nile, Kalahari, Congo/São Francisco and Greenland.

The 750-520 Ma Gondwana assembly included most of the continental fragments rifted apart during the break-up of Rodinia at the beginning of the Neoproterozoic. Successive collision and plate indentation processes occurred during this global event. They are described as Brasiliano-Pan African, East Africa and Kuunga. The configuration of the South America platform was defined during the Gondwana amalgamation where the Amazonian craton was bordered by the Neoproterozoic belts to the east (Araguaia belt formed by previously formed Brasilia belt and Amazonian craton collision.), south (Paraguay belt: Paranapanema block and Amazonian craton collision) and southwest (Tucavaca belt: Rio Apa block and Amazonian craton collision).

The supercontinent Pangea comprises Gondwana and Laurentia at about 230-180 Ma ago. The Amazonian craton margins were not involved in the collisional processes during Pangea because it was probably embebed within Neoproterozoic mobile belt rocks. As a consequence, Amazonian craton borders have no record of the orogenic processes responsible for the Pangea amalgamation.

GRANITOGENESIS EVENTS IN THE NORTHERN PORTION OF THE TOCANTINS PROVINCE, BRAZIL

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The Tocantins Province includes five geotectonic units, named Goiás Massif, Goiás Magmatic Arc, and Brasília, Paraguay and Araguaia belts. The first one involves Archean and Paleoproterozoic rocks, while the others are composed of Neoproterozoic rocks. Four granitic events (G1, G2, G3 and G4) have been recognized in the Goiás Massif and in the Araguaia Belt, which have Paleoproterozoic and Neoproterozoic ages.

The oldest event G1 occurs in the Goiás Massif, and is represented by four granitic plutons (Areias, Carmo, Ipueiras and Itália), grouped in the Ipueiras Suite. They are composed of hornblende-biotite monzogranite, hornblende-biotite quartz syenite, biotite syenogranite and biotite monzogranite, with geochemical signature similar to the A-type granites. The $^{207}Pb/^{206}Pb$ zircon ages of these plutons are around 2.08 Ga and the Sm-Nd T_{DM} ages vary from 2.19 to 2.15 Ga, with $\varepsilon Nd_{(2.08)}$ between +2.5 and +2.9.

The G2 event is represented by the Serrote and Cantão plutons, which represent part of the basement of the Araguaia Belt, overprinted during the Neoproterozoic thermo-tectonic event of this belt. These plutons are composed of biotite-microcline granite, biotite-hornblende syenogranite and hornblende granodiorite. These rocks also have geochemical signatures similar to A-type granites. They present $^{207}Pb/^{206}Pb$ zircon ages at about 1.85 Ga, and Sm-Nd T_{DM} ages around 2.7 Ga, with $\varepsilon Nd_{(1.85)}$ between –5.2 and –6.0.

The G3 event occurs in the Goiás Massif, and is represented by the Lajeado, Matança, Palmas and Aroeira granitic plutons, grouped in the Lajeado Suite. Hornblende-biotite syenogranite, hornblende-biotite monzogranite, quartz syenite and quartz monzonite are the main lithotypes. Orthopyroxene occurs in most of these rocks, suggesting that they are part of a charnokitic magmatic serie. In addition, the Matança and Palmas plutons are affected by the Porto Nacional Shear Zone. The $^{207}Pb/^{206}Pb$ zircon ages of these plutons are around 0.55 Ga, and the Sm-Nd T_{DM} ages vary from 1.7 to 2.1 Ga, with $\varepsilon Nd_{(0.55)}$ between –10 and –13.

The G4 event is represented by the Santa Luzia, Barrolândia, Presidente Kennedy, Ramal do Lontra and Serra da Ametista syntectonic plutons, emplaced in meta-sedimentary rocks of the Araguaia Belt. The main lithotypes are muscovite-biotite monzogranite and granodiorite, presenting peraluminous geochemical signature. The $^{207}Pb/^{206}Pb$ zircon ages are around 0.55 Ga. The Sm-Nd T_{DM} model ages are 1.38 and 1.83 Ga, with $\varepsilon Nd_{(0,55)}$ of –14.3 and –18.9.

The current data indicate that the Paleoproterozoic G1 and G2 granitic events occurred before the evolution of the Araguaia Belt. The G1 event is related to juvenile domains of the Goiás Massif, while the G2 event involves Archean components in the origin of the Paleoproterozoic magmas. In addition, the G2 event is contemporaneous and geochemically similar to the A-type granites of the eastern portion of the Amazonian Craton. The Neoproterozoic G3 and G4 granitic events are coeval and related to the thermo-tectonic evolution of the Araguaia Belt. The G4 granites are interpreted as syn-collisional granites, whereas the G3 granites may be considered as reflex of this collision in the eastward continental block (Goiás Massif) and related to the transtensional tectonic processes.

NEOARCHEAN SANUKITOIDS OF THE FENNOSCANDIAN SHIELD

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Sanukitoids are a series of special-type high-Mg granitoids that are found in Archean cratons all over the world. They were formed during the later stages of cratonization and are narrowly restricted in time. Up to now, about 20 sanukitoid intrusions have been found in the Karelian Craton of the Fennoscandian Shield. The Karelian sanukitoids are divided into eastern and western zones with distinct geochemical characteristics and ages (Lobach-Zhuchenko et al., 2005). The ages of eastern and western sanukitoids are ca 2.74 and 2.70 Ga, respectively. They are 60–100 Ma younger than surrounding TTG granitoids, the major component of the Archean crust (Bibikova et al., 2005). Their geochemical features are somewhat paradoxical and differ significantly from those of TTGs produced by slab melts. Low SiO_2 content, high Mg number, enrichment in Mg, Ni, and Cr point to a mantle-wedge peridotite source, whereas high K content and enrichment in LILE and LREE indicate an enriched (metasomatized) mantle source. The Nd isotope compositions of sanukitoids point to a mantle origin (Kovalenko et al., 2005), but Pb isotopes show a crustal signature indicating that the recycling of older crustal material through sediment subduction may have played an important role in the genesis of sanukitoid magmas (Halla, 2005).

The Karelian sanukitoids are thought to originate in a subcontinental lithospheric mantle (SCLM) that was modified by reactions with slab melts or fluids shortly (up to 200 Ma) before melting. The appearance of sanukitoids is attributed to the formation of a mantle wedge reflecting a shift from shallow to deep subduction in the cooling Earth (Martin and Moyen, 2005). It is suggested that the SCLM beneath the Karelian Craton of the Fennoscandian Shield originally formed in an arc environment, thus representing a differentially metasomatized mantle wedge peridotite. The geochemical differences of sanukitoids reflect the variable enrichment of the respective mantle sources. The mechanism that caused partial melting in the subcontinental mantle is still unclear as well as the role and nature of the crust–mantle interactions in the genesis of sanukitoid series rocks.

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THE PALEOPROTEROZOIC VOLCANO-PLUTONISM AND ASSOCIATED Au AND Cu-Mo MINERALIZATIONS IN THE TAPAJÓS GOLD PROVINCE, AMAZONIAN CRATON

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The acid to intermediate calc-alkaline volcanic and volcaniclastic rocks of the ~1.88 Ga *lato sensu* Uatumã magmatic event cover > 1.100.000 km^2 (30%) of the Amazonian Craton, excluded the Phanerozoic Amazon sedimentary basin. This event also resulted in a large volume of granites. Recent studies have enabled the individualization of younger volcanic sequences at the south of the Cachimbo graben (Morinu, Aripuanã and Teles Pires – ~1.76 Ga; Colíder – 1.79 Ga) and older units in the ~2.0 Ga Vila Riozinho and Surumu areas. Alkaline volcanic rocks (~1.87 Ga) are also present in the Moraes Almeida and São Felix do Xingu. These volcanic units are distributed in the Tapajós–Parima (TPP) and Central Amazon provinces (CAP), which were interpreted as formed in ocean–continent orogenies. The Tapajós Gold Province (TGP) is located in the CAP–TPP boundary and comprises the ~2.1 Ga volcano-sedimentary Jacareacanga Group and granitic rocks of the Cuiú-Cuiú Complex (~2.01 Ga), Creporizão Intrusive Suite (1.97–1.95 Ga), Rio das Tropas Tonalite (~1.90 Ga), and Parauari Intrusive Suite – PIS (~1.88 Ga). Calc-alkaline andesitic to rhyolitic volcanic and volcaniclastic rocks (Iriri Group – 1.88 Ga) overlie the plutonic rocks and are crosscut by the anorogenic Maloquinha Intrusive Suite (~1.87 Ga). Paleoproterozoic fluvial and marine units and several mafic intrusions also occur in the TGP. The Iriri Group was formed in ash-flow caldera complexes, which were genetically linked to the emplacement, in back-arc rifts, of shallow late- to post-tectonic calc-alkaline batholiths of the PIS. The pre-caldera units are composed of andesitic, rhyolitic, and ignimbritic flows. Syn-caldera units consist of several large ash-tuff eruptions and the post-caldera units are represented by rhyolite and ignimbrites, which encompass ring composite volcanoes and domes distributed along the border and within the calderas. Tuffs, epiclastic sandstone and lacustrine sediments form the intra-caldera deposits. Intrusion of granophyric stocks and dikes of rhyolitic and rhyodacitic porphyry marks the end of the caldera evolution. Intense hydrothermal alteration associated with these intrusions in ring volcanoes were responsible for the 1.86 Ga epithermal high- and low-sulfidation mineralizations. The HS Au mineralization occurs in hydrothermal breccia affected by advanced argillic alteration, with alunite, natroalunite, pyrophyllite, andalusite, woodhouseite–svanbergite, diaspore, kaolinite–dickite, and enargite–luzonite. Argillic and propylitic hydrothermal zones enveloped the breccias, and sericitic alteration predominates in deeper parts. Hematite-rich silica cap occurs on top of the hydrothermal breccia bodies. Similar geological setting is identified in the LS Cu–Mo–(Au) mineralization, which is characterized by adularia and sericite in the hydrothermal alteration ore zone. Mesozonal granites, similar to the reduced Au mineralized Batalha Granite, undergone early Na- and K-metasomatism followed by intense propylitic and sericitic hydrothermal alterations. The hydrothermal patterns and biotite halogen chemistry are similar to those observed in Au-rich porphyry systems. Shallow-emplaced granites, such as the Palito granite, host a possible Au–(Cu) porphyry-type mineralization. The Palito granite forms a dome-like intrusion in the contact of a porphiritic granite and granodiorite–quartz diorite bodies. All these intrusive rocks are cut by mafic dikes. In this scenario, Au, Cu–Au, and Cu–Mo porphyries could also be present in shallower and more oxidized late Parauri granites, close to and below the epithermal HS and LS mineralizations.

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SÃO LUÍS CRATON AND GURUPI BELT, NORTHERN BRAZIL: GEODYNAMIC EVOLUTION AND ROLE IN THE ASSEMBLY OF WEST GONDWANA

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The São Luís craton (SLC) is composed of granitoid suites and a metavolcano-sedimentary sequence, all developed in the Paleoproterozoic (Rhyacian). The Gurupi Belt (GB) is a Neoproterozoic orogen developed in the margin of the SLC and shows a more complex framework, with meta-supracrustal and meta-plutonic units developed in the Archean, Paleoproterozoic, and Neoproterozoic. The evolution of these geotectonic units is discussed on the basis of field geology, zircon geochronology and Nd isotope data, along with minor geochemical information.

In the SLC we recognize: (i) a metavolcano-sedimentary succession developed from 2240 Ma to approximately 2200-2180 Ma mostly from juvenile protoliths; (ii) subduction-related batholiths of calc-alkaline tonalite-granodiorite that intruded the metavolcano-sedimentary sequence and formed in an oceanic island arc setting at 2168-2156 Ma from juvenile, mantle- and/or oceanic plate-derived protoliths; (iii) subordinate plutons of potassic granites of 2150 Ma produced by the reworking of the juvenile island arc material, and (iv) muscovite-bearing granite of 2090 Ma showing a collisional signature. These rock associations, geochronology and inferred geological settings are similar to what is described for the Paleoproterozoic domain of the West African Craton (Eburnean orogeny – Birimian terranes).

The external domain (basement) of the GB comprises the reworked margin of the SLC and includes: (i) calc-alkaline/TTG tonalites and gneisses, and K-rich granite of 2168-2147 Ma; (ii) greenschist- to lower amphibolite-facies metavolcano-sedimentary succession with calc-alkaline volcanic rocks of 2148-2160 Ma and juvenile Nd isotope signature formed in arc systems (iii) plutons of peraluminous, muscovite-bearing, collision-type granites of 2070-2100 Ma with Nd isotopes indicating variable reworking of Paleoproterozoic and Archean crust; (iv) sub-greenschist- to greenschist-facies supracrustal sequence of unknown age (older than 2159 Ma?). In a more internal domain occur: (v) small lenses of an Archean metatonalite of 2594 Ma (basement inlier); (vi) amphibolite-facies metasedimentary sequence (passive margin?) likely formed in the Neoproterozoic (youngest detrital zircon of 1100 Ma), with Nd isotope and sedimentologic evidence indicating Archean, Paleoproterozoic, and Mesoproterozoic/Neoproterozoic sources; (vii) deformed (gneissic) nepheline syenite of 732 Ma formed by mixing of mantle and crustal sources; (viii) peraluminous, muscovite-bearing granite of 549 Ma with late/post-tectonic characteristics. In addition, three small continental basins (molassic type?) formed over cratonic and belt sequences after 550 Ma.

The Paleoproterozoic rocks of the SLC and GB are part of an orogen initiated by an accretionary phase (2240-2150 Ma) that ended with a collisional event (2100-2080 Ma), which amalgamated the juvenile and reworked Paleoproterozoic terrains to a hypothetical Archean terrain existing to the south. This landmass broke up before 732 Ma, forming a rift, as suggested by the emplacement of the nepheline syenite pluton. The rift received detritus coming from Archean, Paleoproterozoic, and Mesoproterozoic/ Neoproterozoic sources. We infer that the rift evolved to an oceanic basin and that the closure of this basin occurred at the end of the Neoproterozoic (580-550 Ma), as part of the Brasiliano/Pan-African cycle of orogenies, hence, participating in the assembly of West Gondwana.

REWORKING OF ARCHEAN CRUST AND PALEOPROTEROZOIC CRUSTAL GROWTH IN THE TRANSAMAZONIAN BELT OF THE SOUTHEASTERN PART OF GUIANA SHIELD: AN OVERVIEW

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The eastern portion of the Guiana Shield consists of a large Paleoproterozoic belt, which evolution took place during the Transamazonian event (2.26-1.95 Ga). Archean remnants have been recognized in northern and southeastern parts of this belt. Over the last decade, mapping programs and extensive geochronological studies significantly improved the geological knowledge of the southeastern part of Guiana Shield, which includes Suriname, French Guiana and Amapá and northwestern Pará states, in Brazil. We present an updated chronology of Transamazonian events and a re-appraisal of Archean basement in southeastern Guiana Shield.

The oldest Paleoproterozoic basement is dated at 2.26-2.20 Ga in French Guiana, along the Atlantic Ocean coastline, on gabbros and trondhjemites derived from oceanic tholeiitic magma and, more widely throughout French Guiana, on inherited zircon from migmatitic gneisses. In northwestern Pará, the occurrence of this early magmatic event is also suggested. TTG suite and co-eval greenstone belts reflect the consumption of oceanic juvenile crust during early frontal collision stages of Transamazonian plate tectonics in a subduction context at 2.18-2.13 Ga. Widespread granitic magmatism and migmatization occurred at 2.10-2.08 Ga in a tectonic context dominated by strong sinistral shearing, and accompanied by the formation of pull apart basins from Suriname to northern French Guiana, during the blockage of frontal collision and its evolution to left lateral (NE-SW) sliding of Amazonian and northern African Archean plates. The formation of granulite belts, including UHT assemblages (Bakhuis granulite belt in Suriname) is the ultimate product of continental sinistral shearing at 2.08-2.06 Ga, probably reflecting crustal stretching and subsequent mantle upwelling. Late granitic magmatism also marks the end of the Transamazonian event at 2.06-1.99 Ga.

In Suriname and French Guiana, Nd isotopic signatures of magmatic rocks ($-0.37 < \varepsilon_{Nd} < +2.3$) and T_{DM} values (2.40-2.19 Ga) discard any significant contribution of an Archean basement and define a large Paleoproterozoic juvenile domain. In central Amapá - northwestern Pará, An expressive Archean continental landmass, named Amapá Block has been recognized. Magmatic activity in this block occurred mainly at 2.85-2.79 Ga and at 2.66-2.60 Ga. A protracted episode of crust formation occurred at 3.29-2.83 Ga while crustal reworking dominated during Neoarchean. Reworking of Archean crust dominated during the Transamazonian event with minor juvenile accretion around 2.3 Ga. Granitic pulses are registered at 2.22 Ga, 2.18 Ga and 2.05-2.03 Ga and most of the ε_{Nd} values and T_{DM} ages (2.52-2.45 Ga) indicate an origin by mixing of juvenile Paleoproterozoic magmas with Archean components. At the north of the Amapá block, magmatic and metamorphic rocks from southeastern French Guiana and northern Amapá, provided T_{DM} ages from 2.58 Ga to 2.24 Ga ($-2.86 < \varepsilon_{Nd} < +1.74$), revealing that these rocks originated from a juvenile mantle-derived source as well as from mixed sources, including an Archean crustal component. At southwest, the Amapá Block is limited by a Transamazonian granitoid-greenstone terrane, developed in a magmatic arc context, where widespread calc-alkaline magmatism occurred at 2.19-2.18 Ga and 2.15-2.14 Ga, with minor granitic intrusions at 2.10 Ga. Crustal accretion was recognized at about 2.28 Ga, but T_{DM} values (2.50-2.38 Ga), and $\varepsilon_{Nd} < 0$, point to some participation of Archean components in the source of the Paleoproterozoic rocks.

MAGMATISM OF THE TAPAJÓS GEOCHRONOLOGICAL PROVINCE, AMAZONIAN CRATON, BRAZIL

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The Ventuari-Tapajós or Tapajós-Parima Province is an important Paleoproterozoic geochronological province located in the central southern portion of the Amazonian craton. Recent advances in the geological knowledge of this province have been obtained in the Tapajós Gold Province (TGP), a metallogenetic province of the Amazonian craton, dominated by Paleoproterozoic granitoid and volcanic sequences. The southwester part of the TGP is constituted of rocks deformed by intense compression and transpression The northeaster part is formed by comparatively less deformed younger rocks, with features indicative of formation in a post-collisional setting. The eastern and northeaster parts of the TGP were tentatively included within the Archean Central Amazonian province, while their southwestern and western portions were comprised in the Paleoproterozoic domain of the Ventuari-Tapajós province.

The oldest calc-alkaline-granodioritic and tonalitic rocks, with U-Pb ages of 2033±4 Ma and 2011±33 Ma, respectively, are included in the Cuiú-Cuiú Complex. The volcanosedimentary sequence of the Jacareacanga Group, with 2.10-2.87 Ga U-Pb ages in detrital zircons, is considered older or possibly coeval with the Cuiú-Cuiú rocks. Both units can represent the initial stages of development of the Cuiú-Cuiú magmatic arc. Intermediate to acid high-K, calc-alkaline to shoshonitic volcanic rocks of the 2.0 Ga Vila Riozinho Formation overlie stratigraphically the Jacareacanga Group. The syn- to late-orogenic, medium to high-K calc-alkaline granitoids of the Creporizão Suíte display protomylonitic textures and furnished U-Pb and Pb-Pb zircon ages between 2.0-1.96 Ga. They were interpreted as representative of a continental magmatic arc installed between the older Cuiú-Cuiú island arc and the younger Parauari continental arc. An extensive calc-alkaline magmatism represented by the Parauari Suíte, including the Younger São Jorge Granite, took place at 1.89-1.87 Ga. At ca. 1.88 Ga, a voluminous A-type felsic magmatism, more abundant to the east of the TGP, also took place. It is represented by the granites of the Maloquinha Suite and felsic volcanics of the Iriri Group and Moraes Almeida Formation. Locally were identified andesitic flows of the Bom Jardim Formation, possibly underlying the Iriri Group. Besides the mafic dikes of the Crepori diabase, mafic to intermediate intrusions are included in the Ingarana and Cachoeira Seca suites.

The Vila Riozinho region, situated in the central-eastern part of the TGP, is a key area to the understanding of the tectonic and magmatic evolution of that part of the Amazonian craton. It lies close to the poorly defined limit between the Ventuari-Tapajós and Central Amazonian provinces, and the 2.0-1.87 Ga old, magmatic rocks found regionally in the TGP have been characterized petrographic and geochemically in that area. Nd isotopic data from those rocks point to dominantly Paleoproterozoic sources for the magma with some Archean contribution. The inferred boundaries between Ventuari-Tapajós and Central Amazonian provinces need more detailed field work and better definition.

GEOCHEMISTRY, PETROGENESIS AND STRUCTURAL EVOLUTION OF ARCHEAN GRANITOIDS IN THE XINGUARA REGION, RIO MARIA GRANITE-GREENSTONE TERRAIN, SOUTHEASTERN AMAZONIAN CRATON

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The Xinguara region, in the northern sector of the Rio Maria Granite-Greenstone Terrain, is composed of greenstone belts and diversified granitoid plutons. The Caracol tonalitic complex (CTc) shows enclaves of the greenstone belts. The Água Fria trondhjemite (THaf) is intrusive in the Sapucaia greenstone belt and in the CTc, and coeval with the Xinguara granite (Gxg). Some granodiorite bodies are correlated to the Rio Maria granodiorite (GDrm). They are younger than the CTc and older than the THaf and Gxg. The regional stress ($\sigma 1$ N40E horizontal) remained active during the submagmatic stage of the CTc evolution, as indicated by folds or boudins affecting its banding. The stress field orientation was similar during the two phases of the Archean evolution of the region. This is suggested by the main submagmatic to subsolidus deformation structures in the GDrm, THaf and Gxg. The changing trends of the CTc foliation suggest that the CTc was formed by domic plutons, intruded and sectionated by the younger granitic intrusions. Al-in amphibole geobarometer data suggest that the GDrm crystallized under a lithostatic pressure of ~3 kbar (~10 km depth). The contact effects of the GDrm in rocks of the greenstone belts are coherent with these data and also suggest that its emplacement was not diapiric-controlled. The structures in the Gxg and the deformation imprinted on its country rocks suggest emplacement by ballooning. The emplacement of the THaf was probably controlled by diapiric processes. The CTc is a typical TTG, similar to those of the Archean trondhjemite series. Two different geochemical signatures have been identified in this granitoid, based on large contrasts in La_N/Yb_N ratios. The GDrm is different of the TTG series. It follows the calc-alkaline trend and is similar to Mg-rich granodiorites of the sanukitoid series. The THaf is geochemically similar to the CTc and by extension to the Archean TTG, but is comparatively enriched in K_2O. The Gxg is a high-K_2O, strongly fractionated, calc-alkaline Archean leucogranite. Its REE pattern indicates crustal origin. The dominant, high La_N/Yb_N ratio CTc group crystallized from a liquid probably originated from the partial melting of garnet amphibolites derived from 'normal' tholeiites. The latter should be similar in composition to the Archean metabasalts or to the metabasalts from the Identidade greenstone belt and the degree of partial fusion required would be, respectively, 25-30% and 10-15%. The tonalites with low La_N/Yb_N ratios crystallized from a liquid derived from a garnet-free similar source. Nd isotopic data indicate a mantle source and a juvenile character for the tonalites of the first group. A sample of the second group and an enclave in the Gxg yielded negative εNd values and > 3.3 Ga TDM ages. These data suggest that the tonalites of this group could derive from an older source with a longer crustal residence time. The THaf may have been generated by 5-10% partial melting of garnet amphibolites derived from metabasalts, chemically similar to the metabasalts from Identidade. The liquids of the Gxg were originated by variable degrees of partial melting of a source similar to the oldest TTG granitoids. The Archean geologic evolution of the Xinguara region occurred in two stages, starting at < 2.95-2.91 Ga and 2.88 Ga and it is coincident with a sharp change in crustal behavior. At this time the thickening and stabilization of this Archean crustal segment turned more effective the processes of plate subduction and convergence. As such, the partial melting of an enriched mantle wedge would generate the parental magma of the GDrm and the partial fusion of garnet amphibolites derived from subducted ocean crust would generate the THaf magma. The upward movement of the THaf and GDrm magmas would induce the melting of the TTGs in the lower crust, thus generating the granitic magmas of the Xinguara pluton.

SPATIAL AND TEMPORAL ZONING OF HYDROTHERMAL ALTERATION AND EVOLUTION OF THE SOSSEGO IRON OXIDE-COPPER-GOLD SYSTEM, CARAJÁS MINERAL PROVINCE, BRAZIL

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The Carajás Mineral Province contains the world's largest known concentration of large-tonnage iron oxide-copper-gold (IOCG) deposits. The Sossego deposit (245 Mt of 1.1% Cu, 0.28 g/t Au), which was placed into production in 2004 by the Companhia Vale do Rio Doce, is distinctive because it contains hydrothermal alteration zones similar to those formed at a range of depths in IOCG hydrothermal systems worldwide.

The deposit consists of two major groups of orebodies (Pista-Sequerinho-Baiano and Sossego-Curral) with distinct alteration assemblages, which likely reflect different host rocks (granite, granophyric granite, gabbro, and felsic metavolcanic rocks with minor lenses of metaultramafic rocks), intensity of fluid-rock interactions, and paleostructural levels.

Pista-Sequeirinho-Baiano orebodies have undergone regional sodic (albite–hematite) and sodic–calcic alteration (actinolite-albite-titanite-epidote-allanite) associated with the formation of massive magnetite–(apatite) bodies, similar to those typical of deeper portions of IOCG systems. These alteration stages were controlled by fluid-flow in large-scale regional shear zones and formed by high temperature (> 550 °C) ^{18}O-enriched (6.9±0.9‰) formational/metamorphic fluids, possibly with magmatic contribution. At Pista, distinct potassic alteration assemblage represented by biotite±hastingsite-tourmaline–scapolite pervasively replaced mylonitized felsic metavolcanic rocks. The Sossego-Curral orebodies show the most profound potassic (biotite and potassium feldspar), chloritic, and hydrolytic assemblages, similar to those found in high structural levels of IOCG systems. Zoned actinolite, Cl-apatite, and magnetite represent early infilling of mineralized veins and breccias. Copper-gold mineralization (chalcopyrite-pyrite-siegenite-millerite-vaesite-gold-Pd-melonite-hessite-cassiterite-sphalerite-galena-molybdenite) was late and paragenetically associated with epidote–chlorite–calcite–quartz–allanite–titanite assemblages formed in a brittle structural environment. The mineralization stage was characterized by the introduction of ^{18}O-depleted (–1.8± –3.4‰) meteoric-hydrothermal fluids. All orebodies show heavier sulfur ($\delta^{34}S$ = 4.9±2.4‰) than expected for a mantle source, suggesting sulfur sources derived from surficial reservoirs or leached from the host rocks. The ore geochemical signature (Fe oxide–Cu–Au–Co–Ni–Pd–REE–U) possibly reflects the chemistry of the host rocks leached by hydrothermal fluids, suggesting extensive fluid-rock interaction processes involving the high temperature, deep-seated fluids driven by heat from intrusions.

The consistent paragenetic sequence of alteration and mineralization recognized throughout the deposit coupled with similar fluid evolution suggests a common evolutionary history for different orebodies. The Sossego deposit also appears to record hydrothermal alteration during the transition from a dominantly brittle-ductile to a brittle structural regime. This could be, at least partially, related to episodic decompression due to fluid overpressure, which could have permitted influx of channelled meteoric fluids resulting in dilution and cooling of the hot metalliferous fluid, causing deposition of metals transported as metal chloride complexes.

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PETROGRAPHY AND GEOCHEMISTRY OF THE ARCHEAN SANUKITOID RIO MARIA GRANODIORITE AND MAFIC ROCKS ASSOCIATED, RIO MARIA GRANITE-*GREENSTONE* TERRANE, AMAZONIAN CRATON

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New occurrences of the Archean Rio Maria Granodiorite (RMGD), situated to the east of Bannach town, immediately to the west of its type-area, in the Rio Maria Granite-Greenstone Terrane (RMGGT), southeastern Amazonian craton, were studied. As observed in other areas, the typical granodiorite dominant in the RMGD includes systematically mafic enclaves. However, in the studied area were also identified bodies of intermediate and mafic rocks (IMR) associated with the RMGD. The Rio Maria Granodiorite is intrusive in the Archean greenstone belts. It is intruded by Archean potassic leucogranites and Paleoproterozoic Musa and Bannach granites. The more abundant rocks of the RMGD have granodioritic to subordinate monzogranitic composition and display medium- to coarse- even-grained textures. These rocks show generally a gray color with greenish shades due to strongly saussuritized plagioclase, and display generally a weak or striking WNW-ESE foliation. Two domains of IMR were identified: In the main domain, located near Bannach town, are exposed mostly quartz diorites and quartz monzodiorites; in the second domain, situated in the center of the area, a minor occurrence of layered rocks was described. The dominant rocks in the larger body are mesocratic, dark-green rocks, with fine-to coarse- even-grained texture. The layered rocks, interpreted as cumulatic rocks, are inequigranular with a remarkable concentration of generally quadratic or short prismatic coarse amphibole crystals, enveloped by leucocratic intercumulus material. The RMGD and IMR rocks show similar textural and mineralogical aspects. The RMGD is formed dominantly by epidote-biotite-hornblende granodiorite with subordinate monzogranite. In the main mafic body epidote-biotite-hornblende quartz diorite varying to quartz monzodiorite is dominant. The layered rocks are enriched in mafic minerals, mostly amphibole, compared to monzodiorites and granodiorites. The RMGD and IMR follow the calc-alkaline series trend in some diagrams. However, they display lower Al_2O_3 and CaO and larger MgO, Cr, and Ni contents compared to calc-alkaline series, approaching geochemically the sanukitoids series. The patterns of rare earth elements of different rocks are similar, with pronounced enrichment in light rare earth elements (LREE) and strong to moderate fractionation of heavy rare earth elements (HREE) (La/Yb_n=11.92 a 44.38). However, the $(La/Yb)_n$ ratio is lower in the quartz diorite and quartz monzodiorite (La/Yb_n=17.20 a 22.81), compared to the RMGD (La/Yb_n=15.52 a 44.38). Compared to the RMGD and IMR, the layered rocks are relatively enriched in HREE (La/Yb_n=11.92 a 14.37), probably in response to amphibole accumulation. Geochemical data show that there is a compositional gap between both the granodiorites and IMR and the layered rocks and mafic enclaves, suggesting distinct processes for the origin of the latter group of rocks. Field aspects and petrographic and geochemical characteristics denote that the granodiorites and IMR are cogenetic rocks. However, geochemical data suggest that the intermediate rocks and the granodiorites are not related by a fractional cristalization process. The wide distribution of granodiorites and relatively local occurrence of IMR do not also favor a comagmatic origin for both rocks. It is concluded that the intermediate rocks derived from similar sources than the granodiorites, but probably result of a higher degree of melting, being both cogenetic, but not comagmatic rocks. The layered rocks are genetically related to the sanukitoid association, but crystal accumulation processes played a fundamental role in their magmatic evolution.

GRANITOID MAGMATISM AND PALEOPROTEROZOIC CRUSTAL EVOLUTION IN THE FENNOSCANDIAN SHIELD – INSIGHTS FROM THE FINNISH SVECOFENNIAN

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A salient fraction of the Fennoscandian shield consists of Paleoproterozoic (Svecofennian) crust that was differentiated from the mantle at ~2.1-1.9 Ga (Lahtinen et al., 2005). In Finland, three distinct crustal segments can be indentified: the Primitive arc complex (PA), the Arc complex of western Finland (AWF), and the Arc complex of southern Finland (ASF). These were accreted to a pre-existing (Archean) nucleus at ~1.91-1.89 Ga (Nironen, 2005; Vaasjoki et al., 2003). Svecofennian orogenic granitoid rocks (1.93-1.91 Ga preorogenic granitoids, 1.89-1.87 Ga synkinematic granitoids, 1.88-1.86 Ga postkinematic granitoids, 1.85-1.80 Ga late orogenic granites, 1.81-1.77 Ga postorogenic plutons; Nironen, 2005; Kurhila et al., 2005) are good monitors of processes related to the amalgamation and subsequent crustal evolution:

(1) The 1.93-1.91 Ga preorogenic granitoids (gneissic tonalites) are found only in the PA. They are characterized by positive ε_{Nd} values (~ +3) and no zircon inheritance beyond 1.95 Ga, implying juvenile basaltic sources in a primitive magmatic arc (Vaasjoki et al., 2003).

(2) The 1.89-1.87 Ga synorogenic synkinematic granitoids (gneissic calc-alkaline granites-granodiorites) are ubiquitous in the AWF and the ASF. In the AWF, they have near-zero ε_{Nd} values and point to mantle-crust differentiation at ~2.1-2.0 Ga (Lahtinen and Huhma, 1997). In the ASF, they have a bimodal distribution of ε_{Nd} values (~0 and +2), which suggests that the ASF consists of two distinct ~EW-striking crustal terranes.

(3) The 1.88-1.86 Ga synorogenic postkinematic granitoids (discordant, high-Fe/Mg, A-type granites and quartz monzonites) are found in the PA and AWF but not in the ASF. They have very uniform ε_{Nd} values (~0) and probably relate to magmatic underplating associated with postkinematic transtensional tectonics and reduced crust-mantle sources. They register a shift in the locus of magmatism to the west and east of the site of initial accretion at 1.91 Ga (Rämö et al., 2001; Elliott, 2003; Nironen, 2005).

(4) The 1.85-1.80 Ga late orogenic granites (leucogranites) are found only in the ASF and are associated with high-T, low-P metamorphism and migmatization. They have varying ε_{Nd} values of -1 to +3 (-7 to -5 in the vicinity of Archean crust) and represent relatively low-T anatectic melts from local crustal sources. They also contain 2.1-2.0 Ga inherited zircons (cf. AWF). The leucogranites may relate to extensional collapse of the ~1.91-1.87 Ga orogen and subsequent collision from the south (Nironen, 2005; Korja and Heikkinen, 2005). They were probably emplaced along local transpressional fault systems (cf. Ehlers et al., 1993).

(5) The 1.81-1.77 Ga postorogenic plutons (very high-K granites and monzonites) are found as small discordant intrusions across the ASF (Eklund et al., 1998). They have ε_{Nd} values between -1 and +2 and they were probably derived from enriched mantle lithosphere in response to thermal perturbations caused by upwelling asthenosphere (e.g., Andersson et al., 2006).

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TRANSPORT RATE OF MAGMATIC EPIDOTE CRYSTALS, DEPTH OF EMPLACEMENT AND ^{40}Ar-^{39}Ar AGE OF GRANITOIDS IN NORTHEASTERN BRAZIL

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Magmatic epidote (mEp)-bearing granitoids are known from five tectonostratigraphic terranes in the Borborema province, northeastern Brazil. They are mainly calc-alkalic to high K calc-alkalic plutons, although some shoshonitic and trondhjemitic ones are also known in the Transversal domain of the Borborema province. The high K calc-alkalic and calc-alkalic plutons were emplaced within the 630-650Ma interval with only few exceptions (e.g. Caldeirão Encantado pluton is 880Ma old). Granitoids which share same petrological/geochemical features with them, but that have been emplaced within the 590-570Ma interval, are usually free from mEp.

All the studied calc-alkalic and high K calc-alkalic granitoids show εNd between -1 and -4 and T_{DM} (630) between 1.1 and 1.4 Ga (source material formed during rifting pre-Cariris Velhos = Grenville orogeny) except for the Curral de Cima mEp-bearing calc-alkalic granitoid (Nd = +2 and T_{DM} (600)= 0.9Ga). The Nd-isotope behavior for the Curral de Cima pluton assures Neoproterozoic juvenile crust formation at this province. Most plutons carry amphibole-rich clots, interpreted as pieces detached from the source. One large layered amphibolite xenolith at the Tavares pluton yielded a T_{DM} (600Ma) age of 1.4Ga, in the range of model ages for most of these plutons.

Laser-probe single crystal incremental heating ^{40}Ar/^{39}Ar analysis of coexisting biotite and hornblende from some of the high K-calc alkalic granitoids reveals large age differences between these two minerals in a same intrusion. Amphibole (two grains) from the Brejinho pluton is 572 ± 2 Ma old, significantly older than biotite (two grains), which are 509.6 ± 1.1 Ma old. In the Tavares pluton, amphibole is 604 ± 7 Ma, while biotite is 538.1 ± 1.6 Ma. These data suggest that these two plutons solidified at relatively great depth (above the closure temperature of biotite and below that of amphibole) and remained at depth for a large period of time.

Hornblende from a mEp-bearing granodiorite at Conceição town, Paraíba, which intruded greenschist facies metasediments, yields a ^{40}Ar/^{39}Ar age of 618.8 ± 2.7 Ma while biotite from the same intrusion is 603.8 ± 1.7 Ma (Dallmeyer et al., 1987). Amphibole (two grains) from a mEp-free calc-alkalic pluton near this town (Maxixe locality), however, yields a ^{40}Ar/^{39}Ar age of 613.3 ± 2.0 Ma while biotite (two grains), a ^{40}Ar/^{39}Ar age of 608.7 ± 1.7Ma, suggesting rapid cooling at ca. 610-615 Ma.

Al-in-hornblende barometry indicates that mEp-bearing granitoids in the Borborema province were emplaced at 5 to 7 Kbar pressure (outside the Transversal Domain of the province, some mEp-bearing plutons have been emplaced at 3 to 4 Kbar).

In high K calc-alkalic and calc-alkalic plutons, mEp was transported upward at rates < 2000m.year^{-1} and show dissolution time <35 years. When in contact with microcline, mEp is less corroded than when it is in contact with/hosted by plagioclase. In the São Rafael pluton (Seridó terrane), mEp was transported upward at ~1200m.year^{-1} with average dissolution time of ~15 years. Within three plutons examined in the Cachoeirinha-Salgueiro terrane, mEp underwent corrosion during 15-35 years and has been transported upward at 450-1300 m.year^{-1}. A similar behavior was observed for the mEp studied from six plutons in the Alto Pajeú terrane indicating variable rates of upward migration (650-1050 m.year^{-1}) and time of dissolution (10-25 years). Finally in the Gloria pluton (Macururé terrane), mEp were transported much faster (~1800m.year^{-1}) with shorter mEp dissolution time (~10 years).

Plutons usually display elongate shape suggesting transport by dikes and, in a few cases, seem to be products of inflation, at lower pressure, of dike-transported magmas.

Reference: Dallmeyer, D.R., Sial, A.N., Long, L.E., and McMurry, J., 1987. New evidence for the polyphase tectonothermal evolution of the Brasiliano orogen, Northeast Brazil. Geological Society of America, Annual Meeting, Phoenix, Arizona, p. 634.

SHRIMP U-Pb AGES FOR GRANITOIDS AND GNEISSES FROM WESTERN BACAJÁ DOMAIN, SOUTHEASTERN AMAZONIAN CRATON, BRAZIL

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The Bacajá Domain is located in southeastern Amazonian Craton and it represents the southern part of the Maroni-Itacaiúnas Province. This domain comprises Paleoproterozoic granitoids, supracrustal rocks, granulites, migmatites and charnockitic rocks with associated Archean gneissic remainders. Previous Rb-Sr and K-Ar ages have indicated that Paleoproterozoic rocks are related to the Transamazonian Cycle (1.9–2.2 Ga). The zircon ages have shown a predominance of Rhyacian granitoids (2.07–2.21 Ga) with local occurrences of Neoarchean (2.44-2.67 Ga) and Siderian (2.31–2.36 Ga) rocks. Furthermore, Nd isotope data have distinguished a juvenile Siderian (ca. 2.3 Ga) and Neoarchean crust sources (ca. 2.6 Ga) for Rhyacian granitoids.

New U-Pb SHRIMP data on zircon and monazite were obtained for granitoids and gneisses from the western part of the Bacajá Domain yielding Archean to Rhyacian ages. An orthogneiss has furnished a zircon age of 2487 Ma showing a strong Paleoproterozoic reworking. Pelitic and psammitic paragneisses have shown Mesoarchean to Siderian sources (3122–2303 Ma) and underwent migmatization processes of amphibolite facies between 2147 and 2109 Ma, a granulite metamorphism at 2070 Ma, and a thermal reactivation (retrograde metamorphism?) at 2057 Ma.

A granitoid of 2338 Ma has enlarged the occurrence of Siderian rocks in the Bacajá Domain, testifying the existence of Siderian crust that may have contributed to formation of Rhyancian granitoids. In addition, new occurrences of Rhyacian granitoids of 2160 Ma, 2147 Ma and 2133 Ma have filled the gap of the previous Rhyacian magmatic event registered in this domain. Some these granitoids have shown Siderian inherited zircon crystals.

These new data show a new geological picture for the Bacajá Domain with Archean gneiss remnants reworked during Transamazonian orogenies. They also confirm the existence of Siderian crust associated to Rhyacian magmatic events. Finally, the monazite has registered the last thermal event that probably marked the end of Transamazonian Cycle in the study area.

THE Fe OXIDE-Cu-Au SOSSEGO DEPOSIT, CARAJÁS MINERAL PROVINCE, BRAZIL: DATING OF THE MINERALIZATION AND FLUID CHARACTERISTICS

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The Fe oxide-Cu-Au Sossego deposit lies on the southeastern Amazonian Craton at the contact zone between the ≈3.0 Ga basement rocks (Pium and Xingu Complexes) and the 2.76 Ga Grão Pará Group, which represents a metavolcano-sedimentary sequence containing the rich iron ores of Carajás. Granitoids, including porphyritic varieties, and mafic rocks are the main rock types in the deposit area. They have been deformed and hydrothermally altered at different degrees, giving rise to magnetitites, actinolitites, mineralized and unmineralized breccias and veins as common products. A Cl-biotite-rich rock, normally with milonitic fabric and additionally composed of quartz, Cl-Na-scapolite, Cl-K-Fe-hastingsite and dravitic tourmaline, is also recognized. Rhyolitic to dacitic and gabbroic dikes record the last igneous manifestations in the area. Sodium and iron metasomatism, propylitization, K-feldspathization and carbonation were the most important alteration processes identified in the deposit. Elongated breccia-like ore bodies occur associated with magnetitites, actinolitites and biotite-rich rocks mostly along the contacts with porphyritic granitoids and seem to have been controlled by faulting. They consist mainly of chalcopyrite, magnetite, actinolite, chlorite, apatite and quartz.

Dating of chalcopyrite samples by the Pb-Pb method (total dissolution and leachates) yielded ages of 2530±25 Ma (MSWD=0.64) and 2608±25 Ma (MSWD=18) for the mineralization. A three-point Sm-Nd isochron of 2578±29 Ma (MSWD=0.37) was also obtained for the Sossego ore. These ages are much younger than the widespread granitogenesis that occurred in Carajás at 2.76-2.74 Ga, but closer to that of the unexpressive granitic event recorded farther north at 2.57-2.56 Ga (Old Salobo and Itacaiunas intrusions). On the other hand, they could be related to the magmatic event which is manifested in the neighboring Fe oxide-Cu-Au 118 deposit as rhyolite and dacite dikes dated at 2654±9 Ma and 2645±9 Ma (U-Pb SHRIMP). Neodymium trajectories of ores show an evolution similar to that of both granitoids and Grão Pará volcanics. In addition, ε_{Nd} values for granitoids and Grão Pará basalts, calculated at 2.61-2.53 Ga, overlap with those of the ore, suggesting that these igneous rocks could have been involved in the genesis of the Cu-enriched ores at Sossego.

A fluid inclusion study, carried out on quartz, scapolite, apatite and calcite from different rocks, allowed to recognize two primary fluids, H_2O-NaCl-$CaCl_2$ (fluid 1) and H_2O-NaCl-$FeCl_2$ (fluid 2). Mixing of these fluids resulted in fluid 3 which has Na, Ca and Fe as major solutes. All three fluids were trapped in quartz and apatite crystals, but fluid 2 was identified in neither scapolite nor calcite crystals. Moreover, fluid 3 is not present in scapolite. Homogenization temperatures vary from 500 to 100°C, though the prevalent interval is 150-300°C. Fluid salinity ranges from 55 to 0.2 wt.% NaCl equiv., although values higher than 45 wt.% NaCl equiv. are uncommon. Very saline fluids are credited to sources other than magmatic. Salinity variation is continuous and suggests a progressive dilution caused most likely by surficial waters. Fluid 1 was responsible for the albitization, scapolitization and Cl-K-Fe-hastingsite production, whereas fluids 2 and 3 accounted for the intense Fe-metasomatism and mineralization, respectively.

HOW WAS HIGH SALINITY ACQUIRED BY BRINES ASSOCIATED WITH PRECAMBRIAN Cu-Au SYSTEMS OF THE CARAJÁS MINERAL PROVINCE (BRAZIL)? EVIDENCE FROM BORON ISOTOPE COMPOSITION OF TOURMALINE

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Fluids interpreted as responsible for the formation of Archean and Paleoproterozoic Cu-Au deposits of the Carajás Mineral Province (CMP), south-eastern portion of the Amazonian Craton, are generally represented by highly saline (up to 50 wt% NaCl eq.) brines, with or without carbonic species (e.g. $CO_2 \pm CH_4$). This study explores the boron isotope signature of tourmaline from the Archean Igarapé Bahia and Salobo IOCG deposits and the Paleoproterozoic intrusion-related Breves Cu-Au-(Mo-W-Bi-Sn) deposit to assess how these brines acquired high salinity and enhanced the potential for metal-chloride complexing and the transport of large amounts of Cu and Au at province scale.

Tourmaline is frequent in both IOCG deposits and shows significant compositional variation in Fe, Mg, Na and Ca within the dravite and schorl compositional fields. At the Igarapé Bahia deposit, $\delta^{11}B$ values of disseminated tourmalines of the ore breccia matrix range from 5.8 ± 1.4‰ up to 26.3±0.4‰, but display major concentrations between 12.6‰ and 26.3‰. The boron isotopic composition of tourmaline from discordant veinlets is also enriched in $\delta^{11}B$, with values varying from 15.7 ± 0.4 ‰ to 18.3 ± 0.4‰. Tourmalines from the Salobo IOCG deposit have $\delta^{11}B$ values that range from 14.5 ± 2.1‰ to 22.9 ± 2.0‰ and show a bimodal distribution with values mostly concentrated at 15‰ and 21‰. Tourmaline from the Breves deposit is particularly seen in veins and belongs to an extremely Fe-Na-rich schorl variety. Compared to the Archean Igarapé Bahia and Salobo IOCG deposits, $\delta^{11}B$ values of vein tourmaline in this deposit are considerably lower and confined within a more restricted range, from –3.6±0.4‰ to 1.8±0.5‰, with most values concentrated between –0.5‰ and 0.5‰. Although marine evaporites have not yet been found or recognized in the CMP, probably due to metamorphic or metassomatic obliteration, the high $\delta^{11}B$ values yielded by most of the Igarapé Bahia (12.6‰ to 26.3‰) and Salobo (14.5‰ to 22.9‰) tourmaline samples provide strong evidence that these rocks were the major source of boron transported by the mineralizing fluids. Marine evaporites are characterized by distinctly higher $\delta^{11}B$ values (18.2‰ to 31.7‰) than non-marine evaporites (-30.1‰ to 7.0‰) and other natural solid boron reservoirs, which show even lower $\delta^{11}B$ values. Whether closely linked to magmatic or non-magmatic fluids, the indication that marine evaporites may occur in the volcano-sedimentary pile of the CMP provides an alternative source for the ubiquitous, very high salinities recorded by fluid inclusions encountered in Cu-Au deposits of the CMP. On the other hand, the lower $\delta^{11}B$ values (–3.6‰ to 1.8‰) of the Breves vein tourmaline could be possibly attained by the precipitation from an immiscible $\delta^{11}B$-enriched saline aqueous magmatic fluid, since these values are within the range reported for $\delta^{11}B$ of granites and magmatic tourmaline. However, mixing of this fluid with boron leached from other isotopically heavy sources cannot be ruled out.

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WORKSHOP 2

A-TYPE GRANITES AND RELATED ROCKS THROUGH TIME (PROJECT IGCP 510)

GEOLOGY, PETROGRAPHY AND GEOCHEMISTRY OF THE ANOROGENIC BANNACH GRANITE, RIO MARIA GRANITE-GREENSTONE TERRANE, PARÁ

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The Bannach Granite is intrusive in Archean rocks of the Rio Maria Granite-Greenstone Terrane, located in the eastern border the Amazonian craton. This Paleoproterozoic, elliptic, anorogenic granitic batholith is composed essentially of monzogranites with alkali feldspar, quartz and plagioclase as essential minerals; hornblende, biotite and sometimes clinopyroxene as main mafic minerals; titanite, allanite, apatite, zircon, ilmenite, and magnetite are primary and chlorite, sericite-muscovite, carbonate ± fluorite secondary accessory minerals. Textural and mineralogical characteristics allow us recognize eight varieties of granite: amphibole-biotite coarse-grained monzogranites with variable modal contents of biotite and amphibole (BAMzG and ABMzG), sometimes clinopyroxene-bearing (CBAMzG); porphyritic biotite monzogranite facies (BPMzG); and coarse-grained (CLMzG), early (EMLMzG) and late (LMLMzG) medium-evengrained, and fine- evengrained (FLMzG) leucomonzogranites. The facies distribution within the batholith is zoned, with the less evolved facies (CBAMzG and BAMzG) situated along the border of the body and the more evolved ones in its central portion (LMLMzG and CLMzG).

The Bannach batholith is subalkaline, metaluminous to peraluminous. K_2O/Na_2O ratios are between 1 and 2 and $FeO_t/(FeO_t + MgO)$ between 0.86 and 0.97. The different facies have similar rare earth elements (REE) patterns, being enriched in light REE, slightly depleted in heavy REE and showing a negative europium anomaly that increases from the less evolved to the more evolved facies. The several facies of the Bannach granite plot in the within-plate granite field, as defined by Pearce et al. (1984) for Phanerozoic granites, and into the field of A-type granite, as defined by Whalen et al. (1987). They also show geochemical affinities with the ferroan granites of Frost et al. (2001) and with the A2-subtype (Eby 1992).

All facies of the Bannach pluton display high magnetic susceptibility (MS), decreasing regularly from the facies carrying amphibole-biotite ± clinopyroxene (CBAMzG and BAMzG) to the leucogranites (EMLMzG, CLMzG, LMLMzG and FLMzG).

The different facies of the Bannach granite evolved through fractional crystallization of ferromagnesian minerals and feldspars. The differentiation trend was in the sense: BAMzG-ABMzG-PBMzG-EMLMzG-CLMzG-FLMzG. The LMLMzG facies is interpreted as a separate intrusion derived from more evolved melts. The existence of a compositional gap between the clinopyroxene-bearing monzogranite and the BAMzG facies suggests that the BAMzG liquid could not derive from the CBAMzG by simple fractional crystallization process. The CBAMzG had a particular magmatic evolution probably involving cumulatic processes.

The field relationships, age, and, petrographic, magnetic, and geochemical characteristics of Bannach Granite are remarkably similar to those of the Jamon, Musa, and Redenção plutons which constitute the Jamon Suite, justifying the attribution of the former to the mentioned suite. The latter is representative of the oxidized A-type anorogenic granites of the Carajás province.

THE SYNTECTONIC ARCHEAN (2.7 Ga) A-TYPE GRANITES FROM THE CARAJÁS METALLOGENETIC PROVINCE, NORTHERN BRAZIL

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The Archean basement of the Carajás Metallogenetic Province comprises foliated metagranitoids, widespread greenschist metabasalts and associated metassedimentary rocks. These country rocks are crosscut by 2.7 Ga granites (eg. Estrela, Igarapé Gelado and Serra do Rabo). These granites have E-W elongated shape conformable with the regional structures. Granites developed on their country rocks a ductile inner aureole under hornblende to pyroxene hornfels conditions. Locally syntectonic garnet porphyroblasts have been formed. Some plutons display concentric primary igneous layering (S_0) having flat-laying dips in the central parts and steep-dips on the periphery. This structural array gives rise to a domic architecture. The igneous layering may passes laterally to E-W solid-state subvertical foliation (S_1) as a response of lateral expanding. Late deformation is marked by intraplutonic mylonite zones (S_{1m}) generally parallel to S_1 foliation. The granites are crosscut by synplutonic quartzo-feldspathic pegmatite and aplite veins. Early veins are foliated and moderate to strongly folded, whereas the latter ones are weakly deformed and unfolded. Structural evolution of these bodies testifies to synmagmatic deformation controlled by regional horizontal shortening. Some pegmatites have granophyric textures and tube-textured amphibole megacrysts indicating crystallization controlled by undercooling and shallow-level emplacement conditions. The plutons are composed mainly of monzogranites, granodiorites, syenogranites, alkali-feldspar granites and minor tonalites. Mafic minerals are ferropargasite, hastingsite, annite and rarely hedenbergite. Some granitoids exhibit sieve-textured amphiboles which were replaced by anhydrous phases as plagioclase, magnetite and quartz. Amphibole corrosion suggests degassing at epizonal levels. Ilmenite, allanite, zircon and apatite are the accessory minerals. Sphene, chlorite, epidote, magnetite and sericite are the secondary phases. These rocks are metaluminous to weakly peraluminous, subalkaline and characterized by high FeO/MgO ratios, high Zr, Y, Nb, Ce and earth-rare elements (except Eu) contents. Their chemical signature is comparable to that of the A-type granites. Igarapé Gelado granites present both A-type and I-type signatures. Sm-Nd data, obtained in some plutons, point to Nd model ages between 2.9 Ga and 3.0 Ga, and ε_{Nd} values near -1. Partial melting of anhydrous metagranitoids from the basement would have originated the A-type Archean granite magmas of the Carajás Metallogenetic Province. Heating of the source rocks could have been enhanced by crustal thickening caused by regional shortening stresses.

IRIRI VOLCANISM AND RIO DOURADO GRANITE: A-TYPE PALEOPROTEROZOIC MAGMATISM IN NORTHEASTERN MATO GROSSO - BRAZIL

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This work presents the results of a combined petrographic, geochemical and U-Pb geochronological study on Paleoproterozoic granites and felsic volcanic rocks in the Central Amazonian Province - Amazonian Craton, more specifically in the Xingú-Iricoumé Block, northeastern Mato Grosso The Iriri volcanic rocks occur as effusive and pyroclastic deposits associated with the Rio Dourado Granite. The lavas show porphyritic textures and felsic compositions (rhyolites). Microcline and quartz occur as large, subhedral phenocrysts in much finer grained groundmass formed by microcline, quartz, albite, biotite and magnetite. The pyroclastic deposits are ignimbrites and volcanic breccias. The ignimbrites are typically pink and show apparent porphyritic texture due to the abundance of crystaloclasts, and the volcanic breccias are grey and contain fragments of different types of rocks. The granites show compositional variation between sieno- and monzogranites. They are pink and medium- to coarse-grained and contain microcline with pertite intergrowths as the main alkaline feldspar. Biotite and rare chlorite occur as mafic minerals. Geochemical analyses carried out on two samples of the Iriri volcanic rocks and four samples of the Rio Dourado granite, reveal that these rocks have high contents of SiO_2 (66,9 -77,5%), Na_2O +K_2O (7.3-9.3), F (400-760ppm), Zr (157-380ppm), Nb (10-28ppm), Ga (19-25ppm), and Y (13 – 161ppm) and low MgO contents (0,21-0,85%). Chondritic normalized REE patterns show enrichment in LREE and depletion of HREE. The Iriri Volcanics show negative Eu anomaly. They are sub-alkaline rocks, ranging from meta- to peraluminous nature, and display trace elements characteristics similar to those of felsic rocks formed in within-plate enviroments. U-Pb zircon data show the age of 1898 ± 43Ma for the Iriri volcanic rocks and 1884 ± 4 Ma for the Rio Dourado Granite. The volcanic rocks investigated here have, therefore, characteristics of anorogenic magmatism related to a continental rift. The A-type Rio Dourado granite represents the final plutonic episode related with this event.

FLUID INCLUSION AND REE CONSTRAINTS ON GENESIS OF THE PITINGA CRYOLITE ORE DEPOSIT HOSTED IN THE A-TYPE MADEIRA GRANITE, NORTHERN AMAZONAS, BRAZIL

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Albite granites characterized by metallic mineralization (Nb, Ta, Sn) were initially named by soviet geologist as "apogranites", a genetic term that implies in a metasomatic hydrothermal fluid overprint of previous granite. The discovery of volcanic and sub-volcanic equivalents of apogranites led many workers to consider these albite granites and their metal concentrations as magmatic. The Pitinga Mine is a world class Sn ore deposit, with Nb, Ta and cryolite as co-products and Zr, ETR, Y, Li and U as possible by-products, all hosted in an albite granite facies of the Madeira Granite. The cryolite presence is an original feature and its textural characteristics, fluid inclusions, REE and Y signature establishes constraints on the controversy over the origin of albite granites and their evolution from magmatic to hydrothermal phases. The Madeira albite granite facies is porphyritic, with quartz and alkaline feldspar phenocrysts corroded by an albitic matrix that contains also orthoclase and/or microcline, mica, amphibole, zircon, cassiterite, cryolite, pyrochlore and columbite. Cryolite occurs in the Core Albite Granite (CAG) subfacies, while fluorite is more common in the Border Albite Granite (BAG) subfacies of the Madeira Granite. The cryolite ore can be disseminated (150Mt, at 4.2% Na_3AlF_6) in the albitic matrix or forming massive bodies with three cryolite types named nucleated, caramel and white (MCD, 10Mt, at 32% Na_3AlF_6) located in the central part of the CAG. The MCD is composed by two major sub-horizontal bodies, the Cryolite Zones A and B, and is partially surrounded by a pegmatoid aureole. Additionally there is a deeply eroded superficial third Cryolite zone (Zone Zero). The predominant fluid inclusions type is aqueous two-phase, mainly primary and pseudo-secondary, both in the cryolite, quartz and fluorite of the MCD. The total homogenization temperatures vary between 100ºC and 300ºC and have a strong vertical trend in the Zone Zero reflecting changes in the fluid physicochemical conditions instead of physical changes after trapping. There are two salinity groups, one around 5% wt. eq. NaCl mainly related to the caramel not twinned cryolite and another one above 10% wt eq. NaCl in the twinned caramel cryolite. The low salinity group occurs usually in the zones where the recrystallization seems to destroy the cryolite twin. There are also one-phased and rare saturated three-phased or multiphased inclusions. REE signatures in fluorite and cryolite are similar to those in the Madeira albite granite. The highest $\sum$REE values are found in magmatic cryolite (677 a 1345 ppm); $\sum$REE is lower in massive cryolite. Average values for the different cryolite types are 10.3 ppm, 6.66 ppm and 8.38 ppm (for nucleated, caramel and white types, respectively). Disseminated fluorite displays higher $\sum$REE values (1708 and 1526ppm) than fluorite in late veins (34.81ppm). Yttrium concentration is higher in disseminated fluorite and in magmatic cryolite. There is depletion in Y and total REE and increase in the LREE/HREE rate from disseminated magmatic cryolite to the late massive cryolite probably due to the HREE extraction from fluids during the successive mineral crystallization. In conclusion it seems that disseminated cryolite ore formation initiated in the magmatic phase from a fluorine-rich magma, continued in the pegmatitic phase and had its apex in the hydrothermal phase. During the latter, hydrothermal saline residual fluid from the albite granite, with no CO_2, formed the MCD and enriched the previous disseminated ore. Concomitantly, the hydrothermal system become convective, mixing with meteoric fluid heated in depth, provoking partial dilutions of the mineralized fluid.

THE PITINGA CRYOLITE DEPOSIT (AMAZONAS, BRAZIL)

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In the Pitinga mining district, the dominant rock type is the volcanic rock of the Iricoumé Group (~1880 My), associated with granites, comprising a caldera complex. The Pitinga Mine is a world class Sn ore deposit (Nb, Ta and cryolite as co-products and Zr, ETR, Y, Li and U as possible by-products) hosted in the albite granite facies of the Madeira granite (~1830My). Cryolite occurs in the core albite granite (CAG) subfacies. The cryolite ore can be disseminated (150Mt, at 4.2% Na_3AlF_6), comprising magmatic and hydrothermal cryolite, or forming massive bodies (MCD, 10Mt, at 32% Na_3AlF_6) in the central part of the CAG, with three cryolite types (nucleated, caramel and white). The MCD is composed by two major sub-horizontal bodies, the Cryolite Zones A and B, and a deeply eroded superficial third Cryolite zone (Zone Zero). The predominant fluid inclusions type is aqueous two-phased, mainly primary and pseudo-secondary, in the cryolite, quartz and fluorite of the MCD, T_h range from 100°C to 300°C with strong vertical trend in the Zone Zero reflecting changes in the fluid physicochemical conditions. There are two salinity groups, one around 5% and another one above 10% wt eq. NaCl. REE signatures in fluorite and cryolite are similar to those in the Madeira albite granite. The highest $\sum$REE values are found in magmatic cryolite (677 a 1345 ppm); $\sum$REE is lower (~8ppm) in massive cryolite. Disseminated fluorite displays higher $\sum$REE values (1708 and 1526ppm) than fluorite in late veins (34.81ppm). Yttrium concentration is higher in disseminated fluorite and in magmatic cryolite. There is depletion in Y and total REE and increase in the LREE/HREE rate from disseminated magmatic cryolite to the late massive cryolite probably due to the HREE extraction from fluids during the successive mineral crystallization. Gagarinite-(Y) associated with lower DCM portions is relatively rich in HREE and contains an exsolved phase with fluocerite composition and structure not yet determined. Only REE with ionic radii larger than Sm were exsolved. The host gagarinite maintained the Y, HREE and Na contents forming a structure with low vacancies and better charge balance. A columbitization process, characterized by Pb loss and U and Nb enrichment, forming successively Pb-U pyrochlore and U-pyrochlore, affected the magmatic U-Pb pyrochlore localized on MDC wall-rock. Due to vacancy increasing in A site pyrochlore becomes unstable causing its transformation to columbite with Sn and U geochemical signature inherited from magmatic pyrochlore. Associated with the columbitization process also occurs Ca, F, Ce and Sn enrichment and Fe loss. Inversions in this evolution in AGN-AGB transition zone are related to decreasing F activity in the hydrothermal fluid. ^{208}Pb-^{207}Pb systematic indicates contributions of mantle, deep crust and shallow crust sources. εNd values are compatible with a mantle system and subordinate participation of continental crust. These results are confirmed by stable isotopic studies. The water isotopic composition ($\delta^{18}O$, δD) equilibrated with mica from pegmatitic phase in most samples is the same of magmatic water; but subordinately occur values of formation water and intracrustal granite melt water. The composition of $\delta^{34}S$ from galena is of mantle type. The values of $\delta^{18}O$ from quartz, albite and K-feldspar indicate mantle source with crustal contamination. Aqueous, saline hydrothermal fluids, residual from the albite granite, ascending from the lower part of the pluton, formed the MCD with late contribution of meteoric fluids within a convective system. F-enrichment in albite granite is attributed to mantle ascending F-Nb-fluids mixed at depth with a Sn-bearing crustal magma.

TIN-MINERALIZED GREISENS AND SODIC EPISYENITES ASSOCIATED WITH ÁGUA BOA GRANITE, PITINGA MINE, AMAZONIAN CRATON

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Tin mineralization in the Pitinga mine is associated with Paleoproterozoic A-type, rapakivi Madeira and Água Boa granites. The primary mineralization occurs as (1) disseminated cassiterite in the magmatic albite granite facies of the Madeira Granite; (2) hydrothermal cassiterite, related with greisens and sodic episyenites in the Água Boa Granite.

The greisens are associated with the hornblende-biotite granite facies of the Água Boa Granite, and are controlled by fractures and occur as lenses or veins interlayered with greisenized granites, located at the apical, border zones of the pluton. The sodic episyenites form lens-shaped bodies, enclosed in coarse-grained biotite granite facies.

Three greisen types have been characterized, based on mineralogical and textural features, and fluid inclusion study: siderophyllite-topaz greisen (Gs1), fluorite-phengite greisen (Gs2) and chlorite-phengite greisen (Gs3). The Gs1 is a medium-grained, black rock, composed essentially of quartz, siderophyllite and topaz, with subordinate sphalerite, pyrite, chalcopyrite, cassiterite, zircon, fluorite, siderite and Nb-bearing anatase. The Gs2 is a massive, dark grayish rock, with quartz, phengite, fluorite, and subordinate amounts of green siderophyllite, chlorite, rutile, cassiterite, zircon, monazite, uraninite, adularia, sphalerite and pyrite. The Gs3 is a massive, dark- to light- grayish green rock, composed of quartz, chlorite and phengite, with minor sphalerite, cassiterite, zircon, fluorite, beryl, topaz, pyrite, chalcopyrite and galena.

The greisens were formed by different processes of interaction among three main fluids: (1) low salinity, F-rich, aqueous-carbonic fluid, with initial temperature between 400°-350°C, present during Gs1 and Gs2 formation; (2) low salinity aqueous fluid, with a temperature around 300°C, which during a progressive salinity increasing process, originates a moderate to high salinity residual fluid, with temperature between 200°-100°C, present during the Gs3 formation; (3) low salinity aqueous fluid, with temperature between 200°-150°C, which interplayed with the others two fluids in differents grades, contributing to the formation of all the hydrothermal rocks. The sodic episyenites are medium, even-grained rocks, composed essentially of albite. These rocks have low modal quartz content and are formed by: (a) albitization of K-feldspar; (b) vug formation by dissolution of magmatic quartz; (c) vug filling by albite, chlorite, phengite, cassiterite ± fluorite ± K-feldspar; and (d) deposition of late quartz ± cassiterite in remaining cavities.

Oxygen isotope compositions have been determined for minerals samples in greisens and episyenites. The $\delta^{18}O$ values of albite (+7.9 to +8.2‰) are similar to that obtained from magmatic quartz and K-feldspar, suggesting that hydrothermal albite could have been originated by high temperature fluids derived from magmatic residual fluids. For the greisens, the $\delta^{18}O$ values of quartz range between +8.4 to +8.6‰. Topaz has $\delta^{18}O$ values in the range of +6.9 to +8.1‰, and siderophyllite has a $\delta^{18}O$ value of +7.0‰. Chlorite and phengite samples show $\delta^{18}O$ values in the range of +5.0 to +6.3‰. The available oxygen isotopic data reflect an isotopic re-equilibration with hydrothermal fluids, minor in the high temperature greisens, and major in the low temperature greisens and later stages assemblages of the sodic episyenites. The lower temperature isotopic signature may be ascribed to meteoric waters, as suggested from fluid inclusion study.

THE BREVES DEPOSIT, CARAJÁS, BRAZIL: A HYBRID Cu ± (Au, Mo, W, Sn, Bi, Co) MINERALIZATION RELATED TO 1.88 GA REDUCED A-TYPE GRANITE AND VOLCANO-SEDIMENTARY COUNTRY ROCKS.

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The Breves Cu ± (Au, Mo, W, Sn, Bi, Co) deposit, located 9 km NE from the Igarapé-Bahia mine, is associated with a hydrothermal system developed over and around a reduced A-type biotite granite of alkaline affinity, similar to the ca. 1.88 Ga granites described in the Carajás region. The country rocks are metasedimentary rocks assigned to the Águas Claras formation, and acid metavolcanic and volcanoclastic rocks. Late porphyritic dykes, with fayalite partially replaced by quartz + magnetite, crosscut the biotite granite and the ore. Two main types of hydrothermal alteration occur in the deposit: potassic and phengitic-chloritic. The ore is related to the phengitic-chloritic zone, which has muscovite, chlorite and tourmaline as diagnostic minerals. Other minerals associated with the mineralized hydrothermal assemblages are fluorite, rutile/anatase, ilmenite, apatite, xenotime and monazite. The main ore minerals are chalcopyrite, Co-rich arsenopyrite, pyrite, molibdenite, pyrrhotite, wolframite, cassiterite and bismuthinite.

The concentration of ore elements, such as Cu, Au and Sn in the biotite granite has been masked by hydrothermal alteration and probable supply of metals from the country rocks. In the specific case of tin, the values obtained in less-altered biotite granite samples are between 5 and 10 ppm, which are in the same range as the existing data from less evolved granites of several tin provinces. Magmatic and secondary biotite always have mean Cl contents higher than F values, which suggests that the Breves deposit is part of a chlorine-rich system, although fluorite is a common mineral in the deposit. Among the ore minerals, arsenopyrite has anomalous composition, characterized by high Co contents (up to 10 wt. %) and association with glaucodot. The same characteristics are observed in löllingite, which has Co contents in the same range as those in arsenopyrite and association with safflorite. Although the main ore of the Breves deposit has REE pattern similar to that of the biotite granite, its high Co, Ni and As contents are not consistent with a granitic source. These elements are probably derived from country rocks not identified in the deposit area. Fluid inclusions and O and H isotopes data indicate a system with mixing of initial hot magmatic fluids with colder and low salinity hydrothermal fluids. $\delta^{34}S$ data on sulfides from different ore types, between 0 and 2 ‰, are consistent with magmatic origin for the sulfur.

According to the obtained data, the Breves deposit has mineralogical and geochemical characteristics similar to those found in porphyry-type, IOCG and Sn-W granite-hosted gold deposits. Otherwise, these data also point to a peculiar type of hybrid reduced Cu ± Au deposit, which resulted from a complex evolution that probably involved the reaction of magma-derived mineralizing fluids and meteoric waters with preexisting mineralized rocks.

THE GEOCHEMISTRY OF THE LATE PALAEOPROTEROZOIC OXIDISED A-TYPE ALKALI-FELDSPAR GRANITES OF THE NORTHERN ARAVALLI CRATON, NW INDIA

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Palaeoproterozoic (1800-1660 Ma) granitoid plutons are widespread in the northern segment of Delhi belt that belongs to the NNE-SSW trending Aravalli mountain range in the northwestern India. Of these, majority of the granitoid rocks of Khetri and Alwar basins are typical A-type within-plate granites. The most unusual feature of the Khetri A-type granitoids is that the plagioclase here is virtually pure albite; the rocks are thus alkali-feldspar granites. The individual plutons show a concentric bimodal distribution of alkali-feldspar granites, comprising a volumetrically dominant microcline-albite granite, which is flanked by a subordinate facies, the albite granite. Besides, exclusive albite granite plutons (e.g. Gothara and Gorir) are also encountered. The microcline-albite granite is either amphibole (hastingsite)-bearing (e.g. Biharipur, Dabla, and Dosi) or biotite (annite)-bearing (e.g. Tehara and Bansiyal), whereas the albite granite is invariably amphibole (actinolite and magnesio-ferrohornblende)-bearing except that of Gorir, which is a clinopyroxene-bearing albite granite. The region also records a period of Na-rich felsic magmatism in the form of albitites, which occur along a 170 km long intracontinental rift zone that passes quite close to the A-type occurrences. Geochemically, the albite granites are characterised by low K_2O (~ 0.3 wt%) and high Na_2O (~ 7.0 wt%) abundances, whereas the microcline-albite granite shows normal concentrations of alkali elements. Inspite of disparity of alkalis in the albite granites, these rocks along with the other granite facies display typical signatures of A-type granites. The process of albitisation has been attributed to the pervasive infiltration of a high Na/(Na+K) fluid during late-crystallisational history of these plutons. For the amphibole-bearing alkali-feldspar granites, the initial ε_{Nd}-values (at 1660 Ma) are scattered between -1.3 and -2.9, and the rocks show early Palaeoproterozoic T_{DM} model ages (2.4-2.1 Ga). In contrast, the biotite-bearing alkali-feldspar granites show relatively low initial ε_{Nd}-values (-4.9 to -6.5; at 1711 Ma) and Archean-early Palaeoproterozoic T_{DM} model ages (2.6-2.4 Ga). The granitoids were emplaced in a near-liquidus state at shallow crustal levels under relatively high temperatures (850-900°C) and relatively oxidising conditions, and derived from a lower crustal protolith. This A-type plutonism, which span a time range of 1711-1660 Ma and its comparison with virtually coeval rift-related granulite metamorphism and exhumation (1725-1621 Ma) in the central part of the Aravalli mountains, suggest a widespread extensional regime during late Palaeoproterozoic in the Aravalli craton. The extension-related event may appear correlatable with a breakup phase of the pre-Rodinia supercontinent Columbia, which is speculated to have fragmented at around 1600 Ma.

NEOPROTEROZOIC ANOROGENIC MAGMATISM IN THE SOUTH OF BAHIA STATE: ITARANTIM NEPHELINE SYENITE BATHOLITH

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In the south part of Bahia State there are an association of alkaline intrusions (stocks and batholiths) aligned NE-SW. This trend is attributed to structural control of intrusion by deep faults, which developed during tectonic episodes between the Paleoproterozoic and the Mesoproterozoic. The Itarantim Nepheline Syenitic Batholith whose area is about 220 km^2 is located in the extreme southern part of the SBAP. It is composed of two main facies, aegirine nepheline syenites to the north and biotite nepheline syenites to the south, with gradational contacts between the two. Around this body there is an aureole of fenites. The magmatic syenites (pyroxene-syenites with nepheline and biotite-nepheline-syenites) show difuse contacts and are disposed along a NE-SW trend. The identified geochemistry evolution allows explaining the diversity of pyroxene-syenites through fractional crystallization. However, the biotite-nepheline-syenites, which evolve to lower SiO_2 contents and expressive by of Na_2O (up to 9.6%) and Al_2O_3 (up to 23.5%) increase reflect, probably, crystallization in an open system which is strong influenced by peralkaline fluids, as attested by the presence of fenites and enrichment of Zr (up to 5,100 ppm), Hf (up to 141 ppm), Th (up to 117 ppm), U (up to 74 ppm), Ta (up to 169 ppm) and Nb (up to 1372) in the dykes. The nepheline syenites from Itarantim have a homogeneous Sr initial $^{87}Sr/^{86}Sr$ of six samples have the same value 0.703. The ε_{Nd} values of the rocks are positive (0.61 to 2.65). In the $^{87}Sr/^{86}Sr$ vs ε_{Nd} diagram, the Itarantim rocks group tightly in the depleted-source sector. Thus it is possible that the magma responsible for rocks crystallization of the batholith has been generated by mantelic partial fusion. On the other hand, the under saturated carter of the syenites, high contents of incompatible elements and absence of an important evidence of crustal contamination, allowed us to believe that the rocks the Itarantim are products direct of fractional crystallization of mantelic source. The T_{DM} ages (1.0-1.1 Ga) associated with Sr values put the batholith rocks at the mantle array displaying an OIB geochemistry signature. The T_{DM} model ages of 1.1 Ga are the same observed for the toleitic magmas emplaced at this area. These data suggest that the Itarantim anorogenic magmatism is controlled by a NE-SW geosuture, and represents the rift segment which corresponds to the West-Congo Craton, in which the alkaline magmatism is expressed by ryolites, syenites and carbonatites.

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MINERAL CHEMISTRY OF FELDSPARS AND LITHIUM AND IRON MICAS OF THE ALBITE GRANITE FACIES OF THE MADEIRA PLUTON, PITINGA, BRAZIL

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The Proterozoic Madeira pluton is intrusive in the 1888 ± 3 Ma old acid volcanic rocks of the Iricoumé Group. Four granitic facies were identified in the Madeira pluton. The early facies is an 1824 ± 2 Ma old, porphyritic, metaluminous amphibole biotite syenogranite with rapakivi texture. The rapakivi facies is followed by an 1822 ± 1 Ma old, equigranular, peraluminous alkali feldspar biotite granite. The two latter facies are an 1818 ± 2 Ma old porphyritic, hypersolvus, alkali feldspar granite, and subsolvus albite granite. The subsolvus Madeira albite granite is a magmatic rock crystallized from F-rich, H_2O-bearing melt enriched in Sn and HFSE. It is composed of a peralkaline, cryolite-bearing core facies (CAbG) and a peraluminous to metaluminous, oxidized, fluorite-bearing border facies (BAbG), the latter generated by autometasomatic processes from the core facies. Electron microprobe analyses indicate that the feldspars of the CAbG have near end-member compositions. The K-feldspar (Or ~98%) is not perthitic and show high contents of Rb_2O (~2%) and Fe_2O_3 (~0.6%), while the albite (Ab ~99%) show anomalously high Fe_2O_3 (~1%) and relatively low Al_2O_3. These compositional characteristics indicate: crystallization temperatures around 500°C (or lower) for the CAbG; a Al_2O_3 depleted character for the CAbG melt. Two types of micas were identified in the CAbG, both showing extremely low K/Rb ratios and high contents of Fe, Zn, and Li. The more abundant is a tetrasilicic Zn-Rb-polylithionite. The other is a dark, tetrasilicic Fe-Li mica with high Zn, F, and Rb contents. This mica is relatively impoverished in Al_2O_3 and has Fe in tetrahedral positions, being tentatively classified as a tetra-ferri-Li mica. The unusual chemical compositions of micas and feldspars, as well as the associated Sn, Nb, Zr, and F mineralization indicate that the CAbG derived from a melt geochemically similar to those forming fractionated, rare metal NYF pegmatites. The high Fe_2O_3 in feldspars and high Fe_2O_3/FeO in the dark mica, besides the presence of magnetite in the CAbG, indicate that this rock crystallized under oxidizing conditions (~NNO).

GEOLOGY, GEOCHEMISTRY, AND Nd ISOTOPE DATA OF THE Sn-BEARING ALBITE GRANITE FACIES OF THE MADEIRA PLUTON, PITINGA, AMAZONIAN CRATON, BRAZIL

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The tin deposits of the Pitinga mine are related to the Paleoproterozoic Madeira and Água Boa granites. Both are intrusive in the 1888 ± 3 Ma old acid volcanic rocks of the Iricoumé Group. Four granitic facies were identified in the Madeira pluton. The early facies is an 1824 ± 2 Ma old, porphyritic, metaluminous amphibole biotite syenogranite with rapakivi texture. This rapakivi facies is followed by an 1822 ± 1 Ma old, equigranular, peraluminous alkali feldspar biotite granite. The two latter facies are an 1818 ± 2 Ma old porphyritic, hypersolvus, alkali feldspar granite and a subsolvus albite granite. Field relationships suggest that the hypersolvus granite is comagmatic with the albite granite, implying that they were emplaced almost simultaneously and both have similar age. The subsolvus Madeira albite granite is a magmatic rock crystallized from F-rich, H_2O-bearing melt enriched in Sn and HFSE. It is composed of a peralkaline, cryolite-bearing core facies (CAbG) and a peraluminous to metaluminous, oxidized, fluorite-bearing border facies (BAbG), the latter generated by autometasomatic processes from the core facies. In the magmatic albite granite, crystallization of quartz started at ~700°C, the quartz–K-feldspar cotectic line was attained at ~650°C; at an even lower temperature, the ternary feldspar solvus was reached and crystallization of albite started. The solidus was strongly depressed, allowing reequilibration of feldspar compositions along the solvus. At the solidus, around 500°C, feldspars approached end-member compositions. Massive cryolite and pegmatitic rocks were derived from residual melts. An albite-rich, fluidal textured rock associated with the CAbG is representative of this residual melt. The CAbG shows high contents of F, Na_2O, Sn, Nb, Zr, U, Th, Zn, Li, and Rb, and low CaO, MgO, TiO_2, P_2O_5, Ba, and Sr. These aspects and the extremely low K/Rb and Sr/Rb ratios are evidence of the evolved character of the liquid that originates the CAbG. The REE are distributed as M-type tetrads, showing that processes similar to those observed in rare metal-bearing, evolved granitic systems, controlled the fractionation mechanisms and the distribution of the REE's in the albite granite. Nd T_{DM} ages indicate Paleoproterozoic protholiths for the two early facies of the Madeira pluton, which show slightly negative εNd values. The CAbG and one sample of the hypersolvus granite show low, positive εNd values. Two hypotheses are envisaged: (1) the albite granite and the hypersolvus granite have a protholith which is distinct from that of the earlier facies of the Madeira pluton, implying an independent origin for the two mentioned group or rocks; (2) both group of rocks derived from a same protholith but the Sm-Nd isotopic system of the albite granite and hypersolvus granite was strongly disturbed. All analyzed samples of the BAbG and an oxidized sample of the hypersolvus granite show strongly negative and scattered εNd values. This suggests that the hydrothermal processes that affected these rocks were able to disturb their Nd isotopic system.

DISTINCTIONS BETWEEN A-TYPE GRANITES AND PETROGENETIC PATHWAYS

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Since the inception of the term A-type by Loiselle and Wones (1979), this class of granitoids has proven to be the most controversial and least understood member of the granitoid alphabet soup. Eby (1990, 1992) suggested that there were a variety of granitoids that fell within the A-type classification and that there were multiple petrogenetic pathways that could lead to rocks that met the largely chemical definition of A-type granitoids. The A_1-type (often referred to as anorogenic) was a distinct group that had characteristics of magma derived from an OIB source and was inferred to be the fractionation product of an OIB-like basalt magma. The A_2-type (often referred to as post-collisional or post-orogenic) represented all A-type granitoids not derived by fractionation of an OIB-like magma. These granitoids were generally emplaced shortly after an orogenic period and may have originated by melting of mantle material with crustal interaction or solely by the melting of crustal material.

The North Nyasa and Chilwa alkaline provinces of Malawi and the White Mountain igneous province of the northeastern US are classic examples of A_1-type magmatic provinces. An extreme range of lithologies is found in all three provinces from carbonatites through a variety of both silica-undersaturated and silica over-saturated silicate rocks to alkali granites. Trace element and isotopic data indicate that an OIB-source is an important component in the magmatic history. The White Mountain province is an instructive example. Two periods of A-type magmatism are recognized in this province, the older from 200 to 160 Ma and the younger confined to a narrow time interval centered around 123 Ma.

The older White Mountain series essentially consists of silica-saturated felsic (syenite to alkali granite) igneous rocks. Mafic rocks are only significant in the Pliny Range. Nepheline-bearing syenites are found at Red Hill and Rattlesnake, indicating that silica-undersaturated magmas were present at the time the silica-saturated sequences were emplaced. Detailed studies of the largest unit in the series, the White Mountain batholith, suggest that all the igneous rock groups (syenites, metaluminous granties, peralkaline granites and rhyolites) can be related through variable interactions of mantle-derived melts with the subcontinental lithosphere.

The younger White Mountain series and the temporally and spatially related Monteregian Hills province of Quebec, Canada, shows the extreme range of lithologies often typical of the A_1-type association. Mafic rocks are significant in these two provinces and basalts and rhyolites are found in several intrusions. Based on trace element and isotopic chemistry, a successful model for the origin of the various lithologies involves various degrees of partial melting of a garnet lherzolite source (depleted mantle based on isotopic characteristics) and subsequent variable interaction of the basaltic magmas with the continental crust.

An example of an A_2-type province is the Jurassic granitoids and associated bi-modal volcanics of southern China. These sequences were emplaced in a rift structure that developed shortly after continent-continent collision. The basaltic magmas are continental tholeiites and the rhyolites and the granites apparently formed by differentiation of the basaltic magmas with some crustal contamination.

It is suggested that A-type granitoids can form via three different petrogenetic pathways. The A_1-types form by differentiation of a basaltic magma, with variable degrees of crustal contamination, derived from an OIB-like source. The A_2-types form either by differentiation of a continental tholeiite, with variable degrees of crustal interaction, or by direct melting of a crustal source that had gone through a previous melting episode. The challenge, in the case of the A_2-types, is determine which of these pathways was followed by a particular granitoid.

OXYGEN FUGACITY IN THE WIBORG BATHOLITH, SOUTHEAST FINLAND: A MÖSSBAUER STUDY OF BIOTITE AND AMPHIBOLE

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Oxygen fugacity (fO_2) is a fundamentally important parameter in determining the crystallization sequence of minerals in magmas. This study investigates the redox conditions of granite phases in the Wiborg batholith of southern Finland and examines the use of Mössbauer spectroscopy to determine Fe^{2+}/Fe^{3+} ratios from in mafic silicate minerals. QUIlF equilibria estimates for the dark wiborgite suggest initial fO_2 values -0.5 ΔFMQ and an average temperature of 806°C. Wiborgite, the main phase of the batholith, shows more variation in fO_2 between 0.4 and 1.1 ΔFMQ and temperatures between 760° and 690°C. Fe^{3+} in amphibole from wiborgite was only recognized in the M2 site and comprised 13.6% of total iron. Previous studies have indicated progressive oxidation with cooling and increased oxygen fugacity in more evolved phases of the Wiborg batholith. Fe^{3+}/Fe(tot) in biotite ranged from 10.8% in Wiborgite to 17.9% in Pyterlite and the biotite from the topaz-bearing granite stock at Kymi had intermediate values and only minor amounts of Fe^{3+} (3.9%) in the Kymi pegamite. Mössbauer studies of biotite and amphibole indicate fO_2 values well below the FMQ buffer, except for the Pyterlite granite phase, which is about 0.2 ΔNNO.

BIMODAL PALEOPROTEROZOIC VOLCANISM IN THE SÃO FÉLIX DO XINGU REGION, SE PARÁ STATE

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In the southeast of the Pará state, in the scope of the Carajás Mineral Province, an efusive and explosive volcanism occurs. It is characterized by coherent lava and pyroclastic flow deposits grouped in the Sobreiro and Iriri formations of the Uatumã Group. Geochemical analyses showed the existence of trachybasalt, basaltic-andesite, trachyandesite, andesite, dacite and trachyte and glassy and crystals mafic tuff in the Sobreiro Formation; and rhyolite, felsic glassy and crystals tuff and massive polimitic breccia in the Iriri Formation. These volcanic rocks overlap the Paleoproterozoic Parauari Granite, and units of the reworked Archean basement (Itacaiúnas Shear Belt).

The Sobreiro Formation flow volcanic rocks are massive, with porphyritic and aphyric textures and black, dark-gray to dark-green colors. In the microscope, they show holocrystalline or hipocrystalline microporphyritic to microglomeroporphyritic texture, with microphenocrystals of plagioclase, clinopyroxene and rare amphibole, immersed in a cryptocrystalline, microlitic or spherulitic groundmass. Aphyric terms, consisting of spherical, fan and bow-tie spherulites, formed by crystal fibres of amphibole, are subordinate. Sericite, chlorite, epidote and carbonates are secondary phases. Spherical to sub-spherical amygdales, related to degasification processes, occur locally. They are filled from the center to the border by chlorite, quartz, epidote, carbonates and locally oxides. Zircon, apatite, and oxide minerals are the main primary accessory minerals. The pyroclastic terms are characterized by poorly selected quartz, plagioclase, clinopyroxene and amphibole crystals and crystal fragments, together with lithic fragments of intermediate rocks, glassy shards, and strongly welded pumices lying in a vitrophyric matrix. These rocks were affected by hidrotermal alteration, with development of epidote, oxide minerals, sericite, and rare carbonates. Locally, they show fractures, filled with quartz, epidote, chlorite and carbonate, the same mineral phases associated with hydrothermal alteration of these rocks.

The Iriri Formation flow volcanic rocks are also massive, with porphyritic and aphyric textures and rose color. Porphyritic varieties exhibit millimetric phenocrystals of quartz, plagioclase, and alkaline feldspar in an afanitic groundmass. At the microscope, it is characterized by a holocrystalline texture and a felsophyric, cryptocrystalline, spherulitic or locally granophyric groundmass. Chlorite, epidote, carbonates and sericite are secondary minerals. Zircon and oxide minerals are the main primary accessory phases. The pyroclastic terms are tuffs and breccias with amphibole and plagioclase, crystals and crystal fragments, as well as lithic fragments of felsic and intermediate composition supported by a vitrophyric groundmass. Massive breccias with centimetric fragments of varied lithologies in a vitrophyric groundmass occur locally. Sericite, carbonates and oxide minerals occur as secondary phases.

Geochemical data and discriminant diagrams show a bimodal group of rocks, formed in a latest stage of subduction event and earliest stage of continental rift. The Sobreiro Formation rocks are of metaluminous composition, high-K to shoshonitic transitional calc-alkaline and geochemical affinity of mature to immature volcanic arc. The Iriri Formation rocks are of metaluminous to peraluminous composition, transitional subalkaline to alkaline and intraplate geochemical affinity.

VOLCANIC ROCKS RELATED TO THE SILICA-SATURATED ALKALINE SERIES OF THE IRICOUMÉ GROUP, PITINGA PROVINCE, CENTRAL AMAZONIA

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The Iricoumé Group is the largest unit in Pitinga Province, central Amazonia, and consists of dominant felsic effusive rocks and shallow intrusions, with expressive crystal ignimbrite and minor ash-fall tuffs and surge deposits. The volcanic sequence is intruded by granitoids of the Mapuera Intrusive Suite with the same ages and geochemical signatures, and by younger Sn-Nb-Ta-mineralized granites of the Madeira Suite. Geochronological data indicate ages about 1.88 Ga to volcanics and co-magmatic Mapuera granitoids. Felsic rocks are predominant. The mafic ones are basalts, which occur as peperitic volcanic breccia. Volcanic rocks show porphyritic texture with 10-25% of phenocrystals in an afanitic to fine-grained faneritic groundmass. The ignimbrites are compositionally similar to effusive rocks and show moderate crystal enrichment with abundant welding and devitrification features. The massive-fall deposits were interpreted as co-ignimbritic tuffs and the surge deposits have well-developed bedding with sets of sandwave bedforms, both with quartz-feldspathic composition. Structural and field relations suggest that caldera collapse controlled the emplacement of volcanic and pyroclastic rocks of the Iricoumé Group in the Pitinga Province. Subsequent reactivation of the tectonic structures allowed the emplacement of the Madeira Suite, in the central portion of this wide structure. The Iricoumé felsic magmatism is predominantly composed of rhyolites and trachydacites with SiO_2 contents in the range from 66 to 74 wt%. They are metaluminous to slightly peraluminous and show geochemical features consistent with alkaline affinity or with A-type rocks. They show Na_2O+K_2O contents in the range 8.11 to 9.83 wt%, FeO_T/ (FeO_T+MgO) ratios varying from 0.80 to 0.99, Ga/Al ratios similar to those of A-type rocks and plot in the field of within-plate or post-collisional granitoids in the (Nb+Y) versus Rb diagram. Nb/Y ratios indicate that they comparable to A2 type rocks. The available data suggest that this magmatism can be related to (i) a shoshonitic series, and the relatively lower Sr contents of acid rocks would be explained by extensive plagioclase low-pressure fractionation, or, alternatively, could represent (ii) a bimodal association where the acid magmas have strong crustal influence. The similarity of Iricoumé magmatism with A2 granitoids and its high LREE/Nb ratios suggest that it is related with mantle sources modified by a previous subduction, probably in a post-collisional setting. Alternatively, it can be interpreted as a within plate bimodal magmatism with a strong participation of crustal melts.

TWO DISTINCT SYN-KINEMATIC A-TYPE GRANITES IN THE GUYANA SHIELD NORTHERN AMAZONIAN CRATON

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Two distinct rock groups showing geochemical affinities with A-type granites have recently been characterized in the south-central portion of the Guyana Shield, north Amazonian Craton, along the Central Guyana Belt, Roraima State, Brazil. They have been included in the Igarapé Branco Gneiss (IBG) and Igarapé Miracelha Gneiss (IMG) units. The IBG and IMG take part of a 1.94 Ga bimodal association of A- and C-type foliated granites and gneisses and foliated norites and gabbronorites, and are the country rocks of the 1.54 Ga old Mucajaí Anorthosite – Mangerite – Rapakivi Granite Association (MANGA).

The IBG corresponds to biotite-hornblende gneisses with allanite, ilmenite>magnetite, apatite and zircon as accessories. The IMG consists of hornblende-biotite gneisses and foliated granites. Titanite and magnetite > ilmenite are the main accessory minerals in the IMG, with subordinate allanite, apatite, and zircon. Mafic enclaves with alkali feldspar crystals "dropped" from the granitic host have been observed in the IMG and IBG, recording coexistence of mafic and felsic magmas. The IBG and IMG were partially recrystallized, with microfabrics recording solid-state deformation under very high temperatures (above 650°C), related to the syn-kinematic emplacement of the granitic bodies.

The IBG and IMG are monzogranitic, subalkaline, metaluminous rocks with SiO_2 ranging from 65.60 to 70.70 wt.% in the IBG and from 67.30 to 74.60 wt.% in the IMG. Alkali contents are high in both groups and K_2O is higher in the IBG. Relative to the IMG the IBG shows higher FeO*/FeO*+MgO ratios (IBG 0.89-0.92; IMG 0.76-0.84). Regarding trace elements both groups show high Ga/Al ratios (IBG 3.27-3.89; IMG 2.38-3.06), high Rb, Ga, Zr, Th, Nb, Y, and REE (except Eu) and low Sr. Zr and Y are higher in the IBG.

The geochemical features of the IBG and IMG (high alkali and HFSE contents as well as high FeO*/MgO and Ga/Al ratios) are typical of subalkaline, metaluminous A-type granites. Nevertheless, the IBG and IMG exhibit some important differences. The IGB displays more distinctive A-type affinities and shows marked similarities with reduced Mesoproterozoic rapakivi granites as reflected by its high FeO*/MgO and higher contents of K_2O, Zr, and Y. In the IMG, the presence of the titanite + magnetite assemblage indicates, on the other hand, relatively high oxygen fugacity conditions in the magma. This granite is, thus, included in the oxidized A-type granite group, recognized in SW North America and south-eastern Amazonian craton. The differences between the IBG and the IMG reflect distinct oxygen fugacity conditions in the magma, suggesting differences in their sources.

The IBG and IMG exhibit T_{DM} model ages in the range of 2.05 Ga to 2.06 Ga, only 100 Ma older than their Pb-Pb zircon ages (~1.94 Ga), and ϵ_{ND} (T) values varying from +2.46 to +1.99. The Nd isotopic data suggest Transamazonian sources with very limited crustal residence for both studied granites.

The 1.94 Ga old IBG and IMG represent an important period of magmatism that had not been characterized in the Amazonian craton so far. They record different oxygen fugacity conditions, probably reflecting partial melting of slightly different juvenile Transamazonian crustal sources. These A-type granites have been syn-kinematically emplaced in a transpressional post-collisional setting.

THE MUCAJAÍ ANORTHOSITE–MANGERITE-RAPAKIVI GRANITE ASSOCIATION, NORTH AMAZONIAN CRATON, BRAZIL

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The 1.54-1.53Ga Mucajaí Anorthosite – Mangerite – rapakivi Granite Association (MANGA) is situated in the south-central portion of the Guyana Shield, northern Amazonian craton. The MANGA comprises rapakivi granites, corresponding to typical pyterlites and wiborgites, fayalite-pyroxene quartz mangerites and syenites and a massive-type anorthosite body forming an asymmetrically zoned igneous complex of approximately 4.800 km^2. The anorthosite body is situated in the south-westernmost portion of the complex. Fayalite- pyroxene quartz mangerite and syenite (FMS) occur in the vicinity of the anorthosites and give way to northeast to the rapakivi granites of the Mucajaí Batholith, which are by far the most abundant rocks in the complex. In the Mucajaí Batholith, hornblende-biotite granites (HBG) are in contact with the FMS and the most evolved biotite granites (BG) occur to northeast. Orthopyroxene, clinopyroxene, (fayalite), and (±hornblende) are the main mafic minerals in the FMS, with apatite, zircon, and ilmenite as accessories. The presence of the fayalite-ilmenite-quartz assemblage records low f_{O2} conditions during crystallization of the FMS. In the HBG and BG, hornblende and biotite are interstitial, late-crystallized phases, indicating low H_2O concentration in the magma. Relicts of clinopyroxene are common in the HBG. The accessory minerals are apatite, zircon, ilmenite>magnetite ± allanite ± fluorite in the HBG, and allanite, fluorite, and ilmenite + magnetite in the BG.

The FMS plot in the alkaline field and the HBG and BG in the subalkaline field of the K_2O+Na_2O vs. SiO_2 diagram. The FMS, HBG, and BG are dominantly metaluminous. On the basis of the major and trace elements behavior, it is suggested that the BG and BHG may be related to each other by fractional crystallization of a common liquid. However, geochemical contrasts indicate that origin of the FMS cannot be related to the same common liquid proposed for the BG and BHG. The FMS, HBG and BG exhibit geochemical characteristics of A-type granites (high alkali and HFSE contents; high Ga/Al) and exceptionally high Fe/Mg ratios typical of reduced rapakivi granites. T_{DM} model ages obtained for the FMS, BHG, and BH are in the range of 2.07-2.01 Ga, around 0.50 Ga older than the crystallization age of the granitoids, and $\varepsilon_{Nd}(T)$ values are between –2.37 and –1.27. The Nd isotopic data suggest Transamazonian juvenile crustal sources for the granitoid rocks of the MANGA. The $\varepsilon_{Nd}(T)$ value of –2.91 obtained for the anorthosite is probably due to crustal contamination.

In the Guyana shield, the most prominent rapakivi granite batholiths, consisting of pyterlites and wiborgites, with ages around 1.55 Ga, are situated along a NW-SE belt that extends from the north-westernmost Guyana shield in Venezuela (Parguaza) to the central Roraima region, in Brazil. The MANGA is situated at the southeastern edge of this belt and constitutes the only example of AMCG association, including massive-type anorthosites, in the Amazonian craton. The enclosing country rocks are post-collisional 1.94 Ga old foliated granitoids and gneisses showing geochemical characteristics of A- and C-type granites. The MANGA was intruded in an anorogenic setting at least 0.4 Ga after the end of the post-collisional magmatism in this portion of the Guyana Shield.

The geological scenario depicted for the MANGA shows notable similarities with the classical areas of the Fennoscandian shield and Laurentia enhancing global correlation of Mesoproterozoic rapakivi granite magmatism.

LATE NEOPROTEROZOIC, HOT AND COLD A-TYPE GRANITES – WESTERN PORTION OF THE SUL-RIOGRANDENSE SHIELD, SOUTHERNMOST BRAZIL: MINERALOGICAL, GEOCHEMICAL AND ISOTOPIC CHARACTERISTICS

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We compile and interpret mineralogical, geochemical and isotopic data for Late Neoproterozoic A-type granitoids that occur in the western part of the Sul-Riograndense Shield. They are post-collisional to the Dom Feliciano collisional orogeny (660-580 Ma), and were previously grouped in a single intrusive suite. However, they belong at least to two magmatic events with distinct ages, of 598-586 Ma and 572-548 Ma, contemporaneous with diverse igneous associations. The alkaline granites have a wide compositional range (64% to 79% SiO_2), and they are associated with minor basic to intermediate rocks and more voluminous rhyolite-trachytic sequences. The chemistry of coeval acid volcanics apparently registers the extreme fractionation common in epizonal magma chambers, making more difficult the comparison with granitoids. All A-type and similar granites have oxidized compositions, belonging to the magnetite series, although the Fe_2O_3/FeO ratios define two different trends during the differentiation (oxidized and reduced). Hot A1-types occur only in the early magmatic event, and are contemporaneous with major alkali-calcic granitoids from the Lavras do Sul intrusive complex (LSIC). They are metaluminous, including syenogranite (598 ± 3 Ma) and perthite granite (586.0 ± 2.8 Ma), in which Fe-hornblende, and minor Fe-barroisite and Fe-biotite is late in the crystallization. These granites have $T_{ZR} \geq 850°C$, and the zircons show low Th/U (0.2-0.3) and $^{208}Pb/^{206}Pb$ (0.1). □Nd values and feldspar Pb common isotopes are consistent with their derivation from the olivine minette magma. In the later event, the granitoids have more diversified composition, but all show low $□_{Nd}$, older T_{DM} and less radiogenic feldspar Pb common isotopes, suggesting a major crustal contribution. Despite the $^{206}Pb/^{238}U$ ages are not conclusive, it is possible to suggest two main periods of igneous activity between 572 and 548 Ma, with typical A2-type granites predating the high-K and highly evolved, calc-alkaline granites. A2-type granites include: 1) high silica, metaluminous biotite monzogranite and syenogranite occurring in large bodies – Jaguari granite (JG - 567 ± 4 Ma) and São Sepé granite complex (SSGC - 557.3 ± 7.2 Ma), and 2) metaluminous to weakly peralkaline syenites, with augite/Fe-hornblende to aegirine-augite/Fe-barroisite, as small subvolcanic bodies associated with a voluminous acid volcanic sequence – Leões ring complex (LRC- 572 ± 3 Ma). While the former are cold A-types with lower T_{ZR} (800-700°C), LRC is moderately hot with T_{ZR} of 830-820°C. In LRC and SSGC, the zircons have higher $^{208}Pb/^{206}Pb$ (0.5) and Th/U (0.4-1.0) ratios respectively, and the $^{208}Pb/^{206}Pb$ (0.1-0.2) ratios are lower in the JG that occurs near the LSIC. The last Neoproterozoic/Paleozoic igneous event includes the highly evolved types - Ramada granitic complex (RGC) associated with some alkaline acid volcanics (548.7 ± 4.6 Ma), and high-K calc-alkaline granites. Zircons from these rocks show high Th/U and Pb inheritance (0.6 - 2.2 Ga). RGC includes metaluminous, cold granites that show some geochemical and mineralogical features similar to A2-types. The composition of coeval basic and intermediate rocks accompanies the variations in granitoids, suggesting the change in mantle sources in parallel to the increasing crustal contribution in the last events.

TRANS-ALKALINE GRANITOIDS FROM THE SÃO JOSÉ DO CAMPESTRE AND ALTO PAJEÚ TERRANES, BORBOREMA PROVINCE, NE BRAZIL, AND THEIR TECTONIC IMPLICATIONS

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Three granitic intrusions have been studied within the Central (Queimadas and Aroeiras Plutons) and North Tectonic (Solânea Pluton) domains of the Borborema Province, NE Brazil, associated to large scale E-W dextral shear zones. They are metaluminous to weakly peraluminous, monzogranite to sienogranite in composition, with hastingsitic amphibole and annite-rich biotite. Diorites are frequently recorded as enclave swarms showing evidence of mixing and mingling with the host granites. They have U-Pb zircon ages very similar: 570 ± 24 Ma (Queimadas); 572 ± 4.8 (Aroeiras) and 572 ± 8 Ma (Solânea).

The granites from the three studied plutons show similar geochemical signatures. They are characterized by high Ba (1030 – 1600 ppm) and Y (> 40 ppm), medium to low Sr (120 ppm – 362 ppm) and medium Rb (120 ppm – 230 ppm) values. A positive correlation is observed between Rb and SiO2 contents within the granites, suggesting no biotite fractionation. The Nb contents range from 18.8ppm to 27 ppm in the granites and from 26 ppm to 44.0 ppm in the diorites. Zr (552 ppm – 364 ppm) and Ba (1900 ppm a 4100 ppm) contents are also higher in the diorites compared to the granites. The diorites have high K_2O (>3.5%) with (K_2O/Na_2O) ratios (> 1.0), high LIL (Rb, Ba, K, and Th) and light rare earth elements contents, which are geochemical signatures of rocks of the shoshonitic association. However, high TiO_2 (> 1.8%), Nb (> 30 ppm) and Zr (> 400 ppm) values, recorded in the diorites, do not allow their classification as shoshonites, they are best classified as alkaline.

The granites REE patterns, normalized to the chondrite values, are characterized by negative Eu anomalies (Eu* = 0.41 – 0.67) and $(Ce/Yb)_N$ ratios ranging from 8 to 16. The REE patterns of the diorites show $(Ce/Yb)_N$ ratios ranging from 3 to 20, and negative Eu anomalies (Eu* = 0,79 a 0,84). The spidergrams patterns of the studied granites are characterized by deep troughs at Nb and small at Sr. The patterns of the diorites show small trough at Ti and Nb and no trough at Sr.

They have Sm-Nd T_{DM} model ages ranging from 2.04 Ga – 2.22 Ga, and epsilon Nd (572 Ma) values ranging from –15.40 to –18.11. The oldest T_{DM} ages are recorded in the Solânea Complex, reflecting a little older source rock. These data suggest a paleoproterozoic component involved in the source of these granitoids. The diorites have little younger T_{DM} model ages (1.89 Ga to 2.17 Ga), compared to the granite country rocks.

The granites were probably generated by melting of biotite- and amphibole- bearing tonalitic gneisses, leaving behind a granulitic residue (Skjerlie & Johnston, 1993). This model can explain the A-type signatures of the studied granites, and also their somewhat high Al_2O_3 contents. The diorites were probably originated by melting, under high temperatures, of enriched lithospheric mantle, metasomatised during paleoproterozoic subduction processes.

The studied granitoids are trans-alkaline ferro-potassic granitic intrusions emplaced during an extensional - transcurrent post-collision event. They may represent the final stage of the lateral escape of the Brasiliano compressive event between the São Francisco - Congo Cratons and initial stage of the extensional collapse of the orogen.

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TOPAZ GRANITES IN A-TYPE GRANITE PLUTONS

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Topaz-bearing high-F low-P granites occur as minor late-stage phases in apical parts of many A-type granite complexes (e.g., some of the Proterozoic rapakivi granite complexes in Brazil and Finland, several Phanerozoic plutons in China) or as separate plutons up to tens of km^2 in area (e.g., the Cretaceous Spitzkoppe plutons in Namibia, some Proterozoic plutons in Rondonia, Brazil). They are typically leucogranites with quartz, microcline and albite as main constituents. Fe-biotite and topaz (± fluorite) occur as minor constituents, and accessory heavy minerals include monazite, bastnäsite, ilmenite, columbite, and, in tin-bearing granites, cassiterite. Miarolitic cavities and pegmatite pockets are common, indicating crystallization from fluid-saturated melts. Greisen and quartz veins with Sn-W-Be-Zn mineralization are associated with many topaz granites ranging in age from Paleoproterozoic to Tertiary.

The magmatic/metasomatic origin of the topaz granites has long been a subject of debate. These granites have commonly been regarded as metasomatic "apogranites", but subsequent studies support mainly magmatic origin. Findings of volcanic-subvolcanic equivalents, i.e., ongonites (Kovalenko et al., 1971) and topaz rhyolites or quartz porphyries (Gongdon and Nash, 1991; Haapala, 1977), petrographic and mineralogical evidence of magmatic origin of topaz and accessory cassiterite (Haapala, 1977), analyses of solidified melt inclusions containing up to 3–7 wt. % F (Webster et al., 2004; Haapala and Thomas, 2000), and experimental petrological studies on F-rich granite melts (Weidener and Martin, 1987; Xiong et al., 2002; Lukkari and Holtz, submitted) have given proof of essentially magmatic origin of the topaz granites. Because the topaz granites crystallized from highly evolved volatile-enriched magmas, subsolidus reactions have commonly markedly affected the granites. Exsolution of alkali feldspar has produced coarse perthite textures and, combined with minor recrystallization, swapped albite rims between K-feldspar grains and water-clear albite rims between plagioclase and K-feldspar grains. Biotite is commonly partly altered to chlorite and white mica. Anorthite component of the primary plagioclase has been converted to minute inclusions of topaz, fluorite and quartz by back-reactions with F-bearing fluids; these probably continued from magmatic to postmagmatic stage. Fluid-rock interaction has locally caused cation exchange reactions (albitization) in feldspars. The effects of these reactions to the composition of the topaz granites have been minor compared to the magmatic evolution.

Topaz granites show generally roughly similar initial Nd and Sr isotope compositions as associated granites in A-type complexes suggesting genetic relation. The topaz granites were either produced by advanced magmatic differentiation from the same magmas as the associated granites, or they represent later partial melting of roughly similar sources. The topaz granites associated with the Hercynian granite plutons (mainly S-type) in Cornwall and Central Europe are in part similar to those of the A-type plutons, but some of them have much higher P_2O_5 contents.

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ORIGIN OF AMCG COMPLEXES: A PETROLOGIC AND ISOTOPIC PERSPECTIVE FROM NORTH AMERICA

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Anorthosite-mangerite-charnockite-(rapakivi-)granite [AMCG] suites represent a diagnostic hallmark of the earth's Mesoproterozoic history, yet a consensus regarding their petrogenesis has evaded investigators for decades. Recently, a number of competing hypotheses regarding their origin have been constructed, from different AMCG complexes worldwide, and from a variety of perspectives. Emphasis has alternately been placed on members of the massif anorthosite suite, or the granitoid clan, and from a chemical and isotopic viewpoint, or from an experimental one. This contribution will summarize many of the salient features of these voluminous complexes, particularly those best represented in North America (Labrador, Adirondacks, Wyoming), and a paradigm will be advanced that addresses their major characteristics. Central to the argument is a recognition that the absolute ages of the granitoid and anorthositic members of the suite are of critical importance.

Combined mapping, petrological, geochemical, isotopic and precise U-Pb geochronological (zircon/baddeleyite) studies within the unmetamorphosed Nain Plutonic Suite (NPS), Labrador, and the Laramie Anorthosite Complex (LAC), Wyoming, have resulted in significant advances in our understanding of the origin of massif anorthosite, related troctolitic and ferrodioritic rocks, and spatially-associated monzonitic-granitic suites. Both complexes are Mesoproterozoic in age and were emplaced across major Paleoproterozoic terrane boundaries that suture older Paleoproterozoic and Archean gneisses. Integrated Nd-Sr-Pb isotopic studies implicate substantial mantle-crust interaction for both anorthosite complexes, resolvable because, relative to Grenville-aged massifs, they were emplaced into significantly older, isotopically-contrasted crust. NPS troctolites represent the least-contaminated magmatic members, though rarely do they represent purely isotopically-unaffected derivatives of a depleted mantle source. However, late diabase dykes, immediately succeeding NPS plutonism, have initial ε_{Nd} values up to +4.2 and imply that isotopically depleted mantle underlay the area at the time. In Labrador, a working model has been established (Emslie et al., 1994) wherein mantle-derived basaltic magmas, ponded and underplated at the base of the crust, initiated lower crustal melting (extracted as 1351-1287 Ma potassic, high Fe/Mg granitoids). The resulting hot, dry, plagioclase (+pyroxene)-rich granulitic residues were readily assimilated in quantity by the basaltic magmas, a feature which helped maintain plagioclase on the basalt liquidus for protracted periods. Large volumes of buoyant anorthositic NPS magmas were emplaced between 1330-1295 Ma, and probably exploited crustal paths preheated by the earlier passage of granitoid magmas.

Most Grenville Province AMCG suites are, in contrast, unsuitable for detailed tracer isotopic investigations aimed at distinguishing sources and contaminants because they intruded relatively juvenile crust lacking significantly differing isotopic compositions. Nonetheless, the Adirondack AMCG suite, whose rocks correspond closely with those of AMCG suites elsewhere in the Grenville Province, Labrador, and Scandinavia, also reveal the same temporal relationships between intrusives. Granitoids are low in silica, mildly alkaline, and enriched in ferrous iron, corresponding to rapakivi-suite rocks as well as to A-type granites (Eby, 1990). Though most units have suffered high-grade Grenvillian metamorphic overprinting, new in situ U-Pb age determinations show that Adirondack granitoids, including charnockite and mangerite, preserve igneous crystallization ages that are on average slightly older than (but overlapping) those from most anorthositic units – a feature consistent with the model of Emslie et al. (1994).

ASSOCIATED A-TYPE SUBALKALINE AND HIGH-K CALC-ALKALINE GRANITES IN THE ITU GRANITE PROVINCE, SE BRAZIL: PETROLOGICAL AND TECTONIC SIGNIFICANCE

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The 590-580 Ma Itu Granite Province (IGP) forms a ~ 60 km large roughly linear belt of granite plutons with minor associated basic rocks extending for some 350 km along the N60E direction in the southern edge of the Apiaí-Guaxupé Terrane (AGT), parallel to the contact with the younger accreted Embu Terrane (Mantiqueira Orogenic System).

Granites showing rapakivi texture (plutons within the Itu and São Francisco batholiths) were given special attention in the literature, but more volumetrically significant are several other compositionally similar subalkaline A-type syenogranites granites where this texture is rare or absent (Atibaia, Capão Bonito; other plutons within Itu and São Francisco) and a distinct suite of monzo- and syenogranites with high-K calc-alkaline signature (Morungaba, Sorocaba, Itupeva pluton from Itu). Volumetrically minor are charnockites (São Francisco Xavier), basic to intermediate rocks (Piracaia Monzodiorite) and evolved granites, which may appear as dikes (topaz granite in São Francisco) or small cupolas next to larger plutons (albite granites from Correas and Itu, bearing Sn and W mineralization).

The IGP was installed in geologic domains that were previously intruded by expressive volumes of 630-600 Ma "syn-orogenic" granites, which formed elongated batholiths of high-K calc-alkaline affinity. The country rocks are high-grade migmatites in the NE domain (Socorro-Guaxupé Nappe, SGN) and medium- to low-grade metamorphic belts in the S-SW (Apiaí and São Roque belts). At least locally a small time gap (~10-15 Ma) seems to have existed between the last "orogenic" granites and the earliest IGP plutons. The emplacement of the latter occurred at shallow-level, implying some previous uplift, and was controlled by subvertical NE-SW strike-slip faulting.

The A-type IGP granites have geochemical features typical of the subalkaline A-type association, such as high HFSE (Nb, Y, Zr) and low Sr abundances, low mg# and moderately fractionated REE patterns with La/Yb(n)= 10-30 and strong negative Eu anomalies. The Sr-Nd isotope data show that the IGP granites have very negative εNd_{590Ma} (-10 to -16) and radiogenic $^{87}Sr/^{86}Sr_{590Ma}$ (0.708-0.718), the least evolved values being observed in plutons intruding the high-grade terranes (SGN). These chemical features point to predominant crustal sources, and magma generation at lower $a(H_2O)$, higher T and lower P as compared to typical crustal melts formed during the orogenic stage. Coeval mantle-derived magmas formed small independent occurrences (the Piracaia Monzodiorite, with a high-K-Ba-Sr chemistry, εNd_{590Ma} = -7 to -10, $^{87}Sr/^{86}Sr_{590Ma}$ = 0.7045-0.7055, indicative of a significant component from the enriched subcontinental lithosphere) and are present in most granite plutons- especially in the high-K calc-alkaline association- as small bodies and mafic microgranular enclaves.

The IGP formation was coeval with younger convergent tectonics between the then recently amalgamated Paranapanema and São Francisco plates and the Mantiqueira Orogenic System, which south of the AGT resulted in the oblique accretion of the Embu Terrane. The shift to shallower depths of granite magma generation and emplacement points to a major reorganization of the continental crust, which was thinned and heated, possibly as a result of the impingement of hot astenosphere at the base of the continental lithosphere.

ORIGIN OF THE RAPAKIVI TEXTURE AND OTHER FEATURES RELATED TO FELSIC-BASIC MAGMA INTERACTION IN THE SALTO PLUTON, ITU GRANITIC PROVINCE, SE BRAZIL: PETROGRAPHIC AND GEOLOGIC EVIDENCES

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The origin of the rapakivi texture is still a matter of considerable debate, and it was shown that it might result from a variety of processes. Interaction between basic and felsic magmas is one such a process, and field evidence show that it may be the cause of the widespread occurrence of the rapakivi texture in the subalkaline A-type syenogranites of the ~580 Ma Salto Pluton (Itu batholith, post-orogenic Itu Granitic Province, SE Brazil).

The Salto Pluton is a small subcircular occurrence (~ 9 km diameter; 40 km^2 minimum area), intruding orthogneisses and high-grade migmatites and partly covered by Permo-Carboniferous sediments. It is composed of inequigranular coarse-grained pink hornblende-biotite syenogranites with low (4-8) color index, locally varying to a "porphyry granite" facies with fine-grained matrix and high proportion of quartz, feldspar and hornblende phenocrysts (T.M. Galembeck; Doctoral Thesis, 1997). Besides the rapakivi mantling, other disequilibrium textures are common in the syenogranites, such as rounded quartz mantled by mafic minerals (biotite and/or hornblende), small fine-grained diorite clots mantled by plagioclase, and antirapakivi mantling. Interaction with coeveal basic magma is evidenced by scarce, small (<5 cm) mafic microgranular enclaves showing igneous textures and inferred to be at varied stages of hybridization. Much more common and larger (up to one meter) are subrounded *felsic* microgranular enclaves often bearing quartz and K-feldspar xenocrysts from the host granite, which are thought to derive from upwells of hot (re-heated?) granite magma that intruded and chilled within the crystallizing coarse-grained granite.

In a similar manner to what is shown in studies of mafic microgranular enclaves elsewhere, mantling textures such as rapakivi and mafic mineral mantling of partly resorbed quartz are features commonly originated when crystals from the crystallizing granite are incorporated into a coexisting basic magma. Field observations in the Salto Pluton show that these mafic enclaves were fragmented into very small pieces, liberating the mantled xenocrysts that were then re-incorporated into the granitic magma. Among them, some key field features are the presence in the coarse-grained granite of round rapakivi feldspar with a thick mantle of green plagioclase in turn surrounded by a thin preserved rim of microgranular diorite and mafic mineral-mantled quartz caught in the proccess of being liberated from a mafic enclave.

Larger mafic microgranular enclaves are typical of the neighbor Itupeva Pluton, which has a different chemistry, transitional between A-type subalkaline and I-type calc-alkaline (T.M. Galembeck, *op. cit.)*. The rapakivi texture and mantled quartz are practically absent from the granite and restricted to xenocrysts within the mafic enclaves. This can be related to lesser fragmentation of the enclaves, reflecting different magma chamber dynamics, and perhaps also responding for some distinct physico-chemical properties of the magma.

COMPOSITIONAL VARIATION IN ZIRCONS OF TIN-SPECIALIZED PALEOPROTEROZOIC A-TYPE GRANITES OF THE AMAZONIAN CRATON: METALOGENETIC IMPLICATIONS

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Hf-rich zircons are common in granitic pegmatite and rare in granites. Trace element composition of igneous zircons, as determined by microprobe and laser-ablation microprobe ICPMS analyses, has been used as a petrogenetic indicator by several researchers. The high chemical stability of zircon, associated with the occurrence in its internal structure of trace elements as Hf, Y, Nb, Th, U, ETR, Ca, and P, may be useful in the identification of the geochemical nature of source rocks, in the characterization of magmatic fractionation and in provenance studies of detrital zircons from sedimentary rocks. Hf-rich zircons in granitic rocks are typically associated with evolved, rare metals (Sn, Nb, Ta) rich-granites. Zircons of topaz and rare-metal-bearing granites display extremely low Zr/Hf ratios that are interpreted as a magmatic signature inherited of evolved granitic melts or as the result of hydrothermal alteration of the host rocks by F-rich fluids.

This study is based essentially on backscattered images of zircon crystals, obtained trough a scanning electron microscopy (SEM), and on semi-quantitative Energy Dispersive Spectrometry (EDS) minor element analyses. The analyzed zircon crystals are of tin-specialized granitoids of distinct tin provinces of the Amazonian craton: the South Pará, Pitinga, and Rondônia tin provinces, situated, respectively, in the eastern, northern- central, and southwestern domains of the craton. Zircon compositions of the Oxidized, A-type, not tin-mineralized Redenção and Bannach granites of the Jamon Suite, southeastern of the Amazonian craton, and the Santa Rosa Granite, of the Xingu region are also presented for comparison.

The zircons of the tin-specialized granites are characteristically enriched in Hf, Y, U, and Th and display low Zr/Hf ratios toward the more evolved facies, suggesting that magmatic differentiation was responsible for this particular feature. On the other side, the common occurrence of anhedral Ca- and Hf-enriched, corroded zircons with patchy internal structure, in several of the specialized granites is indicative of intense hydrothermal alteration in these rocks. On the other hand, compared to the zircons of the tin-specialized granites, those of the not mineralized Redenção and Bannach granites show lower contents of these elements and comparatively high Zr/Hf ratios.

The characteristic geochemical signature, with significant enrichment of Hf, Y, U, Th, and Ca and low Zr/Hf ratios, in zircons of the specialized (Sn, W, Mo, Nb, Ta) granites of the Amazonian craton indicate that zircon composition studies can be a useful guide to evaluate the metallogenetic potential of tin-bearing granites. Moreover, it can also contribute to the identification of detrital zircon grains derived from these rocks. The results here presented demonstrate that a preliminary evaluation of the potential for tin in evolved granites may be based on zircon compositional studies based on EDS semi-quantitative analyses obtained with a SEM, being a important tool for exploration surveys.

GEOLOGICAL AND PETROLOGICAL ASPECTS OF GRENVILLIAN A-TYPE TOPAZ GRANITES OF THE BOM FUTURO TIN-MINE, RONDÔNIA, BRAZIL

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Grenville age granitic rocks at the northern part of the Rondônia state, southwestern margin of the Amazonian craton, have been characterized as rapakivi granites and included in two suites: (1) 1.08-1.07 Ga Santa Clara Intrusive Suite; and (2) 1.00-0.97 Ga Younger Granites of Rondônia Suite. Both suites are composed of several early- and late-stage intrusions emplaced in older metamorphic rocks (1.75-1.50 Ga). The late-stage intrusions are volumetrically minor and comprise two compositional rock associations: (1) metaluminous to peralkaline association; and (2) peraluminous association. The topaz granites of the Bom Futuro mine belong to the peraluminous association of the Younger Granites of Rondônia Suite. At the Bom Futuro mine, the topaz granites occur apparently as subvertical radial dykes and low to medium outward dipping ring dykes, both related to a central plug-like intrusion in the Bom Futuro hill. They are spatially associated with two intrusive/explosive (?) breccia pipes, topaz rhyolite porphyry (similar to ongonite), subvolcanic intermediate rocks, and topaz rock (similar to topazite) dykes, and tin-mineralized pegmatite and quartz veins. They are pink or light gray in color, and show porphyritic texture with quartz and microcline phenocrysts (1.0 to 5.0 mm in length) in a fine-grained groundmass composed mainly of albite, quartz, microcline, topaz, and zinnwaldite. The topaz granites occur also at the adjacent Palanqueta hill, composing the apical part of an epizonal granitic stock, besides biotite granites, and tin-mineralized greisen bodies. The main topaz granite facies are pink to pinkish light gray, and the texture varies from equigranular to porphyritic with or without miarolitic cavities. These facies are composed dominantly by albite (36-49%), microcline (20-29%), quartz (22-36%), zinnwaldite (< 5%), and topaz (< 1%). Geochemically, the Palanqueta topaz granites show higher contents of SiO_2 (74.54-77.37 %), Na_2O (3.86-5.70 %), Rb (334-892 ppm), Ga (40-47 ppm), Nb (42-84 ppm), Ta (22-70 ppm), Sn (2-47 ppm), Hf (3-11 ppm) and U (4-18 ppm), and lower of TiO_2 (0.01-0.06 %), FeO_T (0.16-1.20 %), Mn (0.00-0.02 %), MgO (0.01-0.02 %), CaO (0.09-0.50 %), K_2O (3.54-4.68 %), P_2O_5 (0.01-0.03 %), Ba (2-22 ppm), Sr (2-9 ppm) e Zr (19-83 ppm) than common Ca-poor granites. In comparison with Bom Futuro topaz granites, these are mainly depleted in SiO_2 (71.34-71.97 %) and enriched in Al_2O_3 (16.45-17.27 %), Na_2O (5.47-6.77 %), Rb (960-1280 ppm), Ba (53-406 ppm), Sr (42-75 ppm), and Ta (89-251 ppm). The magmatic differentiation of the Palanqueta topaz granites appears to have taken place within a deeper level magma chamber, with successive magma batches emplaced into the present level of exposure, as well as the Bom Futuro topaz granites and rhyolites. The changes of some major and trace elements and their ratios suggest the following magmatic evolutionary trend for the Palanqueta topaz granites: equigranular granite → porphyritic granite → microgranite → granite porphyry. The most distinct feature is the decrease in REE and Al_2O_3 contents, and La_N/Yb_N and Zr/Hf ratios, as well as the increase in Na_2O/K_2O ratios, compared by the increase in SiO_2 contents. Preliminary data indicate that Bom Futuro topaz granites and rhyolites do not follow this geochemical trend.

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THE ESTRELA Cu-Au DEPOSIT, SERRA DOS CARAJÁS, PARÁ: GEOLOGY AND HYDROTHERMAL ALTERATION

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The Estrela Cu-Au deposit in the Serra dos Carajás region is hosted by altered andesites and rhyolites of the Grão Pará Group, Itacaiunas Supergroup, formed at 2.76 Ga. The deposit is in a 400 m thick sequence of altered andesites composed of biotite, quartz, albite, tourmaline, fluorite, hastingsite, pargasite, Fe-hornblende, and magnetite, cut by Paleoproterozoic porphyritic quartz diorite, albite-orthoclase granite, topaz- albite orthoclase granite and episyenite. These rocks intruded the volcanic sequence after the onset of the mylonitic foliation and prior to the episode of brittle deformation. The mineralization is mostly in quartz veins, disseminated in the host rocks, filling foliation fissures, or forming the matrix of brecciated quartz veins. Main sulfides are chalcopyrite, pyrite, and pyrrhotite, with traces of bornite, molybdenite, and gold. The host rocks of Estrela Cu-Au deposit were affected by early calcic-sodic alteration followed by potassic alteration, accompanied by moderate ferrification and sulfidation, which transformed the igneous protoliths into biotite-rich rocks. The hydrothermally altered calc-alkaline andesites of the Estrela deposit have been dated at 2579±150 Ma with ε_{Nd} (T) of –3.2. The Na:Ca ratio in the fluid probably increased with declining temperatures. This was recorded by succeeding mineral assemblages in andesites that went from hastingsite, Fe-pargasite, albite, biotite, and quartz towards the Ca-poor association of biotite, siderophyllite, albite, tourmaline, and fluorite, to the late alteration assemblage of fluorite, topaz, chlorite, tourmaline, quartz, zinnwaldite, and Li-muscovite. A water-rich, variably saline hydrothermal fluid was characterized by fluid inclusion studies. Association of CO_2-deficient inclusions presenting a wide range of homogenization temperatures and salinities has been described in the literature as typical of fluids holding a strong magmatic (granitic) inheritance. Hotter fluids, responsible for potassic alteration and albitization were oxidizing alkaline and held high K and Cl activities, in addition to high Na:Ca ratios. These fluids turned into acidic and reducing towards the late greisenization stage. During cooling, decreasing of the Na:Ca ratio probably occurred, accompanied by sharp increasing of F activity, as evidenced by the massive presence of fluorite. Rare epidote and calcite attest to the slightly growing Ca activity towards the latest hydrothermal phase. Textural data from Estrela, where the REE minerals are always associated with sulfide veins, and occur as inclusions in biotite and siderophyllyte indicate that crystallization of F-rich biotite, fluorite and metallic phases would be the main mechanisms responsible for the crystallization of REE minerals. The inequivocal relationship of Cu-Au mineralization with the albite-orthoclase granite of Estrela is mainly attested by the perfect coincidence of REE patterns of fluorite, tourmaline, biotite, and albite-orthoclase granite. Presence of silicified shear zones at the andesite contacts, acting as a rigid and impermeable body, played an important role for the channeling of the granite-derived circulating hydrothermal fluids. The vein mineralization was simultaneous with the episyenitization (1875±1.5 Ma, U-Pb, zircon) and quartz diorite 1880±5.1Ma, U-Pb monazite) emplacement, at 1857±98 Ma (Sm-Nd, isochron). The early mineralizing fluids were magmatic in origin, as attested by $\delta^{18}O$ and δD values in quartz veins and fluid inclusions. The decreasing of $\delta^{18}O$ values accompanied by temperature dropping suggests a mixing of the hot fluid with meteoric water. This is in accordance with the $\delta^{18}O$ values of +5.3 to +1.3 ‰ calculated for the mineralizing fluid as indicative of a magmatic origin, with metal precipitation produced by fluid mixing. A magmatic source for sulfur is indicated by the $\delta^{34}S$ of chalcopyrite (+0.1‰ to +3.5‰), pyrite (+0.6‰ to 4.1‰), and molybdenite (+0.9‰). It seems that the presence of some *ingredients,* which lead to the metal concentration are very important: splays of regional-scale shear zones together with reactive basaltic rocks, a granitic intrusion acting as a heat engine and as source of fluids, an impermeable unit to act as a barrier to the magmatic-hydrothermal mineralized fluids, and a high basaltic to felsic host rock ratio.

GRANITOID-RELATED IRON OXIDE-COPPER-GOLD MINERALIZATION, GREATER LUFILIAN ARC, ZAMBIA AND NAMIBIA

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The chemistry of various granitoid plutons, their ages of emplacement and metallogenetic potential was evaluated in the Mesoproterozoic to Neoproterozoic Greater Lufilian Arc of southern Africa. Large mineral deposits of the iron-oxide-copper-gold (IOCG) family are thought to be present in the arc. This paper reviews evidence for such deposits in the region, including the presence of iron-oxide bodies (IOB) and hydrothermal breccias.

The Lufilian Arc is composed of a Mesoproterozoic to Neoproterozoic rift basin that closed during the Pan-African orogeny. Its rocks continue into parts of SE Angola, NW Botswana and the Democratic Republic of Congo. Katangan rocks host the Copperbelt world-class Cu and Co deposits. Anorogenic midalkaline magmatism took place during the various rifting phases. Rocks in the granitoid massifs have a wide petrographic variability; they range from alkali to normal granites, through diorites and granodiorites, and into syenites and carbonatites.

IOCG systems occur in and surrounding granitoid massifs of the arc. Favorable environments for development of such systems are widespread. Massive IOB seem to have formed by host rock replacement and infill. Host rocks include true granite, syenite, carbonatite, quartz 'pods', albitized schist, volcaniclastic units and carbonates. Large hydrothermal IOB are found near the intrusive contacts. Subvolcanic intrusions and apophyses of the main massifs are responsible for most mineralization. Many types of structural styles are known, including breccia pipes and vertical and horizontal tabular breccia bodies. Evidence of close temporal and spatial relationships between the IOB and granitic rocks is abundant. IOB occur as cement in hydrothermal breccias, filling for numerous fracture zones and/or replacement 3-D structures in various rocks. Progressive Fe oxide alteration overprints textures of hydrothermal breccias, granitic and sedimentary rocks; in some places, to a point where the original rock is unidentifiable. Environs of IOB generally display Na and Na-Ca alteration assemblges; part of them carry sulfide mineralization, including pyrite, bornite and chalcopyrite. In western Zambia, large IOB protrude as needles > 100 m above the broad plateau; such structures are unknown in Namibia. Multiphase hydrothermal breccias with strong K-Fe alteration and pyrite development surround IOB. In places, the breccias have an Fe oxide matrix. Round-clast breccias cemented by iron oxides are a common feature in some IOCG systems of the arc. IOCG mineralization is controlled by long-lived crustal fractures that developed during the onset of rifting, and has likely been reactivated as strike-slip and normal faults. Selective replacement in bedded rocks may produce thick, extensive, stratabound IOB; some of these have been misidentified as BIF.

IOCG mineralization of uncertain extent lies below the Witvlei sedimentary-hosted Cu deposit, Namibia. Cu in the latter may have been derived from previous hydrothermal IOCG minera-lization; similar phenomena might have taken place elsewhere. Investigations at the Kombat Cu mine show geological features akin to the IOCG deposit type. Although no direct relationship with intrusive rocks has been established, most ore-grade material is hosted by hydrothermal breccias and stockworks, and primary Cu mineralization occurs near or around large IOB. Some Namibian Neo-Prote-rozoic syenitic and carbonatitic magmas are associated with hydrothermal brecciation, diatremes, massive IOB and Fe oxide-filled veins. Zambian deposits and prospects with IOCG deposit characteristics include: Dunrobin (Au), Nampundwe (pyrite+Cu±Au), Kalengwa (Cu+Ag± Au), Kasumbalesa (Cu±Au), Hippo (Cu±Au), Silver King (Ag), Sable Antelope (Ag±Zn), Luiri Hills, Shimyoka, Kitumba and Kantonga.

Lufilian Arc IOCG prospects and deposits differ from the classic IOCG deposit type model. Country rocks have not been subject to high temperatures and strong metamorphic deformation; they tend to be undeformed. Most original hydrothermal textures are pristine. High temperature gradients due to nearby plutons seem to be the only major alteration source.

ANOROGENIC RING COMPLEX CLUSTERS AND THEIR SIGNIFICANCE IN MINERAL EXPLORATION

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Groups of multiple anorogenic ring complexes may produce plutonic bodies of batholithic dimensions. These have been called Anorogenic Ring Complex Clusters (ARCC). Clusters of complexes have been recognized throughout geological history, are widely spread in various continents, and produce major volumes of economic mineralization. Recent observations in several granitoid bodies of Namibia and Zambia, Africa led to the identification of Anorogenic Ring Complex Clusters as one of the main features of intra-continental plate geology. Recognition of ARCC and their characteristics described herein, as well as further research on specific clusters, may be useful to carry out mineral exploration and understand the development of continental crust.

ARCC form one of the most fertile mineral provinces of the Earth. They are primary sources for a large number and great volume of metals, minerals and rocks, which include: iron, copper, uranium, manganese, rare earths, gold, aluminum, tin, tungsten, feldspar, phosphates, nepheline syenite, as well as porphyritic granitoids and syenites for dimension stone and construction. These complexes of plutonic bodies are the main source of uranium and thorium known on the planet, and constitute strategic resources under the growing world energy crisis.

The Carajás province in Brazil is a well-known ARCC for its rich mineral content. That region has abundant precious metal, copper, uranium, light rare earth, iron and bismuth mineralization. Other known localities are the Oslo Valley, Norway; the Kola Peninsula, Russia; several in Nigeria, Namibia, Zambia and Mali, Africa; the St. Francois Mountains in Missouri, U.S.A.; and various others in Siberia, Australia, Canada and South America.

ARCC granitoids have been forming since early Archean times and up to the present. Many of the youngest ring complexes have not been eroded deep enough to expose their roots and lie under active volcanic fields in intracontinental rift zones.

Main characteristics of ARCC include: A) They form by amalgamation of multiple ring complexes of varying composition and dimensions that may intersect each other. B) Volcanic and plutonic rocks of equivalent compositions coexist. C) Succesive magmatic events of variable composition intruding through continental crust produced numerous opportunities for magma mixing and recycling of crust material. D) The surface expression of ring complex clusters has the shape of an isosceles triangle; approximate dimensions are 220 km x 120 km. E) Precursor and late magmatic events are generally present, and they tend to be less voluminous than the main event. F) Magmas in ARCC tend to be mid-alkaline, but occasionally may vary to alkaline and sub-alkaline. Rock chemistry can even be peralkaline in extreme cases. Significant volumes of carbonatites may also be present. G) Isolated bodies of mafic and ultramafic rocks are generally emplaced during the late stages of the process. H) Total duration of ring complex cluster cycles averages 110 million years.

In some localities, several ARCC cycles occur repeatedly in the same site. Such repeated cycles may be separated in time by periods that range from 1095 to 50 Ma.

ARCC seem to have formed near triple point rift sites, especially under aulacogens or aborted rift arms. Particular mineral deposit zonations have been identified within ARCC.

QUARTZ PODS: AN EXPLORATION GUIDE TO IRON OXIDE-COPPER-GOLD MINERALIZATION IN ANOROGENIC GRANITOID ENVIRONMENTS?

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Quartz pods have been identified throughout most of the Lufilian Arc region of Zambia and Namibia. The term 'quartz pod' (QP) is an informal name coined by the author for massive and/or sugary quartz units of varying dimensions. Most QPs consist of white quartz, but color varies greatly, from milky white to dark grey, smokey tones through to light-pink or yellow tints. Both translucent and milky quartz occur together. Different portions of a single QP may be saccaroidal and/or massive. At some locations, large QPs contain isolated cubic or spherical magnetite and/or hematite inclusions that vary in size from 1.5 to 10 cm. QPs occur in many different types of rocks including limestones, dolostones, granitoids, various schists and gneisses. In places, rare xenoliths of any rock type are included within QPs; shapes of these xenoliths vary greatly.

QPs differ from veins and pegmatitic quartz units, particularly in geometry; outcrops of undeformed bodies are typically round to elliptical, and vary from a few meters to several hundred meters in diameter. Outcrops of some QPs exceed four kilometers, and there is geophysical evidence of even larger ones. They are thought to be roughly cylindrical. A drillhole through a 500-m-diameter QP at Egue farm, NE of Otjiwarongo, Namibia, in the environs of the Otjikoto iron-oxide-copper-gold (IOCG) deposit, intersected only quartz with minor disseminated pyrite along its entire 325-m length. The spatial association with IOCG mineralization systems and intrusive bodies is common. In many locations, QPs host IOCG mineralization; the brittle character of quartz renders them a suitable host for massive iron-oxides and associated sulfides, braided or sub-parallel sheeted veinlet systems and stockworks. Numerous field examples consist of hydrothermal breccias, where quartz is rebrecciated within quartz. They are rarely noted on published geological maps of Zambia and Namibia, and very few are documented in the literature. They have been documented by the author over an extensive area of roughly 2000 km by 300 km, and they probably outcrop in SE Angola, the Katanga province of the Democratic Republic of Congo and NW Botswana. They typically occur in rift environments but their origin is not yet completely understood. In places, the country rock is deformed upward around the QPs, as if they were emplaced forcefully in a fashion similar to that of diapirs.

Many parts of the Lufilian Arc have a four-fold rock association including small bodies of: a) gabbro or diorite; b) red-tinted felsic intrusive rocks; c) massive iron-oxide bodies (magnetite and/or hematite); and d) QPs. Many hypotheses for the genesis of QPs come to mind. They may be: a) a rarely documented type of silica alteration; b) the result of precipitation of silica that has been dissolved elsewhere by hyperalkaline fluids; c) produced from extremely alkaline, HF-rich fluids that dissolved silica from the country rocks replacing it by iron oxides; or d) possible remnants of quartz-only magmatic rocks or 'quartzolites'.

The fact that QPs are spatially related to IOCG mineralized systems is very significant. Confirmation of their genetic association with IOCG systems would provide a major breakthrough in mineral exploration. Comparison of the chemical signature of QPs from mineralized IOCG systems and that of outcropping QPs may help identify a geochemical characteristic that can be used in exploration. In arid regions, circular areas of abundant white quartz float may be detected easily on black-and-white air photographs and other remotely sensed images including ASTER. Finally, improved identification in the field and an increased understanding of their physico-chemical features may aid in the exploration of IOCG mineralization.

THE PETROGENESIS OF A-TYPE GRANITES AND RHYOLITES

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The concept of A-type felsic magmas, introduced close to thirty years ago to describe melts emplaced in an anorogenic context by Marc Loiselle and David R. Wones, was never fully explained by the originators. Owing to the premature death of one of the originators, it was left to others to fill in the blanks. Although some influential petrologists have not seen the need to add A to the genetic alphabet, most petrologists today would agree that A-type granites and rhyolites are sufficiently distinct as a category to merit all the attention that they are getting, for example at this symposium. But HOW do they differ from felsic rocks generated at plate margins marked by crustal convergence? Subduction-related felsic rocks, after all, are widely accepted as products of melting of crustal rocks in response to underplating of the crust by a mantle-derived basic magma. Most masses of subduction-related magmas are known to contain a mixture of I and S components, but batches of "wet" basic magma derived from the mantle wedge can fractionate, once in the crust, to give a nearly 100% I-type signature, and small collision-related plutons are known to have a virtually 100% S-type source. These findings thus beg the question: if A-type felsic rocks are indeed distinct, in which way is their genesis distinct? After all, they also commonly contain a genetic signature that is a mixture of crust and mantle components, although some examples do exist in which either an ultimate origin by melting of crust or by fractionation of a mantle-derived basic magma largely predominates. This is a challenging question that continues to baffle.

The answer to this petrological enigma lies in an appreciation of the key role of tectonic setting in defining petrological processes. The tectonic setting of A-type felsic magmatism is one of distension. Zones of distension in the crust are zones of high heat-flow, and the main mechanism of heat transfer is vertical transport of fluid from the subjacent mantle below the attenuated crust. These days, the concept of regional metasomatism of the mantle in such zones is firmly entrenched, but few have considered the logical extension of the concept to the crust immediately above. Zones of distension are zones of degassing of the mantle, and the fluids are expected to rise efficiently owing to their buoyancy so as to metasomatize the lower and middle crust from below. Open-system behavior is the general theme, and the lower crust becomes fenitized on a regional scale. At the same time, the diapiric uprise of hot mantle induces decompression-induced melting. Two phenomena can occur in parallel fashion: 1) the basic magma can fractionate to give an A-type product, and 2) the metasomatized crust can melt to give an A-type product. Mixtures of the two A-type products can be expected where mingling is possible.

Unlike the case in subduction- and collision-related environments, melting in zones of distension FOLLOWS a metasomatic transformation of the deep crust. The rare-earth and high-field-strength elements are added to the lower crust as a result of these modifications. Experiments in fenitization show that where it is intense, focused alkali metasomatism can lead to a Ne-normative crust, which could melt to give an anatectic phonolitic melt. Where the fluid emanations bring in CO_2, carbonate-bearing products can be expected. The hypothesis thus can account for the juxtaposition of SiO_2-oversaturated, saturated, and undersaturated magmas, and even of carbothermal derivatives. During most of the Archean, ensialic zones of distension were probably not areas of focused alkali metasomatism of the lower crust.

A-TYPE ROCKS AND THEIR RELATION WITH THE SILICA-SATURATED ALKALINE SERIES

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Basic and intermediate rocks related to the silica-saturated alkaline series are identified in the TAS (SiO_2 versus Na_2O+K_2O) diagram. For acid rocks, however, the distinction is more difficult since alkali elements can behave as compatible or incompatible elements during differentiation. Acid rocks of alkaline affinity have been characterized by a set of features such as: Na_2O+K_2O contents higher than 9 wt%, $FeO_T/(FeO_T+MgO)$ greater than 0.9, high Ga/Al ratios (10^4*Ga/Al > 2.6), and high HFS element contents. Alkaline acid rocks are better characterized by their genetic relationship with less differentiated alkaline rocks or with peralkaline rocks, if that can be demonstrated. When basic and intermediate counterparts are lacking, the geochemical criteria are applied and the acid rocks can be identified as A-type rocks. From this point-of-view, four distinct groups of A-type acid rocks could be identified: (i) those related to the sodic silica-saturated alkaline series, (ii) to the potassic silica-saturated alkaline series, (iii) to the ultrapotassic ($K_2O/Na_2O > 2$) silica-saturated alkaline series, and, (iv) alkaline-like rocks produced by crustal melting. The sodic group (i) is probably related to the bimodal alkaline magmatism where syenitic or trachytic rocks are generally present. It is dominated by metaluminous rocks, but peralkaline types are particularly important in volcanic associations, where comendiites are more abundant in post-collisional settings and pantellerites in anorogenic ones. Intermediate and acid rocks of this group show K_2O/ Na_2O ratios close to 1. (ii) Acid rocks belonging to shoshonitic or potassic series are typically associated to latitic or monzonitic rocks and show characteristic Sr and Ba enrichment. Their Ga/Al ratios can be higher than 2.6, like A-type rocks, however, they do not show some of the typical features of other A-type magmas: they have lower alkali and HFSE contents. For this reason, acid rocks of shoshonitic affinity should probably be excluded from A-type rocks. (iii) Acid rocks related to the silica-saturated alkaline series are frequently genetically associated to syenitic or trachytic ultrapotassic ($K_2O/Na_2O > 2$) rocks and show typical features of A-type magmas, as the very high Na_2O+K_2O contents. Ultrapotassic acid magmas are generally products of fractional crystallization in mantle-derived mafic magmas. (iv) A-type granites particularly those of Paleoproterozoic age, are sometimes assumed to be produced by partial melting of mafic or granulitic crust. Rapakivi granites are included in this group by several authors. A-type magmatism can be generated mainly in post-collisional or anorogenic settings and their geochemical discrimination has been based on the relative proportions of Nb, Y, Zr, Ta, Hf, and other HFS elements. As far as the geotectonic setting does reflect different mantle sources for the primary A-type magmas the geochemical criteria can be useful.

GRAVIMETRIC, RADIOMETRIC, AND MAGNETIC SUSCEPTIBILITY STUDY OF THE PALEOPROTEROZOIC REDENÇÃO AND BANNACH PLUTONS: IMPLICATIONS FOR ARCHITECTURE AND ZONING OF A-TYPE GRANITES

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The Redenção and Bannach granites are part of the 1.88 Ga, anorogenic, A-type Jamon suite. These plutons and associated dikes, are intrusive in 2.97 – 2.86 Ga-old Archean granitoids of the Rio Maria Granito-Greenstone Terrane in the eastern Amazonian craton (northern Brazil). Petrographic and geochemical aspects associated with magnetic susceptibility and gamma-ray spectrometry data showed that the Redenção and the northern part of Bannach plutons are normally zoned. They were formed by two magmatic pulses: (1) a first magma pulse was fractionated in situ after emplacement at shallow crustal level generating a series of coarse, even-grained monzogranites with variable modal proportions of biotite and hornblende; (2) a second, slightly younger magma pulse, located to the center of the plutons, was composed of a more evolved liquid from which even-grained leucogranites derived. Gravity survey indicates that the Redenção and Bannach plutons are sheeted-like composite laccolithic intrusions, ~6 km and ~2 km thick, respectively, emplaced at shallow crustal level. These plutons follow the general power law for laccolith dimension and are similar in this respect to classical rapakivi granite plutons. Gravity data suggest that the growth of the northern part of the Bannach pluton results of the amalgamation of smaller sheeted-like plutons that intruded in sequence from northwest to southeast. The Jamon suite plutons were emplaced in an extensional tectonic setting and the stress was oriented approximately along NNE-SSW to ENE-WSW, as indicated by the occurrence of diabase and granite porphyry dyke swarms, orientated WNW-ESE to NNW-SSE and coeval with the Jamon suite. The 1.88 Ga A-type granite plutons and stocks of Carajás are disposed along a belt that follows the general trend defined by the dikes. The inferred tabular geometry of the studied plutons and the high contrast of viscosity between the granites and their Archean country rocks can be explained by magma transport via dikes.

MAGMA MIXING TEXTURES IN HYBRID ROCKS OF THE SANTO ANTÔNIO INTRUSIVE SUITE, RONDÔNIA, BRAZIL

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It is recognised that A-type granites occur typically in bimodal magmatic associations, and the acting of mingling and mixing processes involving silicic and mafic magmas are relatively common during the evolution and emplacement of the magmas. The 1.4 Ga Santo Antônio Intrusive Suite (SAIS) is an example of bimodal A-type granitic association in the SW margin of the Amazonian craton. The SAIS consists mainly of homogeneous granites, i. e., coarse-grained, seriate to locally porphyritic biotite granite with sparse rapakivi and antirapakivi textures, and medium grained equigranular biotite granite. Mafic rocks are present as synplutonic diabase dykes (Fe-rich tholeiitic magma) and quartz monzodioritic magmatic mafic enclaves. Hybridization between silicic and mafic magmas generated heterogeneous hybrid rocks. At the current level of erosion, hybrid rocks of the SAIS occur as small intrusions and dykes cutting the biotite granites. These rocks are highly variable in textures and modes, and are grouped in three textural varieties: 1) porphyritic I, showing granitic to quartz monzonitic in composition; 2) breccia, showing granitic to quartz monzodioritic in composition, and 3) porphyritic II, showing granitic in composition. The porphyritic I type is characterized by abundant rounded plagioclase megacrysts, and sparse magmatic mafic enclaves, quartz and K-feldspar megacrysts and inclusions of quartz-feldspatic rocks. The breccia-type contains large amounts of inclusions of granitoid rocks and quartz and feldspars megacrysts (xenocrysts). The porphyritic II type is a relatively homogeneous medium grained granitoid. Geochemical data (linear trends in variation diagrams) provide much of the evidence for hybridization in the SAIS, but fundamental to such interpretations is the recognition of textural relations compatible with magma mixing. The textures described in the hybrid rocks of the SAIS and interpreted as product of magma mixing, are: 1) boxy cellular plagioclase with patchy zoning of relatively calcic to more sodic compositions and abundant quartz and hornblende inclusions; the plagioclase occur as rounded megacrysts (up to 30 mm) and mantles around K-feldspar xenocrysts; 2) hornblende-mantled quartz grains and quartz aggregates; 3) granular mafic clots (c. 2 to 4 mm long) of hornblende, with minor biotite, zircon and opaque minerals; some of them contain pyroxene nuclei; 4) rapakivi and antirapakivi textures; 5) acicular apatite (quench texture) in magmatic mafic enclaves and mafic clots; 6) rare hornblende-mantled grains of magnetite-ilmenite intergrowths, and 7) rare sphene ocellar texture. It is proposed here that the interaction of felsic and mafic magmas for the generation of the hybrid magmas has occurred at moderate to deep crustal levels. The injection of the hybrid magmas took place after the emplacement and crystallization of the main granitic magmas of the SAIS and the opening of the required channelways and fractures.

A-TYPE GRANITE-CHARNOCKITE SUITE IN MANNEFALLKNAUSANE, WESTERN DRONNING MAUD LAND, ANTARCTICA: A PRELIMINARY ASSESSMENT

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The bedrock in western Dronning Maud Land, Antarctica is characterized by Precambrian crystalline basement and Jurassic CFB-type volcanic rocks related to the onset of Gondwana breakup (Luttinen et al., 1998; Vuori and Luttinen, 2003). The crystalline basement is composed of the Archean Grunehogna craton in the north and the Mesoproterozoic Maud mobile belt in the south (Groenewald et al., 1995). Approximately 100 km south of the Archean-Proterozoic transition, the Mannefallknausane mountain district (~ 74.5°S, 15°W) comprises half a dozen nunataks dominated by Precambrian granitoid rocks and rare paragneisses. Three principal granitoid types can be identified. A white, garnet-bearing K-feldspar-megacrystic biotite granite is dominant in the central parts of the area. The megacrysts often define a clear fabric and aplite dikes are locally abundant. The white granite cuts a garnet-cordierite gneiss in southern Mannefallknausane. The eastern part of the area is occupied by a red biotite-hornblende±clinopyroxene granite with plagioclase-mantled K-feldspar-megacrysts (rapakivi texture). The contact between the white and red granites is exposed in one locality but does not resolve the order of emplacement. The westernmost nunataks of Mannefallknausane are dominated by a dark green porphyritic charnockite with orthopyroxene and hornblende as the main mafic minerals. The charnockite includes up to 20 cm long K-feldspar megacrysts. The contact between the charnockite and the white and red granites has not been found. A U-Pb age of ~1070 Ga has been measured for the charnockite (Weber et al., 1987). K-Ar ages of ~720 Ma to 970 Ma (Jacobs, 1991) may register a later deformation event.

The granites and the charnockite fall in the field of monzogranite in the QAP diagram. Geochemically, they are rather similar to each other and show an overall A-type granite signature. They are potassic (4.2-7.7 wt.% K_2O), metaluminous to marginally peraluminous (A/CNK values between 0.91 and 1.14) and, in the Frost et al. (2001) classification, classify as ferroan [FeO*/(FeO*+MgO) 0.82-0.92] and alkali-calcic/calc-alkalic. In these respects they are similar to the locus classicus Finnish rapakivi granites. The white granites have higher silica values (mean 72 wt.% SiO_2) than the red granites and the charnockites (mean 69 wt.% SiO_2), whereas their mean Sr and Zr values (110 ppm, 130 ppm) are lower than those of the red granites (140 ppm, 230 ppm) and charnockites (160 ppm, 270 ppm). One of the charnockites from Mannefallknausane has an initial ε_{Nd} value of +1.4 and a depleted mantle model age of 1491 Ma, thus registering a Mesoproterozoic source. In early Rodinia, the Mannefallknausane granitoid suite has a close counterpart in the Mesoproterozoic granite-charnockite intrusives of southeastern Africa (cf. Kerr and Milne, 1994).

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THE PRE-CARIRIS VELHOS A-TYPE GRANITES IN BASEMENT OF THE BORBOREMA PROVINCE, NORTHEAST BRAZIL

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The recent recognition of Paleo to Mesoproterozoic anorogenic magmatic events in basement inliers present into the Cariris Velhos and Brasiliano belts of the Borborema Province, has better allow unravel the tectonic evolution of the Province in the context of reconstruction of the Late Proterozoic supercontinents. Three extensional events associated to typical intra-plate magmatism are, to the moment, identified in the 2.0 and 1.0 Ga interval, in which characteristic A-type granites have played an important role. The oldest one, the Serra da Formiga event, marks the early vestige of destabilization of an Archean-Paleoproterozoic plate, which is well documented by 1.96 to 1.79 Ga volcano-sedimentary rift sequences and bi-modal plutonic suite of the Rio Grande do Norte Subprovince (RNSP). The felsic branch of this suite is formed by granitoid orthogneisses whose composition varies from quartz monzodiorites to syenogranites, and shows characteristics of a potassic calc-alkaline and slightly alkaline series. The geochemical distribution of trace elements and REE is consistent with the patterns generally exhibited by rapakivi and post-collisional granites. Afterward a more expressive anorogenic episode (Orós and Passira events) would occur during the Statherian, especially in two distinct areas of the Province. In the first one, in westernmost region of the RNSP, the Orós-Jaguaribe belt comprehends a rift-type volcano-sedimentary sequence, which includes mafic and felsic volcanic rocks and pyroclastics and a contemporaneous orthogneissic granitic suite. The granitoid composition ranges from tonalitic, quartz dioritic to syenogranitic, forming a metaluminous subalkaline and alkaline series. The REE and trace elements patterns are compatible with those of the A-type granites of extensional continental settings. U-Pb in zircon dates constrains the age of 1,673 Ma for emplacement of these granitoids. In other domains, the Alto Moxotó (AMT) and Rio Capibaribe (RCT) terranes of the Transversal Subprovince (TSP), massif gabbro-anorthosite complexes predominate, with associated granites, in which Fe-Ti mineralizations are common. In the Passira type-area, the mafic-anorthositic pulse is cut by late granitoids, which vary from quartz monzonites, monzogranites, syenogranites, alkali-fedspar granites to aegyrine alkali-feldspar granites. Dates using U-Pb in zircon and monazite systematics indicate ages of 1,718 Ma (anorthosites) and 1.58 to 1.68 Ga (granites). The last anorogenic event is restricted to the Serra de Taquaritinga A-type granite occurring in the RCT. This granite cut the Paleoproterozoic basement and a Late Orosirian mafic pulse, showing a deformed porphyritic texture and a composition confined to the monzo and syenogranitic fields, and compositional patterns of A-type granitoids. The age constrained for crustal emplacement was defined by one U-Pb concordia in zircon of 1,521 Ma. This picture, confirming a relative stability before the opening of the 1.0 to 0.6 Ga basins and the subsequent orogenic history of the Borborema Province, is in accordance with the worldwide sequential cycle admitted for Late Proterozoic Rodinia and Gondwana supercontinent generation.

THE ARCHEAN SYNTECTONIC SERRA DO RABO GRANITE: PETROGENESIS AND EMPLACEMENT MECHANISM

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The Archean tectono-thermal Carajás Metallogenetic Province (northern Brazil) has been considered one of the most important mineral provinces in the world. The Serra do Rabo Granite (SRG, *ca.* 2743 Ma) crops out near the eastern termination of the Carajás fault as two granite stocks, elongated approximately in an E–W direction, concordant with the regional structures, and that crosscuts supracrustal rocks.

The SRG also has relatively high SiO_2, K_2O, and Na_2O contents; high FeO*/(FeO*CMgO) ratios; high Zr, Ba, Nb, and Ga; and very high rare-earth element contents. The chemical signature is moderately alkaline and metaluminous, comparable to that of the A-type, A2, and ALK-3 granites. The low modal content of oxide minerals and the predominance of ilmenite as the primary oxide are reflected in the low-magnetic susceptibility (MS) values of these rocks. On the basis of mineral compositions one can estimate that the crystallization of the SRG occurred under relatively high temperatures and low-oxygen fugacity. Mineral chemistry and MS parameters permit to compare these rocks to those of the subalkaline, monzonite ferro-potassic and ilmenite-series. The origin of the SRG magmas may be related to the partial melting of crustal sources, such as previously metamorphosed calc-alkaline granites.

Granophyric textures and sieve-textured amphibole of some rocks suggest loss of aqueous fluids during fast ascending to shallow levels. Degassing would have induced undercooling conditions during crystallization. The SRG stocks raised and emplaced during weak horizontal shortening, which has imposed progressive deformation under decreasing temperature regime. This is translated by the decreasing of TiO_2 contents and FeO/(FeO+MgO) ratios of amphibole neoblasts from mylonite granites. Increasing of Al_2O_3 in amphibole neoblasts seems to be related to the increasing of deviatory stress during magma crystallization.

The coexistence of sieve-textured amphiboles and quartzofeldspathic granophyric texture suggest crystallization under low-pressure (~2.5 kbar) conditions in which degassing would be favored. The occurrence of magnetite in the sieve array seems to indicate increasing oxygen fugacity during the late stage of the SRG crystallization. It is consistent with the substitution of ilmenite edges to sphene and also with the sphene-albite-bearing symplectites between amphibole and feldspars.

The SRG were crystallized from magmas of relatively high temperatures and low viscosities so that shallow-levels of emplacement were reached. Emplacement occurred during a rather weak horizontal flattening *ca.* 2748 Ma ago. Ascent magma via fractures could permit the fast movement of magma upwards so that phases as amphibole would not be able to remain stable in the system. The final emplacement through ballooning in shallow levels would be responsible for heating and ductile aureole flattening of the brittle metavolcano-sedimentary rocks previously metamorphosed under greenschist facies conditions.

Further studies must be done in order to determine possible connections between fluids of Archean granites and mineralizations in some deposits from Carajás Metallogenetic Province.

PEDRA DO GAVIÃO MASSIF: RECORD OF THE 1.23 Ga A-TYPE MAGMATISM IN THE SOUTHERN GUIANA SHIELD

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The Pedra do Gavião massif is located near to Moura district (State of Amazonas, Brazil). In this region occur gneissic and granitic rocks inserted in the geological context of Jauaperi Complex, northern Ventuari-Tapajós Province (1.95–1.80 Ga). The Pedra do Gavião massif is a semi-circular stock represented by pinkish and medium-grained rapakivi biotite syenogranite with several gneiss and amphibolite xenoliths. This massif presents high-K subalkaline, metaluminous and within-plate A-type granite geochemical features, enriched in Ba, Rb, Zr, Y, Ga and high Ga/Al ration. The rare-earth element (REE) composition indicates high enrichment from REE light to REE heavy, with $(La/Yb)_N$ ration between 8.73 and 13.92, contrasting with strong negative Eu anomaly, with $(Eu/Eu^*)_N = 0.22–0.57$. The five zircon crystals from Pedra do Gavião massif were dated by U-Pb ID-TIMS method and yielded an age of 1231±4.7 Ma. This age, interpreted as crystallization time, suggest that the southern Guiana Shield was submitted to an anorogenic magmatism episode, which has not been recorded before. Cratonic magmatism events are represented in the southwestern portion of Amazonian craton by granitic plutons with age 1.3 and 1.0 Ga comparable to the magmatism occurred in Grenville orogeny (1.3 to 1.0 Ga). The record of the Pedra do Gavião rapakivi magamtism offers perspectives to reinforce the temporal correlation of anorogenic magmatism between Laurentia Baltican and Amazonian cratons during the Mesoproterozoic.

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FLUID INCLUSION AND STABLE ISOTOPE EVIDENCE ON METALLOGENESIS OF SANTA BÁRBARA GRANITIC MASSIF, RONDÔNIA TIN PROVINCE, BRAZIL

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The Santa Bárbara granitic massif is part of the Younger Granites of Rondônia (998-974 Ma), composed of granitic rocks with geochemical characteristics of within-plate A-type rapakivi granites. It comprises three subsolvus units, emplaced into medium to high-grade metamorphic rocks (1.75 and 1.50 Ga). The latest unit, called Santa Bárbara facies association, hosts tin mineralization and is composed by two albite-microcline granite facies, with transitional contacts: a pink-medium grained pyterlite, and an even-grained to porphyritic pink-whitish to white fine-grained granite restricted to the granite cupola system, both described as peraluminous in character. Zinnwaldite is the dominant mafic mineral, while fluorite, topaz, zircon, thorite, cerianite, columbite, La-Nd-Y oxides and cassiterite are the accessory mineral phases. The tin mineralization covers a 500 m by 150 m zone, and is mainly expressed by horizontal to subhorizontal lens-shaped topaz-zinnwaldite-quartz greisens (up to 40 m thick). The hydrothermal alteration, which affected the granites, can be divided into: 1) pervasive alteration style which is represented by the lens-shaped bodies of greisen (0.5% SnO_2) (greisenization I), besides greisenized granite and salmon albitized granite (sodic feldspathization); 2) pervasive fissural alteration style, well exemplified by greisenization II, silicification I, muscovitization, silicification II and argillization, which encompass morpho-structural bodies, such as: cassiterite-bearing topaz-zinnwaldite-quartz greisen stockwork, and cassiterite-quartz veins, muscovite veins, barren-quartz veins and argillic stockwork. The pervasive-alteration metasomatites are spatially related, alternate with each other and exhibit gradational contacts, denoting a concordant layering in relation to the granite upper contact, which defines a bedded greisen cupola model. The structures generated by the fissural alteration are vertical to subvertical and mainly developed within the fine-grained Santa Bárbara facies. The mineralizing fluids are dominantly magmatic, aqueous-carbonic and have salinities varying from 6 to 14 wt% NaCl eq., but low-salinity (1 to 3 wt% NaCl eq.) meteoric fluids partly mixed with magmatic fluids are largely confirmed at the end of the pervasive alteration and mainly during fissural alteration. Immiscibility conditions prevailed in the system at temperatures varying from 370 to 390°C. Oxygen isotope data for quartz-pods and lens-shaped greisens indicate temperatures of the order of 570°C and 500°C, respectively, for the ore genesis. The crystallization temperature for the cassiterite-quartz veins is 415°C. The calculated $\delta^{18}O_{H2O}$ of the tin-bearing fluids in equilibrium with host metasomatites ($\delta^{18}O_{H2O}$ = 5.2 to 7.3‰; quartz-water pair) indicates that the fluids equilibrated with an evolving residual granitic magma or with a high temperature albite-granite, consistent with a magmatic origin. The $\delta^{18}O_{H2O}$ deduced from the equilibrium mica-water indicates mixture with meteoric water, already at the pervasive magmatic-hydrothermal stage ($\delta^{18}O_{H2O}$ = 1.1 to 9.8‰). The late muscovite veins ($\delta^{18}O_{H2O}$ = -6.4‰ at 380°C) and late quartz ($\delta^{18}O_{H2O}$ = -3.8‰ at 380°C) formed at the post-magmatic fissural hydrothermal alteration stage, implying a dominant meteoric water component. Three processes are responsible for cassiterite genesis: 1) immiscibility in conditions of high degree of rock/fluid interaction in lens-shaped greisen bodies and greisen stockwork, 2) boiling of sodic aqueous fluids in cassiterite-quartz veins, and 3) mixing of saline magmatic fluids with high proportions of cold low-salinity meteoric fluids, in muscovite veins.

GEOCHEMICAL CHARACTERISTICS OF TUNGSTEN BEARING DEGANA GRANITE, NORTHWESTERN INDIA

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Degana Granite in the Aravalli-Delhi fold belt (Northwestern India) intruded into metasedimentary rocks of the Delhi Supergroup. This granite is characterized by disequilibrium textures and miarolitic cavities and has two major textural variants: medium to coarse grained and granite porphyry. Numerous wolframite bearing quartz veins intrude the Degana Granite. Greisenization and alkali metasomatism are the major post-magmatic changes associated with the granite.

Geochemically, the Degana Granite is characterized by moderate alumina, higher K_2O/Na_2O, FeO/MgO ratios and low to very low CaO, MgO, TiO_2 and P_2O_5. Higher concentrations of rare alkalies and other incompatible elements like Li, Rb, W, Th, U, Cs and lower Sr, Ba, Hf values are characteristic feature of this granite. The Rb/Sr and Ga/Al ratios are quite high while the Ba/Rb and Sr/Li ratios are very low. Both granite variants have similar chondrite normalized REE pattern, suggesting their co-magmatic nature. The moderate to high negative Eu anomaly with low Eu/Eu* ratio (0.014 - 0.034) suggest plagioclase fractionation under relatively reduced condition. The Fe- rich and Mg- poor nature of biotite from Degana also suggest the low fO_2. Chemistry of the granite is alsoo affected by the hydrothermal alteration.

The chemistry of Degana Granite classifies it as A-type within-plate granite. Further the presence of primary wolframite, topaz and fluorite in granite, high content of the Li and F in micas and high concentration of F, Li and W in the whole rock analysis of the granite confirm that the magma responsible for the formation of Degana Granite was enriched in tungsten and lithium apart from the other volatiles like fluorine. The formation of Degana Granite by fractional crystallization is suggested. The normative composition of the Degana Granite indicates a minimum temperature of crystallization of parent magma to be near 650 °C at less than 1 Kb confining pressure.

PETROGRAPHY AND MINERALOGY OF THE PERALKALINE GRANITES FROM THE MORRO REDONDO COMPLEX (PR-SC), SOUTH BRAZIL, AND SOME CONSTRAINTS FOR THE DEVELOPMENT OF RARE MINERALS

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The Morro Redondo Complex is one of the most expressive occurrence of granites and associated bimodal volcanic rocks from the Graciosa Province, an important Neoproterozoic (ca. 580 Ma), post-collisional, A-type province in south-southeast Brazil. It crops out close to the Paraná-Santa Catarina state limits and covers an area of about 250 km^2.

The granites were emplaced in Archean rocks from Luis Alves Craton and comprise two main intrusive units with subcircular to irregular outlines: the Papanduva Pluton, in the north, is composed of plagioclase-absent peralkaline granites, while the Quiriri Pluton, in the center-south areas, is made mainly of "subalkaline", plagioclase-bearing, biotite granites.

The granites from the Papanduva Pluton have high agpaitic indexes and are among the most evolved rocks found in the *alkaline petrographic association* within the province. Typical rocks are coarse- to medium grained alkali-feldspar granites with variable amounts of quartz, mesoperthitic alkali feldspar, sodic amphiboles and pyroxene, and accessory minerals, which include several rare agpaitic phases. Idiomorphic laths of almost pure albite found in intergrowths with interstitial pyroxene, amphiboles, and accessory minerals in some samples point to its co-precipitation in the late magmatic stage. Late- to post-magmatic tectonic stress leads to the development of slightly oriented to mylonitic rocks with porphyroclasts of amphiboles and/or pyroxene and relatively albite-poor alkali feldspar in a granoblastic matrix with quartz, K-feldspar and albite.

The amphiboles include both arfvedsonite and riebeckite with *mg#* $[Mg/(Mg+Fe^{2+})]$ around 0.005 and (Na+K)/Al between 15 and 30. Sodic pyroxene is almost pure aegirine (Eg_{90-97}) with $0.12 < mg\# < 0.20$. Late- to post-magmatic aegirine appears as interstitial crystals or as mantles over amphibole; in some samples its composition corresponds to a titanian aegirine, with TiO_2 contents up to 7 wt. %. The accessory minerals are zircon, apatite, ilmenite, astrophyllite, chevkinite, narsarsukite, aenigmatite, neptunite, britholite, nacareniobsite, ekanite, (Na-K)-zirconosilicates, and other unidentified phases. The rare minerals are relatively more abundant in the more evolved granites, which contain britholite and (Na-K)-zirconosilicates instead of apatite and zircon, and always present some evidence of deformation.

The inferred magmatic crystallization conditions are close to the FQM buffer. Some samples, with arfvedsonite + aegirine + aenigmatite and no Fe-Ti oxides, point to conditions inside the *non-oxide* field (Nicholls & Carmichael, 1969, *Contrib. Mineral. Petrol. 20: 268-294*). The textural and mineralogical features of the evolved and deformed granites suggest that the deformational event played an important role in the development and circulation of late- to post-magmatic alkali-rich fluids and the crystallization of several among the rare minerals.

PRECISE ZIRCON U-Pb (TIMS) DATING OF DIORITIC ROCKS AND IMPLICATIONS FOR THE AGE OF THE GRACIOSA PROVINCE OF A-TYPE GRANITES AND SYENITES, SOUTHERN BRAZIL

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The Neoproterozoic Graciosa Province of A-type granites and syenites (S-SE Brazil) comprises a large number of plutons with subcircular to irregular map outlines along the SSW-NNE direction, emplaced at shallow crustal levels, and related bimodal volcanic rocks. The plutons intruded Archaean and Neoproterozoic rocks of the Luis Alves and Curitiba microplates during the waning stages of the Brazilian-Pan-African Cycle, in an inferred post-collisional environment. Two contrasting petrographic associations can be recognized: an *alkaline association* composed by metaluminous to peralkaline alkali-feldspar syenites and granites and an *aluminous association* made of metaluminous to weakly peraluminous ("subalkaline") sieno- and monzogranites. Coeval dioritic rocks are relatively rare within the province.

There is a great number of dating results concerning emplacement, crystallization and/or cooling ages for several plutonic and volcanic occurrences within the province, obtained by different isotopic methods. However, data analysis show that most of them are subject to large deviations and the available results cover a large age interval, between 565 and 605 Ma, with some concentration between 575 and 590 Ma. Granites were the most common selected samples for dating and probably a significant part of the results reflects late- to post-magmatic phenomena affecting minerals and rocks. Taking into account that any good geodynamic model must be based on precise isotopic data and in order to avoid those problems we select the coeval dioritic rather than granitic or syenitic rocks for zircon U/Pb (TIMS) dating.

Two samples of coarse- to medium-grained biotite-hornblende quartz monzodiorites were selected. The first one comes from the Corupá Pluton (SC), the southernmost occurrence in the province, while the second comes from the Serra da Graciosa (PR) region, located in the northeast. In both occurrences the dioritic rocks are closely associated with rocks from the *alkaline association* and field relations suggest mingling and local mixing between basic and intermediate-acid magmas. We had success to obtain at least one concordant zircon fraction in each sample. Taking a 95 % confidence level, the first sample gives 583 ± 3 Ma (MSWD = 0.01, Prob. = 0.92) and the second 580 ± 3 Ma (MSWD = 0.50, Prob. 0.50), λ errors included in both cases.

These two results may be considered identical within the quoted errors. Taking them as a guide and considering also some similar data from the literature we suggest that the interval between 580 and 583 Ma should be taken as the best reference age for the Graciosa Province as a whole.

THE ESTRELA COPPER DEPOSIT, CARAJÁS, BRAZIL: A Cu-RICH STOCKWORK GREISEN HOSTED BY A PROTEROZOIC A-TYPE GRANITE

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Cu±Au deposits of the Carajás Mineral Province contain a combined total resource in excess of 2500 Mt at ~1% Cu and ~0.5 g/t Au and the majority have been classified as belonging to the iron oxide copper-gold class (e.g. Salobo, Pojuca, Cristalino, Bahia-Alemão, Sossego-Sequerinho, and 118). Recent discoveries of Gameleira and Breves have, however, been denoted as intrusion-related and suggestions have been made for a Cu-Au-(W-Bi-Sn) classification (Tallarico et al. 2003).

The recently discovered Estrela copper deposit, located within the eastern region of Serra dos Carajás contains 230 Mt at 0.5% Cu with minor Mo and rare Au and Sn. The deposit is situated at the eastern termination of the E-W Carajás Strike Slip Fault System within the Serra do Rabo Fault splay. The deposit geometry is controlled by the host intrusion and related features, plus regional east-west structural trends. Hosted by an A-type granite and Archaean supracrustal rocks the Cu-Mo-Au-Sn mineralisation is confined to stockwork veins, other magmatic-hydrothermal features of the Estrelinha granite system (e.g. aplites, greisen, pegmatites), and within alteration zones of the deformed country rocks. EPMA monazite analyses from molybdenite-bearing aplites, stockwork veins hosting Cu-mineralisation and allanite from fluorite-sulphide rich veins suggest a major mineralising hydrothermal event took place at Estrela between 1850 and 1830 Ma.

The paragenesis of alteration and mineralisation at the Estrela copper deposit is intimately associated with the Estrelinha granite and provides a down-temperature succession of overprinting events from granitophile magmatic-hydrothermal infill-alteration with a strong rare earth element signature through to sulphide precipitation and late oxidised low-temperature fluids. The geochemical character of mineralisation is dominated by Fe-Cu-F-B-Li-REE and the development of greisen is only weakly correlated with W but not Sn; rare cassiterite is hosted by late "fractionated" veinlets associated with tourmaline.

The Estrela copper deposit is interpreted to comprise a Proterozoic granite-related deposit and together with the Breves, Gameleira and possibly Águas Claras deposits, forms a Cu-Au-(W-Bi-Sn) class of deposits in Carajás.

The Cu-rich nature of metallogenesis in the Carajás Mineral Province suggests that there is a relationship between crustal source, granite type, granitogenesis and metallogeny. The Amazon Craton is considered to have evolved through the accretion of magmatic arcs and Proterozoic mineralisation is distinguished by an A-type rapakivi tin-granite metallogenesis (e.g. Pitinga deposit and Rodônian Tin Province). This may indicate the particular metallogenic nature of the Carajás Mineral Province as Cu-rich, Sn-poor but comparisons can be drawn with tin provinces world-wide (e.g. Cornwall, England and Herberton, Australia) as these are also known to host Cu-rich hydrothermal intrusion-related deposits.

Reference

Tallarico FHB, McNaughton NJ, Groves DI, Fletcher IR, Figueiredo BR, Carvalho JB, Rego JL, Nunes AF 2004. Geological and SHRIMP II U-Pb constraints on the age and origin of the Breves Cu-Au-(W-Bi-Sn) deposit, Carajás, Brazil. Mineralium Deposita.

DISCRIMINATION BETWEEN ARCHEAN A-TYPE GRANITOIDS AND SANUKITOID SUITES USING TECTONIC SETTING, GEOCHEMISTRY AND FERTILITY TYPE

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The Late Archean (2.6-2.8 Ga) is remarkable for the earliest manifestation of syenite-granodiorite-granite magmatism of alkaline affinity. From the published data this magmatism can be related to either "sanukitoid" (subduction) or "A-type granitoid" (anorogenic) magmatism. Key examples from the Superior, Yilgarn, and Baltic shields were studied to discriminate their origin: 2680-2670 Ma alkaline granites, syenites and associated nepheline syenites of the Abitibi greenstone belt (Sutcliffe et al., 1990; Corfu et al., 1991); 2650-2630 Ma alkaline granites and syenites of the Eastern Goldfields granite-greenstone terrane (Libby, 1989; Smithies & Champion, 1999); and 2610-2680 Ma alkaline granites, syenogranites, and associated nepheline syenites of the Keivy complex of the Central Kola granite-greenstone domain (Mitrofanov et al., 2000; Zozulya et al., 2005).

The first two examples consist of small (10-90 km^2) stocks spatially and temporally associated with potassic volcanics and lamprophyres, and they have structural and genetic links to greenstone belts. The Keivy complex consists of several sheet-like bodies of 100-500 m thickness, having vast exposed areas (100-1300 km^2), that are spatially and temporally associated with massif-type anorthosite bodies.

Granitoids from the various provinces have common mineralogical and petrochemical characteristics: anhydrous primary phases, Fe- and Na-rich mafic silicates, low Ca, Mg, Al, and high total alkalis. At the same time the granitoids show different trace element characteristics and fertility types. Coupled with different geological structure this suggests different tectonic settings.

The Superior and Yilgarn felsic alkaline rocks show extremely high concentrations of Ba (c. 500-4500 ppm) and Sr (c. 300-3000 ppm); low Zr, REE (no Eu anomaly), Y, Nb, Ta, and Rb; and low Ga/Al and high Y/Nb and (La/Yb)n ratios. Gold occurrences are detected. Based on these geochemical features the granites were formed in a subduction environment and correspond to sanukitoid suites.

Keivy felsic alkaline rocks are low in Ba (c. 40-200 ppm) and Sr (c. 5-30 ppm); extremely high in Zr, REE (except for a distinct negative Eu anomaly), Y, Nb, and Rb; and have high Ga/Al (for granite) and low (La/Yb)n and Y/Nb (Yb/Ta) (for syenite) ratios. The granites and syenites host Zr-Y-REE deposits and occurrences. The granitoids were formed in a within-plate setting and belong to the A-type granite group (A_2 subgroup). The associated nepheline syenites have geochemical affinities to OIB-derived magmas.

Sutcliffe et al. (1990) and Shirey & Hanson (1984), based on Nd isotope studies and elemental constraints, suggested that the "Superior" type granites are derived from depleted mantle sources that were enriched in LILE shortly before melting. Based on Nd and Sr isotopes, the "Keivy" type has a highly evolved enriched mantle source (EM2). It is likely that the Keivy granites are the product of a high degree of fractional crystallization of mantle-plume-derived alkaline basalt magma. Thus the Late Archean felsic alkaline magmatism is of two types: (1) subduction related sanukitoid-like with a depleted mantle source and (2) anorogenic A-type with an enriched mantle source.

PITINGA MINE

GEOLOGICAL SETTING AND FIELD TRIP PROGRAM

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A BRIEF HISTORICAL REVIEW OF THE PITINGA MINE

The first evidence of cassiterite-bearing alluvial deposits in the Pitinga region was recorded in 1978. The cassiterite mineralization was found during a regional mapping project executed by CPRM/Geological Survey of Brazil, which final report was published in 1979 (Veiga Jr. *et al.*, 1979). At that time, the rights for the exploration of the area have been claimed by a company subsidiary of the Paranapanema Group, which had started the follow-up and stream sediment sampling along the main creeks of the Água Boa pluton in the end of 1978. In 1980 was opened the first airstrip, allowing the access of C-47-type airplanes to the area. In the first legs, the airplane brings disassembled parts of a small concentration plant, starting up the mining of the tin-rich alluvial deposits of the Água Boa pluton.

In 1982 it was started the opening of the road linking Pitinga to the BR-174 highway, to the west. During the opening of the road, there were discovered large tin-rich alluvial deposits associated to the Madeira pluton. This discovery launched an extensive geological survey in the whole region. The detailed mapping and close spaced soil sampling led to the discovery of the albite granite facies of the Madeira pluton, which makes Pitinga the largest tin-mine of Brazil.

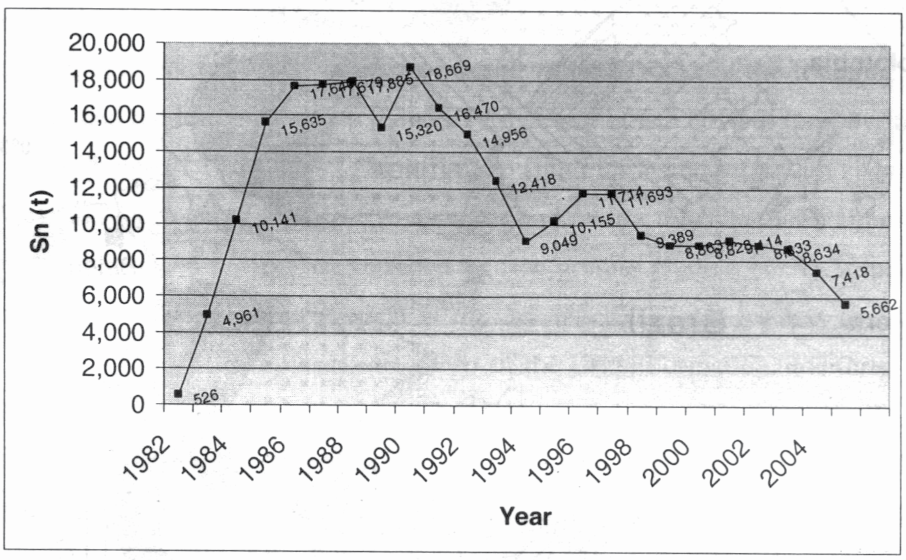


Figure 1 - Historical tin production of the Pitinga mine

After the peak production in 1990, when had been started the mining of the tin-rich saprolitic cover developed over the albite granite, the tin production has continually declined. The main reason was the almost complete exhaustion of the largest, strongly mineralized alluvial deposits. Today, when even the saprolitic cover is almost over, the main tin production comes from the mining of coarse-grained tailing deposits. Actually, besides tin, the Pitinga mine also produces Nb and Ta concentrates and Fe-Nb-Ta alloys.

A GENERAL VIEW ON THE GEOLOGY OF THE PITINGA PROVINCE

1 - Introduction and Geological Setting

The Pitinga Province is located in the southern part of the Guiana Shield (Almeida *et al.*, 1981; Gibbs & Barron, 1983) in the Central Amazonian province, near the Tapajós-Parima Province of the Amazonian Craton (Fig. 2, modified from Santos *et al.*, 2000). Both provinces are characterized by widespread occurrence of calc-alkaline granites and acid volcanic rocks of the Uatumã Supergroup, which are intruded by A-type rapakivi granites (Dall'Agnol *et al.*, 1999a). The geochronological data for this region point to crustal evolution starting in the Paleoproterozoic (the Transamazonian cycle at 2100 ± 100 Ma), and lasting until the Mesoproterozoic.

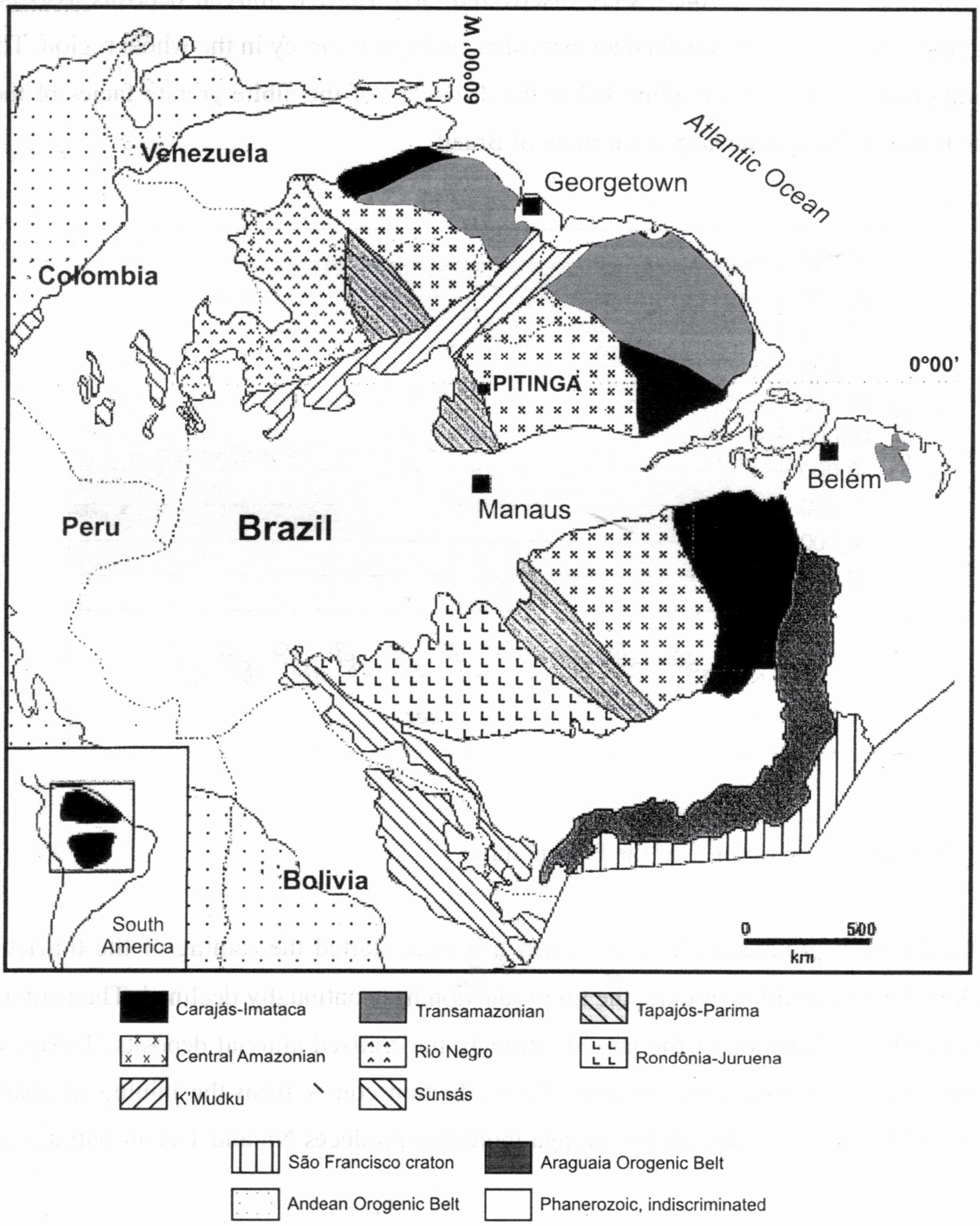


Figure 2 - Geochronological Provinces of northern Brazil (Santos *et al.*, 2000).

The Pitinga Province and the Rondônia Province in the southwestern region of the Central Brazil shield are the two main tin metallogenic provinces of the Amazonian Craton (Bettencourt *et al.*, 1995; Dall'Agnol *et al.*, 1999a). The Pitinga mine is the principal tin-producer of Brazil. Tin-deposits are related to Proterozoic A-type granites that intruded felsic volcanic rocks of the Iricoumé Group (Horbe *et al.*, 1991; Costi *et al.*, 2000; Fig. 3). In the Pitinga mine, both Iricoumé Group (Uatumã Supergroup) and tin-mineralized A-type granites are well exposed and mapped, providing an important area to be visited for all those interested in this type of geological setting.

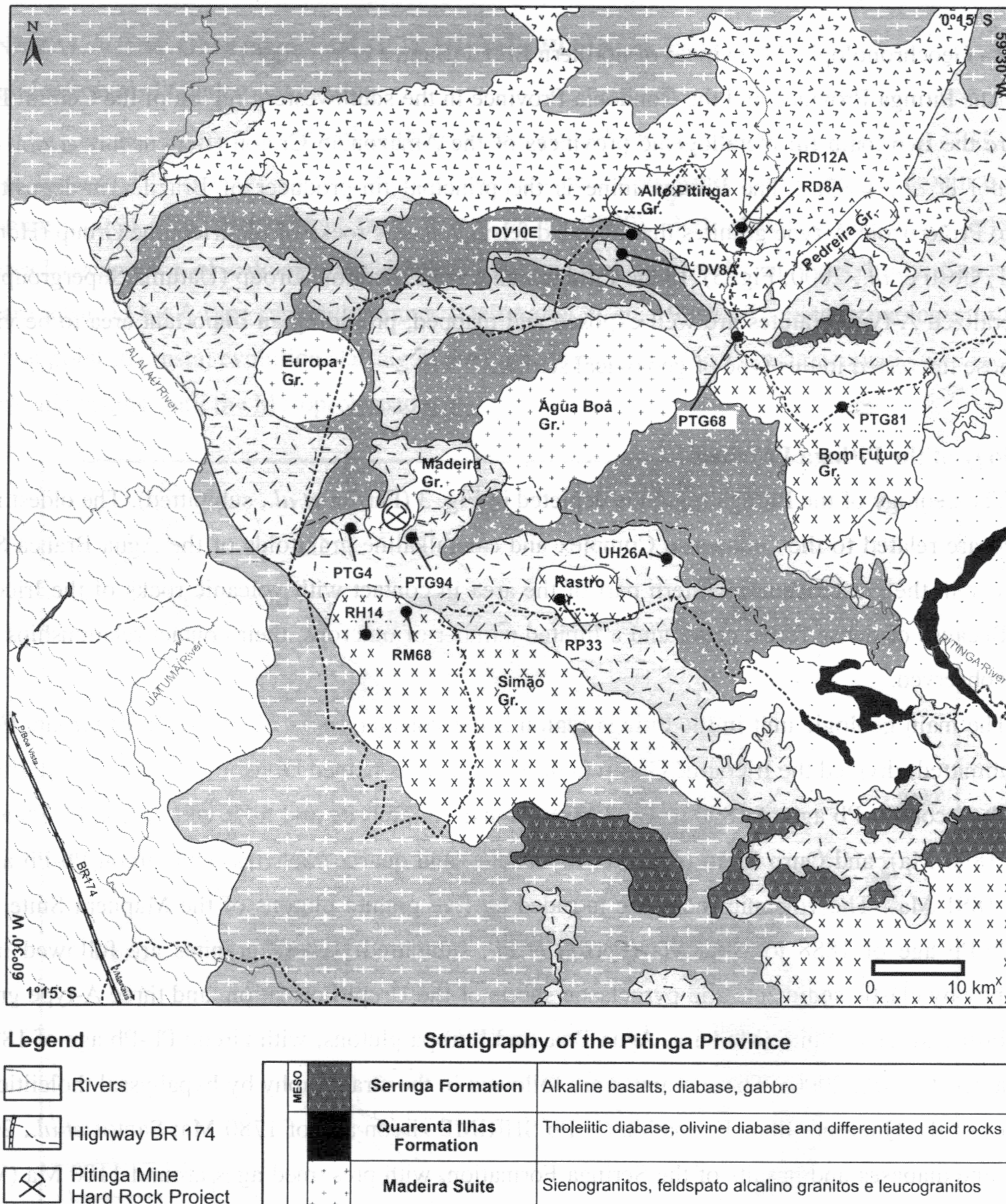
2 - Geology of the Pitinga Province

The geology of the Pitinga region is depicted in Fig. 3 (Ferron *et al.*, submitted). The oldest rocks identified are related to the Guianense Complex and calc-alkaline granitoids of the Água Branca Suite. They occur in the western/southwestern part of the area in contact with volcanic rocks of the Iricoumé Group. Because of dense forest cover and a limited number of outcrops, their contact relationships were not fully observed.

The main geologic unit in the Pitinga region is the volcanic rocks of the Iricoumé Group. Ferron *et al.* (submitted) divided the Iricoumé Group in three formations named Divisor (porphyritic andesite and latite with zircon Pb-Pb age of 1896 to 1892 Ma), Paraiso (ignimbrite and tuffs with zircon Pb-Pb age of 1882 to 1890 Ma), and Ouro Preto (rhyolite, rhyodacite, and quartz trachytes with zircon Pb-Pb age of 1886 to 1881 Ma). The volcanic rocks are intruded by five granite plutons of the Mapuera Suite, with zircon Pb-Pb age of 1888 to 1882 Ma (Ferron *et al.*, submitted). These granites are followed in the stratigraphy by clastic sediments and pyroclastic sheets of the Urupi Formation, and three A-type granite plutons of the Madeira Suite (Madeira, Água Boa, and Europa plutons, with zircon Pb-Pb age of 1829 to 1818 Ma; Costi *et al.*, 2000). These granites are followed in the stratigraphy by hypabyssal tholeiitic sills and dykes of the Quarenta Ilhas Formation (U-Pb SHRIMP zircon age of 1780 Ma; Santos *et al.*, 2002). The alkaline diabases and basalts of the Seringa Formation, with presumed ages around 1100 Ma (Veiga Jr. *et al.*, 1979), are the youngest magmatic rocks identified in this area.

The felsic volcanic rocks of the Iricoumé Group show widespread brittle deformation, with the development of narrow fractures filled by epidote, chlorite, carbonate, and quartz. They commonly show rounded enclaves and globules of porphyritic, mafic volcanic rocks, suggesting that the occurrence of mixing/mingling processes influenced their genesis.

The field relationships between the Iricoumé Group and the Madeira pluton are exposed in quarries along the road that links Pitinga to Manaus. Contact relationships between the volcanic sequence and the Água Boa granite were observed in the northern part of the pluton. The contacts are normally sharp and centimeter- to meter-size enclaves of the volcanic rocks are found inside the granites.



Stratigraphy of the Pitinga Province

PROTEROZOIC	MESO		Seringa Formation	Alkaline basalts, diabase, gabbro
PROTEROZOIC	PALEO		Quarenta Ilhas Formation	Tholeiitic diabase, olivine diabase and differentiated acid rocks
PROTEROZOIC	PALEO		Madeira Suite	Sienogranitos, feldspato alcalino granitos e leucogranitos
PROTEROZOIC	PALEO		Urupi Formation	Quartz arenites, siltites and pyroclastic rocks of the Paraíso Fm. Intercalated on basal portions
PROTEROZOIC	PALEO	Uatumã Supergroup	Mapuera Suite	Syenogranites, monzogranites and leucogranites
PROTEROZOIC	PALEO	Uatumã Supergroup – Iricoumé Group	Ouro Preto Fm.	Rhyolites, rhyodacites and quatz trachytes
PROTEROZOIC	PALEO	Uatumã Supergroup – Iricoumé Group	Paraíso Fm.	Acid tuffs and ignimbrites
PROTEROZOIC	PALEO	Uatumã Supergroup – Iricoumé Group	Divisor Fm.	Porphyritic andesites and latites
PROTEROZOIC	PALEO		Água Branca Suite	Monzogranites, biotite monzogranites, granodiorites, biotite granodiorites and tonalites
PROTEROZOIC	PALEO		Guianense Complex	Foliated granitoids, gneisses and mylonites derived from granitoid rocks

Figure 3 - Regional geological map of the Pitinga Province (Ferron *et al.*, submitted).

3 - Geology of the Madeira and Água Boa plutons

The Madeira and Água Boa plutons (Fig. 4) are the carriers of the tin-mineralization exploited in Pitinga and have been studied in detail (Macambira *et al.*, 1987; Daoud, 1988; Horbe *et al.*, 1991; Lenharo *et al.*, 2003; Costi, 2000; Costi *et al.*, 2000).

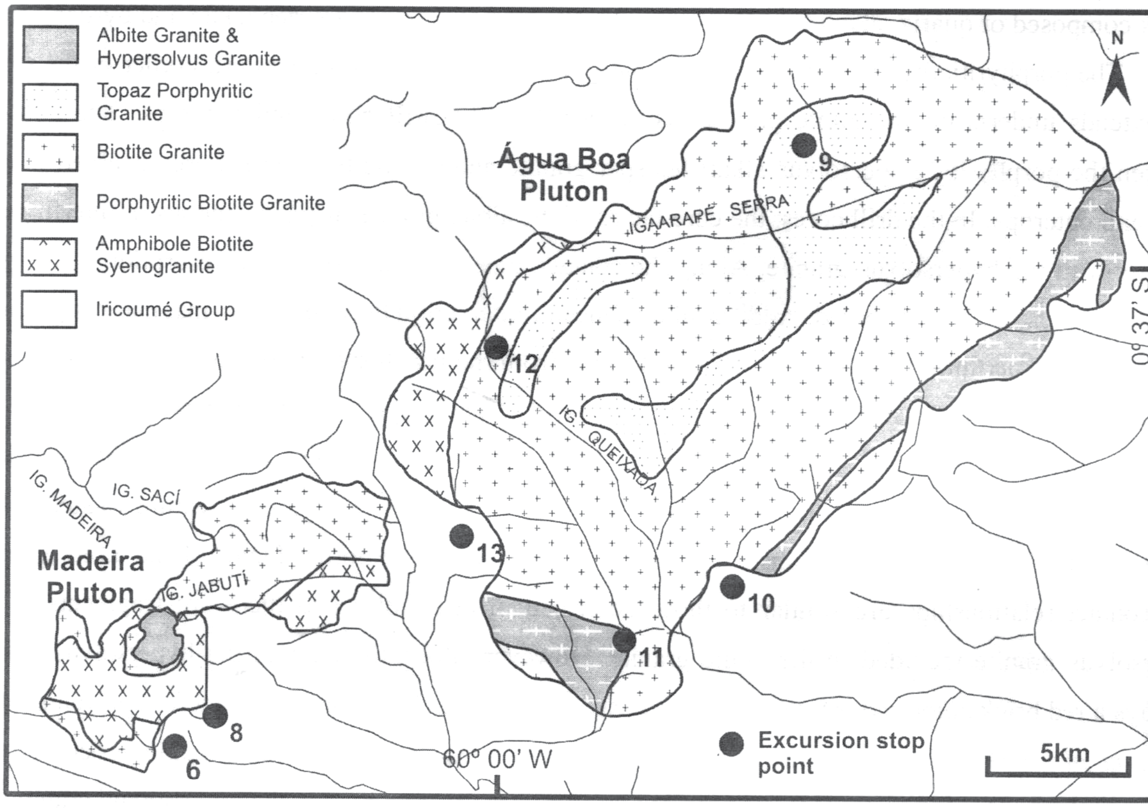


Figure 4 – Geological map of Madeira and Água Boa plutons (modified from Costi *et al.*, 2000).

The Água Boa pluton is elongated in the NE-SW direction and is composed of four facies (Daoud, 1988; Lenharo *et al.*, 2002, 2003). Field evidence indicates that the early facies is a coarse-grained pyterlitic amphibole biotite syenogranite, known as the rapakivi facies. It is followed successively by a fine-grained porphyritic biotite syenogranite, a coarse- to medium-grained biotite alkali feldspar granite, and topaz-bearing porphyritic granite. The primary tin-mineralization in the Água Boa pluton is associated with greisen (Daoud, 1988; Borges *et al.*, 1996) and episyenites (Costi *et al.*, 2002), but only alluvial cassiterite deposits have been exploited (Daoud, 1988).

The Madeira Pluton facies are similar to those of the Água Boa pluton (Horbe *et al*, 1991). A metaluminous, porphyritic amphibole biotite syenogranite, commonly showing rapakivi texture, is the first facies to crystallize. A peraluminous, equigranular, and medium-grained biotite alkali feldspar granite intrude the rapakivi facies. Both these facies are cut by a near circular-shaped stock, with a diameter of ca. 2-km.

This stock (Fig. 5) was mapped at detailed scale and covered by an extensive drilling program by the mining staff. The stock is a sheet-like intrusion formed by porphyritic hypersolvus alkali feldspar granite and albite granite. The latter is composed by a magmatic peralkaline cryolite-bearing core facies surrounded by an autometasomatic, peraluminous, fluorite-bearing border facies (Costi *et al.*, 2000). The core facies passes into the border facies along interfingered transitional zones. The porphyritic hypersolvus alkali feldspar granite shows euhedral quartz and alkali feldspar phenocrysts in a fine-grained matrix composed of quartz, alkali feldspar, biotite, fluorite, opaques and rare riebeckite and pyrochlore.

The porphyritic hypersolvus alkali feldspar granite is exposed in the western border of the stock, and extends underneath the albite granite, as observed in the drill cores and outcrops. The contacts between the porphyritic hypersolvus alkali feldspar granite and the albite granite were observed in drill cores and outcrops. In the drill cores, the core facies of the albite granite displays sinuous or interfingered contacts with the hypersolvus granite. Along the contact zone, evidence of partial resorption of the gray hypersolvus granite was observed. Additional evidence of interaction between both "magmas" is given by the presence of perthitic xenocrysts of alkali feldspars from the porphyritic hypersolvus granite included in the albite granite. In some places, the alkali feldspar phenocrysts of the hypersolvus granite are corroded and cryolite occurs filling the cavities. The contact is commonly marked by thin bands of leucogranites and the hypersolvus granite becomes clearly enriched in zircon, a feature related to the albite granite. At the surface, the observed contact involves only the border facies of the albite granite. The contact relationships are similar to those described in drill holes and there are fragments of the hypersolvus granite included in the albite granite. However, along the contact the hypersolvus granite displays a red brick color and is intensely altered, showing evidence of albitization and/or episyenitization (Costi *et al.*, 2000). This suggests that the solutions responsible by the metasomatic processes that generated the border facies also affected the hypersolvus granite. Obviously, the hypersolvus granite and the albite granite were only partially crystallized when they were juxtaposed, indicating a short time span between the emplacement and crystallization of both facies.

The albite granite is in contact with the rapakivi and biotite granite facies in the eastern, northeastern, north and northwestern sectors of the stock. The contacts, exposed after the mining of the tin-rich saprolitic cover of the albite granite, are generally marked by the presence of the border facies. The contacts are sharp, dipping between 25° to 40° outward from the center of the stock. A greisen or a 2 to 3 m-thick zone of alternation of pegmatites and greisen (stockscheider) has generally developed at the top of the albite granite. The hanging-wall granite shows minor alteration and the development of narrow fractures filled by greisen or chlorite ± quartz ± galena ± fluorite.

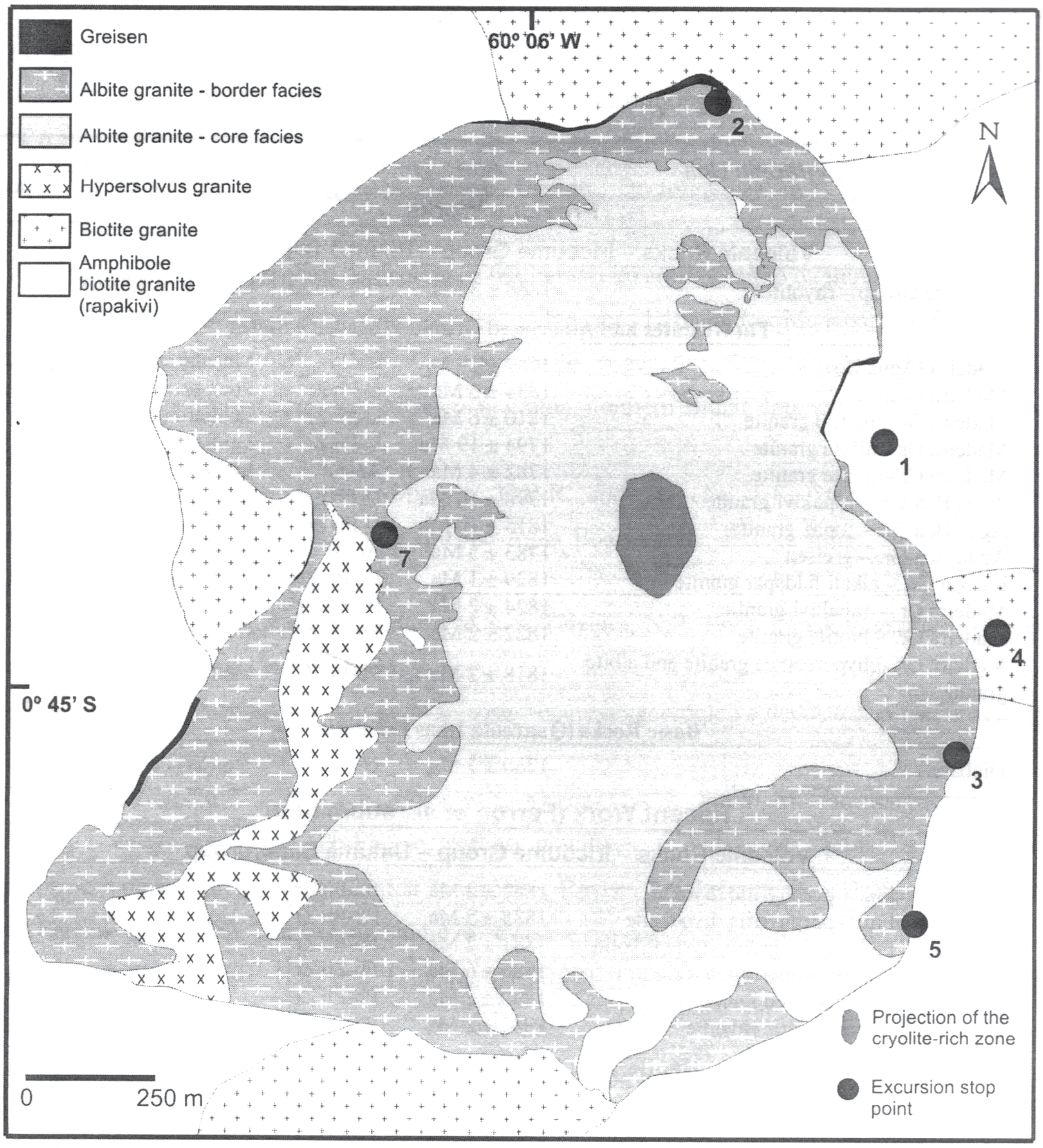


Figure 5 - Geological map of the albite granite (modified from Costi *et al.*, 2000 & Mineração Taboca, unpublished report).

A cryolite deposit formed by pods and thick veins of this mineral intercalated with the core albite granite facies was identified around 100 m below the present surface of the albite granite sheet. Coarse-grained quartz and perthitic feldspar and meter-thick layers of massive lithium-iron mica are associated with the cryolite veins. They are particularly abundant on the top and along the flanks of the deposit. These features suggest that pegmatitic processes (Costi & Dall'Agnol, 1999) controlled the origin of the massive cryolite and associated rocks. The cryolite deposit is divided in two zones by an irregular sheet of hypersolvus granite, which is strongly albitized and alternates with the albite granite core facies. The hypersolvus granite is also found under the base of the cryolite deposit. In the deepest zones reached by the drill cores, the hypersolvus granite is generally followed by a fine-grained porphyritic rock, probably a volcanic rock related to the Iricoumé Group.

Table 1 - Summary of the geochronological data for the Pitinga Province

Stratigraphic Unit	*Age*	*Method*	*Reference*
Previous Works			
Volcanic Rocks – Iricoumé Group – Uatumã Supergroup			
Iricoumé Group – rhyolite	1888 ± 3 Ma	Pb-Pb Zr[1]	Costi *et al.* (2000)
Tin Granites and Associated Granites (Madeira Suite)			
Madeira /Água Boa	1689 ± 19 Ma	Rb-Sr rt	Macambira *et al.* (1987)
Madeira Granite	1834 ± 6 Ma	U-Pb Zr[2]	Fuck *et al.* (1993)
Madeira Gr – biotite granite	1810 ± 6 Ma	U-Pb Zr[3]	Lenharo (1998)
Madeira Gr – albite granite	1794 ± 19 Ma	U-Pb Zr[3]	Lenharo (1998)
Madeira Gr – albite granite	1782 ± 4 Ma	Ar-Ar[4]	Lenharo (1998)
Água Boa Gr. – rapakivi granite	1798 ± 10 Ma	U-Pb Zr[3]	Lenharo (1998)
Água Boa Gr. – topaz granite	1815 ± 10 Ma	U-Pb Zr[3]	Lenharo (1998)
Água Boa Gr. – greisen	1783 ± 5 Ma	Ar-Ar[4]	Lenharo (1998)
Europa Gr. – alkali feldspar granite	1829 ± 1 Ma	Pb-Pb Zr[1]	Costi *et al.* (2000)
Madeira Gr. – rapakivi granite	1824 ± 2 Ma	Pb-Pb Zr[1]	Costi *et al.* (2000)
Madeira Gr. – biotite granite	1822 ± 2 Ma	Pb-Pb Zr[1]	Costi *et al.* (2000)
Madeira Gr. – hypersolvus granite and albite granite	1818 ± 2 Ma	Pb-Pb Zr[1]	Costi *et al.* (2000)
Basic Rocks (Quarenta Ilhas Formation)			
Diabase	1780 ± 3 Ma	U-Pb Zr[3]	Santos *et al.* (2002)
Recent Work (Ferron *et al.*, submitted)			
Volcanic Rocks – Iricoumé Group – Uatumã Supergroup			
Ouro Preto Fm. – porphyritic rhyolite	1882 ± 2 Ma	Pb-Pb Zr[1]	
Ouro Preto Fm. – porphyritic rhyodacite	1885 ± 8 Ma	Pb-Pb Zr[1]	
Ouro Preto Fm. – micrograophyric rhyolite	1881 ± 2 Ma	Pb-Pb Zr[1]	
Ouro Preto Fm. – porphyritic rhyolite	1886 ± 6 Ma	Pb-Pb Zr[1]	
Paraiso Fm. – porphyritic ignimbrite	1890 ± 2 Ma	Pb-Pb Zr[1]	
Paraiso Fm. – porphyritic rhyolite	1882 ± 2 Ma	Pb-Pb Zr[1]	
Mapuera Suite – Uatumã Supergroup			
Simão Granite (biotite granite)	1882 ± 4 Ma	Pb-Pb Zr[1]	
Simão Granite (biotite alkali feldspar granite)	1885 ± 4 Ma	Pb-Pb Zr[1]	
Rastro Granite (granophyric syenogranite)	1882 ± 2 Ma	Pb-Pb Zr[1]	
Bom Futuro Granite (syenogranite)	1882 ± 3 Ma	Pb-Pb Zr[1]	
Alto Pitinga Granite (cataclastic biotite monzogranite)	1885 ± 3 Ma	Pb-Pb Zr[1]	
Alto Pitinga Granite (biotite monzogranite)	1888 ± 3 Ma	Pb-Pb Zr[1]	

1 $^{207}Pb/^{206}Pb$ double-filament zircon evaporation, 2 U-Pb zircon TIMS, 3 SHRIMP II $^{207}Pb/^{206}Pb$, 4 Ar-Ar in micas.

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FIELD TRIP PROGRAM TO THE PITINGA MINE

Field trip leaders:

Hilton Tulio Costi - Museu Paraense Emílio Goeldi

José Maximino T. M. Ferron (**Max**) - Mineração Taboca S.A. (Paranapanema Group)

Maurício Prado - Mineração Taboca S.A. (Paranapanema Group)

Day One (Wednesday, August, 02, 2006) – bus trip from Manaus to Pitinga

11:30 a.m. – Before take the road, the organizing committee will offer a lunch for the participants. The lunch will be had at the Restaurante Fiorentina, situated close to the Lider Hotel (see map).

00:30 p.m. – The bus will leave the hotel and take the road to Pitinga. This leg will last close to six hours, with some fast stops to drink some water or soft drinks. The arrival at Pitinga is estimated at 6:00 pm.

02:00 p.m. – arrival in the city of Presidente Figueiredo (BR-174, km 107).

04:30 p.m. – the bus will leave the BR-174 highway (km 250) and take the access to Pitinga, nearly 60 km to the East, by an unpaved road.

6:00 p.m. – arrival at the Pitinga village. Accommodation at the Kitarrá Hotel.

7:00 – 7:30 p.m. – welcoming presentation of the Pitinga Project and introduction to the geology of the Pitinga region by the mining staff (Max and Mauricio).

Day Two (Thursday, August, 03, 2006)

The initial part of the day will be dedicated to the detailed observation of the albite granite facies and its field relations with the earlier granitic facies of the Madeira pluton. Outcrops of the early facies of the Madeira pluton and volcanic rocks of the Iricoumé Group will also be visited.

7:30 a.m. - The bus leaves the Kitarrá Hotel and takes the road to the Madeira pluton, to the northwest.

Stop 1 – eastern border of the albite granite facies of the Madeira pluton

This point is located in the highest side of the albite granite hill. From the stop point is possible to take a panoramic view of the Serra do Madeira hill, which comprises the albite granite facies and its limits with the earliest facies of the Madeira pluton. The top of the albite granite is now completely exposed as a hard rock. The tin-rich saprolite profile developed over it was almost completely mined out in the last years. After a short explanation of the geology of the albite granite facies, the visitors will be invited to observe in detail some of its essential aspects.

Stop 2 – northern limit of the albite granite facies of the Madeira pluton

In the northern limit, the albite granite (border facies) is in contact with the biotite granite facies of the Madeira pluton. The contact is observed in a ten meters high cut opened in the saprolitic cover. The contact plane dips 30-35 degrees to north. The border facies of the albite granite is separated from the biotite granite by a meter-thick, Y-rich zone composed of greisen and coarse-grained pegmatitic quartz and feldspar (stockscheider). The saprolite developed over the albite granite near the contact zone was also tin-rich and so was completely mined out.

This point is also the site of deposition of large blocks of albite granite (core facies) that have been blasted in the central part of the body. These blocks were stockpiled as a reserve of material for future processing tests. The blocks of albite granite shows textural and mineral features found in the pegmatitic parts of the albite granite core facies.

After the observation of this point, the participants will be invited to walk in direction to the central-western side of the albite granite. This sector is affected by a close spaced set of narrow N-S trending faults and fractures that cut the core facies of the albite granite. The faults allows a way for the ascending of F-rich, low viscosity magma, interpreted as the more evolved type of albite granite core facies. The rock is fine or medium-grained, and in some places is coarse-grained with pegmatitic texture. The development of fluidal texture is frequent. Coarse-grained quartz, feldspars, dark mica, and cryolite filled a lot of pockets and vesicles. This is the only place where this type of rock outcrops, and is the only outcrop where cryolite can be easily identified by naked eye. Similar rock type is found in boreholes, generally close or associated with the cryolite veins and pods.

Stop 3 – eastern limit of the albite granite facies of the Madeira pluton

Contact zone with the albite granite (border facies) with the rapakivi facies of the Madeira pluton. The contact is complex, showing sets of narrow faults and fractures filled with greisen and massive quartz and pink feldspars. Along the contact zone the rapakivi granite is fractured and penetrated by veins of greisen and feldspars.

Stop 4 – 200 meters off the eastern limit of the albite granite facies of the Madeira pluton.

Outcrop of boulders of biotite granite of the Madeira pluton ($^{207}Pb/^{206}Pb$ zircon age of 1822 ± 1 Ma; Costi *et al.*, 2000). Short stop to observe the textural aspect of this rock. The best outcrops of this facies are difficult to access, and this point is one of few others where the biotite granite is exposed.

Stop 5 – southeastern limit of the albite granite facies of the Madeira pluton

Contact zone with the albite granite (border facies) with the rapakivi facies of the Madeira pluton. This point is the southern extension of the contact zone observed in the stop 3. The contact zone is shallow dipping to east, marked by greisen developed at the top of the albite granite. It will be seen fresh samples of the rapakivi facies.

Stop 6 – southern limit of the albite granite facies of the Madeira pluton.

This visiting point is located at the margin of the Ouro Preto mining tailings deposit. Along the side of a low hill, it will be observed blocks and boulders of amphibole biotite syenogranite with rapakivi texture. This is a representative example of the earliest facies of the Madeira pluton, with a $^{207}Pb/^{206}Pb$ zircon age of 1824 ± 2 Ma (Costi *et al.*, 2000). Some blocks shows nearly rounded enclaves of a felsic, porphyritic rock, interpreted as partially resorbed fragments of the enclosing volcanic rocks, which are found few hundred meters to the south. Some other blocks are cut by veins and narrow dikes of a fine-grained granitic rock related to the late biotite granite facies.

Stop 7 –southwestern sector of the Madeira pluton - western contacts of the albite granite and porphyritic hypersolvus granite of the Madeira hill

This point is reached through a secondary road, now closed to vehicles. It will be visited a nearly west to east profile across the Madeira hill. The profile starts in the rapakivi facies, exposed on the cut along the road and passes to the albite granite border facies to the east. The direct contact cannot be see due to the weathering of the cut surface, but the change from one type of rock to the other occurs in a short distance. Going further to the east, there is seen a complex interaction between the albite granite border facies and the porphyritic hypersolvus granite. The porphyritic hypersolvus granite usually is a grayish rock, but in this point, it is oxidized, taking a reddish color. Following through the road it is possible to see, in lower topographic levels, sharp contacts between the porphyritic hypersolvus granite and the albite granite. The porphyritic hypersolvus granite is always found below the albite granite, as observed on a large rock wall few meters ahead.

After visiting this point the route will change to southwest, down the slop of the hill. During the descending way there will be seen the contact between the porphyritic hypersolvus granite or rapakivi granite and the border facies of the albite granite. The contact is subhorizontal and is marked by greisen, developed on the albite granite. The greisen can shows coarse-grained or very coarse-grained crystals of cassiterite. The tin mineralization, however, is irregularly distributed in the greisen, bringing some difficult to the evaluation of the deposit in this sector.

Stop 8 – southeastern sector of the Madeira pluton

In this stop it will be visited a quarry of volcanic rocks of the Ouro Preto Formation (Iricoumé Group) close to the contact with the Madeira pluton. The quarry was opened by blasting the flank of a small hill, few meters away off the road. It is composed of large blocks of dark, fine-grained, massive porphyritic quartz trachyte and minor rhyolite. The quartz trachyte can show small vesicles, actually filled by epidote or quartz. The rock shows a dense array of narrow brittle fractures, probably originated by the emplacement of the Madeira pluton.

Day Three (Friday, August, 04, 2006)

This day will be dedicated to visit outcrops of the granite facies of the Água Boa pluton and volcanic rocks of the Iricoumé Group.

7:30 a.m. - The bus leaves the Kitarrá Hotel and takes the road to the Água Boa pluton, to the East.

Stop 9 – northeastern sector of the Água Boa pluton

In the first stop of the day it will be observed the more evolved facies of the Água Boa pluton, defined as porphyritic topaz granite by Lenharo *et al.* (2002). The outcrop is found in the left margin of the Anta creek, in the northernmost portion of the Água Boa pluton. The rock is a light gray, massive porphyritic granite, with phenocrysts of K-feldspar and a fine to medium-grained quartz-feldspar groundmass. The rock is moderately fractured, showing fractures filled by quartz, chlorite, and sericite. Very fine grained cassiterite may be found in thin sections of this rock.

Stop 10 – southeastern border of the Água Boa pluton

Close to the margin of the road, crossing the Paraíso creek, occurs a quarry of fine-grained, grayish ash-flow tuff of the Paraiso Formation (1888 Ma), Iricoumé Group, forming a base-surge deposit. The tuff is of rhyolitic composition, moderately welded, and showing a sharp flow structure.

Approximately 1 Km to the north occurs an outcrop of amphibole biotite syenogranite with rapakivi texture, which is the earliest facies of the Água Boa pluton. In the weathered profile cut by the road, it will be observed a rounded enclave of altered pyroclastic rock. This is interpreted as evidence of the intrusion of the Água Boa pluton in the volcanic country rocks.

Stop 11 – southern sector of the Água Boa pluton

In this point will be visited an outcrop of the porphyritic biotite granite facies of the Água Boa pluton. The outcrop occurs at the Perdigoto creek, where the granite forms a smooth rapid along the course of the creek. The rock is a massive, porphyritic to equigranular, seriated, light red biotite granite. It is composed essentially of K-feldspar and quartz, with subordinated amounts of sodic oligoclase (less than 10%). The biotite is the only mafic phase recorded in this facies. In outcrops along the road, close to this point, the biotite granite shows rare fine-grained, dark, enclaves or xenoliths. The enclaves or xenoliths are rounded, small, and sharply outlined within the biotite granite.

Stop 12 – eastern sector of the Água Boa pluton

The exposure is located in the high course of the Queixada creek. In this stop will be visited an open pit where a greisen occurrence was recently mined. The greisens are found filling subhorizontal fractures along the bed of the creek. This type of greisen systems is interpreted as the main source for the tin mineralization in the Água Boa pluton.

Stop 13 – southwestern border of the Água Boa pluton

In this stop will be visited a waterfall with nearly 4 meters high in the Caetitu creek. The outcrop consists of fractured, grayish or brownish, fine-grained, porphyritic rhyolite of the Ouro Preto Formation. The rock is massive and shows scattered vesicles filled up by quartz, chlorite, and epidote. This is the most common type of volcanic rock found in the Pitinga region, being observed along the borders of the Água Boa and Madeira plutons.

Day Four (Saturday, July, 5, 2006)

7:30 a.m. - The bus leaves the Kitarrá Hotel and takes the road back to Manaus.

This is the last day of the excursion. The last activity of the excursion will be a visit to the deposit where are stored the drill cores recovered during the drilling of the albite granite.

There will be observed a representative profile across the albite granite, displayed by the continuous coring of a borehole drilled in the central part of the stock (around 300 m). It will be seen the textural variation within the albite granite, and the changes it displays when approaching the zone of occurrence of the massive veins and pods of cryolite. It is noteworthy to record the occurrence of the porphyritic hypersolvus granite in the deepest levels of the borehole.

11:30 a.m. – travel to Manaus and ending of the excursion.

ARCHEAN AND PALEOPROTEROZOIC GRANITOIDS OF THE CARAJÁS METALLOGENIC PROVINCE, EASTERN AMAZONIAN CRATON

GEOLOGICAL SETTING AND FIELD TRIP PROGRAM

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GENERAL ASPECTS OF THE GRANITOGENESIS OF THE CARAJAS METALLOGENIC PROVINCE

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INTRODUCTION

The Carajás Metallogenic Province (CMP) is characterized by the great diversity and high economic value of its ore deposits. At present, it is the most important mineral province of Brazil. Besides world class, high-grade iron ore mines, the CMP has manganese and copper mines in exploitation, the latter with associated gold and silver, and nickel mines in implantation. This region has been extensively studied during the two last decades (DOCEGEO 1988, Huhn et al. 1988, Machado et al. 1991, Araújo et al. 1994, Teixeira 1994, Costa et al. 1995, Macambira & Lafon 1995, Souza et al. 1996, 2001, Pinheiro et al. 1997a,b, Barros et al. 1997, 2001, Dall'Agnol et al. 1994, 1999a, 2005, Althoff et al. 2000, CPRM 2000, Pidgeon et al. 2000, Lindenmayer et al. 2001, Galarza-Toro 2003??, Talarico et al. 2004, 2005, Dreher 2004, Sardinha et al. 2006, Lindenmayer et al. 2006, Lobato et al. 2006, Botelho et al. 2006, Silva et al. 2006).

The knowledge about granitoid rocks and associated mineralizations of the CMP has increased significantly due to regional prospecting and mining exploitation projects undertaken by Companhia Vale do Rio Doce (CVRD) and other prospecting and mining companies, as well as by specific studies induced by the Agência para o Desenvolvimento da Indústria Mineral Brasileira (ADIMB; see Marini et al. 2006). The regional mapping surveys developed by the Companhia de Pesquisas de Recursos Minerais (CPRM), even if yet limited in scale, have also contributed with significant advances. More specific recent studies on magmatism, crustal evolution, and metallogenesis have been developed by the Pronex nucleus of the Center of Geosciences of Universidade Federal do Pará (UFPA), represented by their groups of research on Granite Petrology (GPPG), and Metallogenesis and its Isotope Geology Laboratory (Pará-Iso), with the collaboration of Universidade do Vale do Rio dos Sinos (Unisinos-RS), and CPRM, as well by other Brazilian Universities.

The aims of the field trip and the present excursion guide are to give a general overview of the Archean and Paleoproterozoic granitoids found in the CMP and to situate its granitic magmatism in the tectonic setting of the Amazonian craton.

TECTONIC SETTING AND STRATIGRAPHY

The Archean age of the PMC is clearly established by confident geochronological data (Machado et al. 1991, Macambira & Lafon 1995, Galarza et al. 2002?, Rolando & Macambira 2003, Leite et al. 2004, Talarico et al. 2004, 2005, Barros et al. 2004, Lindenmayer et al. 2006, Botelho et al. 2006) and it is the more important Archean province of the Amazonian craton identified so far. Costa et al. (1995) distinguished three major tectonic domains in the CMP: The Rio Maria Granite-Greenstone Terrain (RMGGT; Medeiros et al. 1987), limited at the North by the Itacaiúnas Shear Belt (ISB) and at the South by the Pau D'Arco Shear Belt (PDSB). However, Althoff et al. (2000), Souza et al. (2001) and Rolando and Macambira (2003) demonstrated that the RMGGT extends, at least, until the Inajá region, south of the area of occurrence of the Redenção pluton (Figure 1). According to this model, adopted in the following discussions, the CMP is divided in two major tectonic domains, the RMGGT and the Carajás Basin (CB).

The limit between the RMGGT and CB is also controversy, being situated either immediately at the south of the Xinguara granite (Costa et al. 1995) or to the north of the Sapucaia greenstone belt (Souza et al. 1996, 2001). Leite (2001) and Leite et al. (2004) studied the TTG granitoids and gneisses that occur in the Xinguara area including them in two new units: Caracol tonalitic complex and Água Fria Trondhjemite. They also identified a new occurrence of the Rio Maria Granodiorite, which is intrusive in the Caracol tonalitic complex and is intruded by Agua Fria Trondhjemite. Finally they presented a detailed study of the Archean Xinguara leucogranite (see Leite & Dall'Agnol 1999). They concluded that the limit between the RMGGT and CB was located to the north of the Xinguara region. The extension of the TGGRM until the Inajá area, south of Redenção, was demonstrated by Rolando & Macambira (2002, 2003). They obtained Pb-Pb ages in zircon and Sm-Nd isotopic data in rocks of that region and correlated them to the Arco Verde Tonalite, Rio Maria Granodiorite and Mata Surrão Granite.

The stratigraphy and principal units of the RMGGT and CB can be seen in geological maps of Figures 1 and 2, respectively. Additional information can be obtained in the literature and in the discussions about specific areas of the CMP in the following topics.

Considering the undefined limit between the RMGGT and the CB, for the purposes of this guide, it is distinguished a Transition Domain between both major tectonic domains. The Transition Domain, poorly studied so far, is probably a terrane originally similar to the RMGGT that was intensely affected by the magmatic and tectonic events recorded in the CB (Soares 2002, Gomes 2003, Gomes et al. 2004, Sardinha et al. 2004, Sardinha 2005). In this approach, it is interpreted as a segment of the RMGGT intensely reworked during the compressional phase of the tectonic evolution of the CB. Shear deformation is intense in the Carajás Basin and in the Transition Domain. The Itacaiúnas Shear Belt was defined in those areas (Araujo & Maia 1991, Costa et al. 1995).

Table 1 summarizes the most relevant geochronological data about the Archean rocks of the CMP (Macambira & Lafon 1995, Rolando & Macambira 2003, Leite et al. 2004, modified). Geological and geochronological data demonstrate the existence of important differences between the RMGGT and the CB (Machado et al. 1991, Althoff et al. 2000, Souza et al. 2001, Dall'Agnol et al. 2005):

1- The supracrustal sequences of these two tectonic blocks differ in age and petrologic characteristics. In the RMGGT the greenstone belts of the Andorinhas Supergroup are aged of 2.97 to 2.9 Ga and composed dominantly of metamorphosed tholeiitic basalts and komatiites. In the CB, the supracrustal sequences are included in the Itacaiúnas Supergroup, dated at ca. 2.76 Ga and composed essentially of mafic and intermediate metavolcanics and banded iron formations.

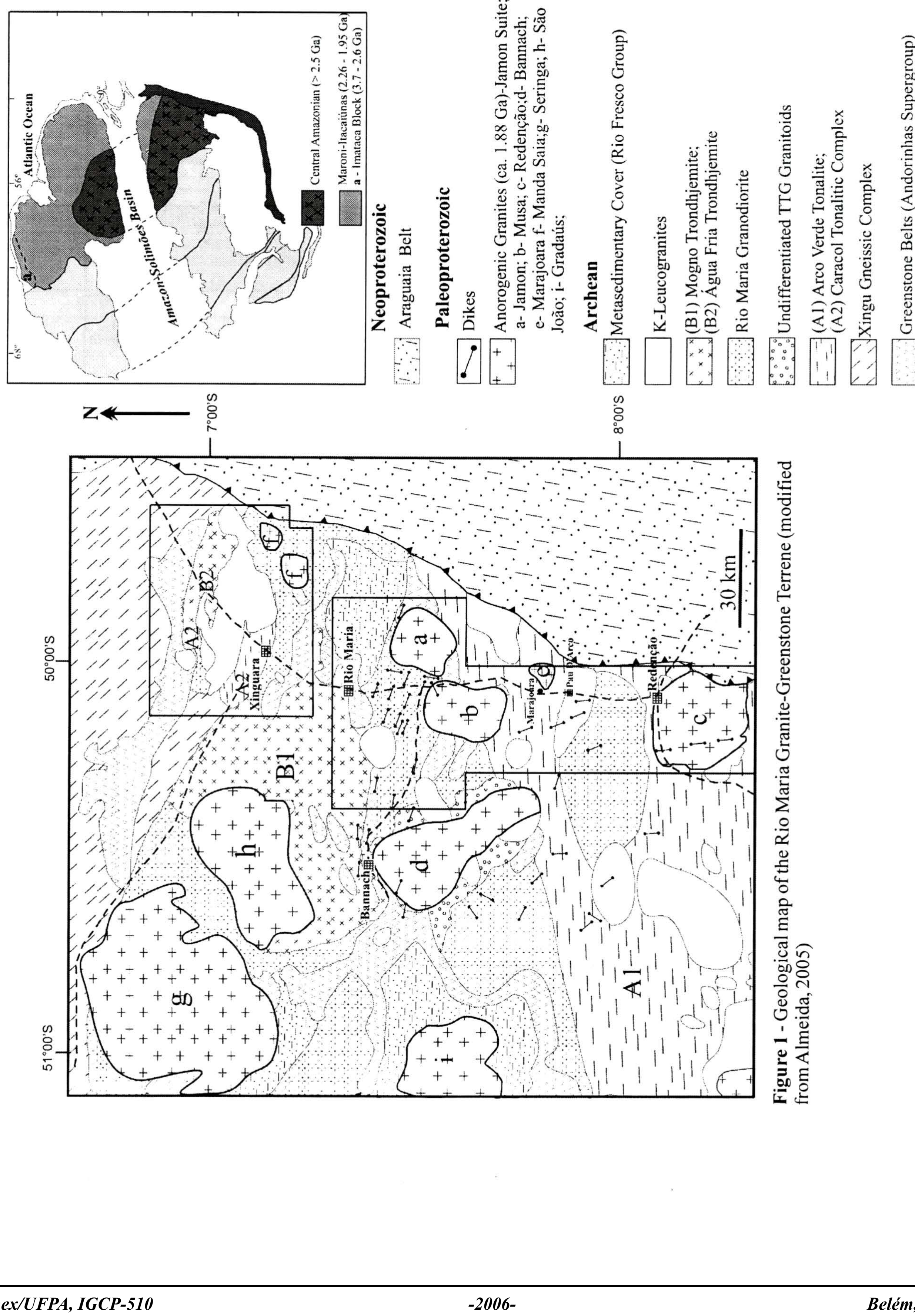

Figure 1 - Geological map of the Rio Maria Granite-Greenstone Terrene (modified from Almeida, 2005)

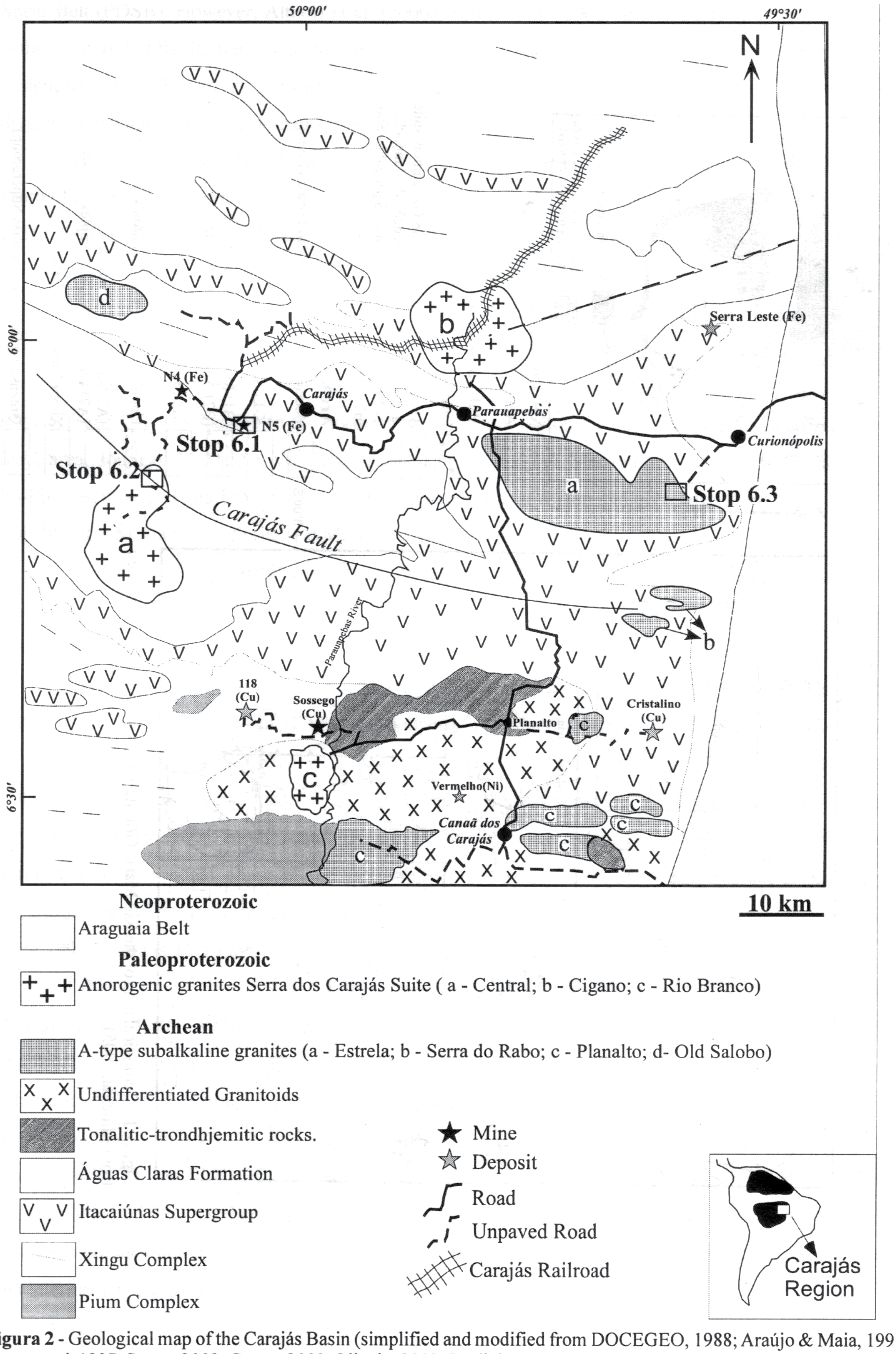

Figura 2 - Geological map of the Carajás Basin (simplified and modified from DOCEGEO, 1988; Araújo & Maia, 1991; Barros et al, 1997; Soares 2002; Gomes 2003, Oliveira 2003; Sardinha 2005)

Table 1 - Geochronology of the Archean rocks of the Basin Carajás, transition domain and Rio Maria Granite Greenstone Terrane.

Stratigraphic Unit	Rock	Method	Analized material	Age
CARAJÁS BASIN AND TRANSITION DOMAIN				
Subalkaline Granites				
Old Salobo Granite	Granite	U-Pb	Zircon	2573± 2 Ma (1)
Estrela Granitic Complex	Granite	Pb-Pb	Zircon	2763±7 Ma (4)
• Planalto Granite	Granite Granite	Pb-Pb Pb-Pb	Zircon Zircon	2747±2 Ma (3) 2734±4 Ma (19)
Serra do Rabo Granite	Granite	U-Pb	Zircon	2743±2 Ma (12)
Plaquê Suite	Granite	Pb-Pb	Zircon	2729±29 Ma (6)
Dioritic Intrusions	Diorite	Pb-Pb	Zircon	2738±6 Ma (3)
TTG series	Tonalite-Trondhjemite	Pb-Pb	Zircon	2750±3 Ma (19)
	Tonalite-Trondhjemite	Pb-Pb	Zircon	2765±39 Ma (19)
Itacaiúnas Supergroup				
Igarapé Salobo Group	Amphibolite	U-Pb	Zircon	2761±Ma (1)
			Titanite	2497±Ma (1)
	Amphibolite	U-Pb	Zircon	2555±Ma (1)
Igarapé Pojuca Group	Amphibolite	U-Pb	Zircon	2732±2 Ma (1)
Grão Pará Group	Felsic Vulcanic rock	U-Pb	Zircon	2757±2 Ma (1)
	Rhyolite	U-Pb	Zircon	2758±39 Ma (2)
Calc-Alkaline Leucogranites	Granite	Pb-Pb	Zircon	2982±1 Ma (19)
Pium Complex	Granulite	SHRIMP	Zircon	2850±10 Ma (5)
	Granulite (enderbite)	SHRIMP	Zircon	3002±14 Ma (5)
Xingu Complex	Granitic Leucossome	U-Pb	Zircon	2859±2 Ma (1)
	Gneiss felsic	U-Pb	Zircon	2851±4 Ma (1)
RIO MARIA GRANITE-GREENSTONE TERRANE				
Calc-Alkaline Leucogranites				
Xinguara Granite	Leucogranite Leucogranite	Pb-Pb Pb-Pb	Zircon Zircon	2865 ± 1 Ma (10) 2875 ± 11 Ma (15)
Mata Surrão Granite	Leucogranite	Pb-Pb	whole rock	2872 ± 10 Ma (16) 2868 ± 5 Ma (14)
Guarantã Granite	Leucogranite	Pb-Pb	Zircon	2930 Ma (17)
Sanukitoid Granitoids				
Rio Maria Granodiorite and related rocks	Granodiorite Granodiorite Quartz-diorite Granodiorite	U-Pb U-Pb Pb-Pb Pb-Pb	Zircon Zircon,Tit. Zircon Zircon	2874 + 9/-10 Ma (7) 2872 ± 5 Ma (8) 2878 ± 4 Ma (18) 2879 ± 4 Ma (15) 2877 ± 6 Ma (13)
Younger TTG series				
Mogno Trondhjemite	Trondhjemite	U-Pb	Titanite	2871 ± ? Ma (8)
Água Fria Trondhjemite	Trondhjemite	Pb-Pb	Zircon	2864 ± 21 Ma (10)
Older TTG series				
Caracol Tonalitic Complex	Tonalite Tonalite Tonalite	Pb-Pb Pb-Pb Pb-Pb	Zircon Zircon Zircon	2948 ± 5 Ma (10) 2936 ± 3 Ma (10) 2942 ± 2 Ma (10)
Arco Verde Tonalite	Tonalite Tonalite Tonalite	U-Pb Pb-Pb Pb-Pb	Zircon Zircon Zircon	2957 + 25/-21 Ma (7) 2948 ± 7 Ma (15) 2981 ± 8 Ma (13) 2936 ± 4 Ma (14)
Greenstone Belts				
Andorinhas Supergroup	Metagraywacke Felsic Metavulcanic rock Felsic Metavulcanic rock	U-Pb U-Pb U-Pb	Zircon Zircon Zircon	2971 ± 18 Ma (7) 2904+29/-22Ma (7) 2972 ± 5 Ma (8)

Data Source: (1) Machado et al. (1991), (2) Gibbs et al. (1986), (3) Huhn et al. (1999), (4) Barros et al. (2001), (5) Pidgeon et al. (2000), (6) Avelar (1996), (7) Macambira (1992), (8) Pimentel & Machado (1994), (9) Dall'Agnol et al. (1994), (10) Leite et al. (2004), (11) Althoff et al. (2000), (12) Sardinha (2002), (13) Rolando & Macambira (2003), (14) Dall'Agnol et al. (In press), (15) Rolando & Macambira (2002), (16) Lafon et al. (1994), (17) Althoff et al. (2000), (18) Dall'Agnol et al. (1999a), (19) Sardinha et al. (2004).

2- The rocks exposed in the RMGGT were formed in between 2.98 and 2.86 Ga (Macambira 1992, Pimentel & Machado 1994, Rolando & Macambira 2003, Leite et al. 2004) and the principal shearing deformational event identified in this block occurred around 2,87 Ga (Althoff et al. 2000, Souza et al. 2001, Leite 2001, Leite et al. 2004). In the CB, the main stratigraphic units were formed in the period of 2.76 to 2.70 Ga and the last Archean deformational events have been dated at 2.58 to 2.50 Ga (Machado et al. 1991). These data indicate that the tectonic stabilization of the RMGGT preceded that of the CB.

3- The Archean granitoids of the RMGGT are represented by several magmatic series which are similar in their broad aspects to those found in other Archean terrains of the World and yielded ages between 2.98 and 2.86 Ga. In the CB, the events of granite formation are not entirely defined, but the occurrence of subalkaline A-type granites, dated at ca. 2.75 Ga and 2.57 Ga (Table 1), besides younger TTG assemblages (~2.76 Ga) represents an important difference between this tectonic domain and the RMGGT.

4- In the northern part of the RMGGT, the final geometric architecture of the greenstone belts was related to a transpressive regime due to the intrusion of the 2.87 Ga granitoids (Souza 1994, Souza et al. 2001). A marginal back-arc basin setting was admitted for the evolution of the mafic-ultramafic sequences of the greenstone belts (2.97 Ga). It evolved to an island magmatic arc, during the generation of the 2.87 Ga granitoids. Althoff et al. (2000) consider that the regional deformation observed in the Marajoara region, in the southern part of the RMGGT, was related essentially to a homogeneous, horizontal shortening. The probable tectonic setting is supposed to be that of a hot protoplate, presenting ductile behavior. Leite (2001) admitted that the Archean geologic evolution of the Xinguara region occurred in two stages. The first started in the interval of <2.96 to 2.91 Ga and was apparently similar to the evolution observed in the Pilbara and Darwhar cratons. The second stage started at 2.88 Ga and was coincident with a sharp change in crustal behavior. At this time, the increasing thickening and stabilization of the primitive Archean crust made more effective the processes of plate subduction and convergence. In this tectonic context, the partial melting of an enriched mantle wedge would generate the parental magma of the Rio Maria Granodiorite and the partial fusion of garnet amphibolites derived from the subducted ocean crust would give origin to the Agua Fria Trondhjemite magma. Finally, the upward movement of these magmas would induce the melting of the older TTGs in the lower crust, thus generating the granitic magmas of the Xinguara pluton.

In the CB, Gibbs et al. (1986) and Lindenmayer (1990) assumed the hypothesis that the supracrustal sequences were related to a continental rift tectonic setting, while Meirelles & Dardenne (1991) and Teixeira & Egler (1994) proposed a model involving a continental margin setting, which evolution was related to the subduction of an oceanic crust, followed by a continent-continent collision (Teixeira & Egler 1994). These two models are still matter of controversy. However, Nd isotope data obtained in the Paleoproterozoic, anorogenic, A-type granites of the CB indicate strong similarities with analogous granites of the RMGGT and favor an ensialic evolution for the CB (Dall'Agnol et al. 2005).

5- It was concluded that, independent of the model to be adopted, the evolution of the Rio Maria Granite-Greenstone Terrane, in one hand, and of the Carajás Basin, in the other hand, show important differences in time and tectonic setting. This is reflected in the contrasting geochemical and petrologic characteristics of their dominant granitic rocks.

GRANITOID SERIES OF THE CARAJÁS METALLOGENIC PROVINCE

Seven granite groups can be distinguished according to geochemical and petrological features. Six groups (1 to 6) have Archaean and one (7) Paleoproterozoic ages. The Archean granitoids furnished ages between 3.0 and 2.57 Ga and the Paleoproterozoic granites between 1.88 and 1.86 Ga. The older Archean granitoid groups occur in the RMGGT: (1) Older tonalitic-trondhjemitic series (TTG); (2) The Rio Maria Granodiorite and similar rocks (sanukitoid series); (3) Younger tonalitic-trondhjemitic series (TTG); (4) Potassic leucogranites of calc-alkaline affinity. The groups (5) and (6) occur only in the Carajás Basin and in the Transition domain. They are represented, respectively, by the granitoids of the Plaquê Suite (Araújo & Maia 1991, Jorge João et al. 1991), exposed only in the transition zone between the RMGGT and the CB, and the subalkaline foliated granites aged of ca. 2.75 Ga (Huhn et al. 1999, Barros et al. 2004, Sardinha et al. 2004), exposed in the Carajás Basin and in the transition zone. The group (7) corresponds to the ca. 1.88 Ga anorogenic, A-type granites and occurs indistinctly in all tectonic domains of the province.

Group 1 - Granitoids of the older (2.98 to 2.93 Ga) tonalitic-trondhjemitic series (TTGs) - These granitoids are represented by the Arco Verde Tonalite (AVT) and the Caracol Tonalitic Complex (CTC), both exposed in the RMGGT (Figs. 1, 9, 11). Similar rocks have been described in the Xingu Complex in the Transition Domain between the RMGGT and the CB, as well as in the CB itself, but in most cases the ages of these TTG granitoids have not been defined. The AVT and the CTC display strong petrographic and geochemical similarity, and analogous stratigraphic position even if their ages are not always coincident (Table 1). The AVT yielded U-Pb and Pb-evaporation ages in zircon of 2.98 Ga to 2.93 Ga (Macambira & Lafon 1995, Rolando & Macambira 2003, 2004; Table 1) and the CTC of 2.95 to 2.93 Ga (Pb-Pb evaporation in zircon ages, Leite et al. 2004; Table 1). These TTGs are the oldest dated granitoids so far, in the CMP. Similar ages were obtained in TTGs of the Xingu Complex (Avelar 1996). The contact relationships of the AVT and the greenstone sequences (Andorinhas Supergroup) are not exposed.

Group 2 - The sanukitoid Rio Maria Granodiorite and associated rocks - The Rio Maria Granodiorite (RMGD) and associated rocks yielded in different areas of occurrence remarkably uniform U-Pb and Pb-evaporation ages of ~2.87 Ga (Table 1). These granitoids are intrusive in the Andorinhas Supergroup (greenstone sequences; Souza et al. 2001) and in the Caracol tonalitic complex and are intruded by the Agua Fria Trondhjemite (Leite 2001). The dominant rocks in the Rio Maria Granodiorite display very typical petrographic features, making relatively easy to identify and to correlate different occurrences of this granitoid. It covers a large area of the RMGGT, being exposed, besides the type area, south of Rio Maria, to the south and NE of Xinguara and to the north of Redenção (Figure 1, 9, 11). Some granitoids described in the Xingu and Carajás regions have been correlated to the RMGD (Costa et al. 1995, DOCEGEO 1988, Avelar 1996), but more detailed studies are necessary to confirm these assumptions. Although a little younger than the RMGD, the Cumaru Granodiorite is also similar petrologically to the RMGD (~2.816 Ga; Santos & Leonardos 1994). Mafic and intermediate rocks, forming enclaves (found in all occurrences of the RMGD), or, more rarely, small bodies (Bannach region, Oliveira 2005), are associated with the RMGD.

Group 3 - Granitoids of the younger (~2.87 Ga) tonalitic-trondhjemitic series (TTGs) – This group is stratigraphically later than the older TTGs described above. It is exposed only in the Rio Maria and Xinguara areas of the RMGGT (Figure 1, 11), and represented by the Mogno Trondhjemite (MTR), and the Água Fria Trondhjemite (AFTR). The MTR yielded an age of 2.87 Ga (U-Pb in titanite; Pimentel & Machado, 1994), and is intrusive in the Identidade greenstone sequence (Huhn et al. 1988, Souza 1994). The AFTR was dated at ca. 2.86 Ga and is intrusive in the Caracol Tonalitic Complex and coeval of the Xinguara Granite (Leite 2001; Leite et al. 2004).

Group 4 - Potassic leucogranites of calc-alkaline affinity - This group is represented by the Xinguara (XG), Mata Surrão (MSG) and Guarantã (GG) granites and by small granitic stocks found in contact with the Identidade greenstone sequence (Figure 1, 9, 11). Several other batholiths and stocks of granitic composition found in the RMGGT were correlated to the mentioned granites (Araújo et al. 1994, Costa et al. 1995, Oliveira 2005). The Mata Surrão Granite is intrusive in the Arco Verde Tonalite (Duarte 1992) and yielded an age of 2.87 Ga (Lafon et al. 1994, Table 1). The Xinguara Granite intruded the Caracol Tonalitic complex and the Rio Maria Granodiorite and is coeval of the Água Fria Trondhjemite (Leite 2001, Leite et al. 2004). The Xinguara Granite furnished an age of ~2.86 (Leite et al. 2004, Table 1). The Guarantã Granite is also intrusive in the Arco Verde Tonalite, however preliminary geochronologic data suggest that it is older than the Mata Surrão and Xinguara granites (Althoff et al. 2000, Table 1). If that age is confirmed, it implies the existence of more than one generation of potassic leucogranites in the RMGGT.

Group 5 - Granitoids of the Plaquê Suite - The Plaquê Granite Suite occurs in the Transition Domain between the RMGGT and the CB. It was defined and originally studied by Araújo & Maia (1991). Leucogranites forming lens or sheeted bodies, elongated along EW are described as representative of this suite. The granites are generally strongly foliated and their contacts with the country rocks of the Xingu Complex are controlled by E-W trending, sinistral reverse-slip faults dipping 60° towards S (Costa et al. 1995). An age of 2729±29 Ma was obtained for a granite of this suite (Avelar 1996; Table 1). This age was interpreted as a minimum age for the suite. However, if admitted that this age corresponds to the crystallization age of the suite, as normally observed in other Pb-Pb zircon ages of the Carajás province (Macambira & Lafon 1995), it implies that the Plaquê Suite is younger than the granitoids of groups 1 to 4 and not related to the evolution of the RMGGT. This hypothesis is assumed in the model proposed by Jorge João et al. (1991) to explain the genesis of the Plaquê Suite. They admit that the Plaquê magmas are related to the melting of the upper crust during the Itacaiúnas Shear Belt development. Field, petrographic, geochronological, and geochemical data of the Plaquê Suite are, however, still very limited and additional information is necessary to a complete characterization of this suite. Many granitic stocks exposed in the transition domain, south of Serra dos Carajás, which were originally included in this suite (Araujo & Maia 1991), have been more recently characterized as subalkaline A-type granites (Gomes et al. 2004, Sardinha 2005), and correlated with the Planalto granite ((Huhn et al. 1999, Oliveira 2003, Table 1).

Group 6 - The ~2.75 Ga subalkaline foliated A-type (?) granites - This group is exposed only in the Carajás Basin and in the Transition Domain. It is represented by the Estrela Granite Complex (Barros et al. 1997, 2004, Barros & Barbey 2001), Serra do Rabo Granite (Sardinha 2002, Sardinha et al. 2006), and Planalto Granite (Huhn et al. 1999, Oliveira 2003, Gomes et al. 2004, Sardinha et al. 2004). The ages of these granites are situated in the interval between 2.76 and 2.73 Ga (Table 1). The area of occurrence of this group of granites is probably underestimated at present. Nevertheless, the absence of this group of subalkaline granites in the Rio Maria Granite-Greenstone Terrane is remarkable, demonstrating the contrasts in tectonic evolution between the later and the Carajás Basin. This indicate that the origin of these subalkaline granites is related to Neoarchean events recorded only in the Carajás Basin domain. The principal petrographic and geochemical aspects of the subalkaline granite group will be discussed in the following. In summary, they are composed dominantly of monzogranites to alkali-feldspar granites, displaying high whole rock and mineral Fe/Mg ratios, as well as HFSE contents. Their geochemical signature is similar to that of A-type granites (Collins et al. 1982, Whalen et al. 1987) and differs entirely of the other Archean granite groups distinguished in this work. This is noteworthy because this kind of granites is commonly subordinate, even not rare, in Archean terranes (Sylvester 1994). On the other hand, these granites are in general strongly deformed and a syn-tectonic emplacement is admitted for the Estrela Complex (Barros & Barbey 2001). In these aspects they differ entirely of the dominant pattern of A-type granites and the tipology and classification of these granites is still debatable.

Other Archean granitoids of local area of occurrence - Besides the granitoids comprised in the six Archean granite groups, there are some worthwhile local occurrences of Archean granitoids, all of them identified in the Carajás Basin or in the Transition Domain. Near Canaã dos Carajás, some distinct granitoids have been identified (Gomes 2003 Gomes et al. 2004, Gomes & Dall'Agnol 2004, Sardinha et al. 2004): 2.93 Ga old calc-alkaline leucogranites, geochemically similar to the potassic leucogranites of the RMGGT (Group 4); Y, Zr, and Ti-rich tonalites and trondhjemites that yielded ages of 2.76 to 2.75 Ga (these peculiar TTG rocks differ from the RMGGT TTGs of groups 1 and 3, in age and geochemical characteristics); 2.74 Ga old dioritic rocks. There are also some geochronologic data suggesting the existence of a second and younger (2.57 to2.52 Ga) generation of subalkaline granites in the northern area of the Carajás Basin. In that area, the Old Salobo Granite (Machado et al. 1991, Lindenmayer et al. 1994), and the foliated granitoids exposed along the Itacaiúnas river (Souza et al. 1995) were described. Their geochemical characteristics are similar to those of the group 6 subalkaline granites.

Group 7 - Proterozoic anorogenic granites - The Proterozoic anorogenic magmatism is one of the most important magmatic events of the Amazonian craton (Dall'Agnol et al. 1994). The anorogenic granites and related rocks of the Amazonian craton are actually correlated to the rapakivi granite series of the Fennoscandian and North-American shields (Rämö & Haapala, 1995, Bettencourt et al. 1999, Dall'Agnol et al. 1999, 2005).

The Proterozoic anorogenic granites of the CMP yielded ages concentrated around 1.88 Ga (Table 2) and are the oldest anorogenic granites of the craton. They form several granite batholiths and stocks, exposed indistinctly in the RMGGT and CB (Figs. 1, 2, 9, 11, 12). They are non-foliated, high-level granites, which were emplaced in a rigid crust and cut discordantly their country rocks. In the contact zones, xenoliths of the country rocks are commonly included in the granites and thermal effects in the adjacent rocks attained the hornblende-hornfels facies contact metamorphism (Dall'Agnol et al. 1994, 1999, 2005, and reference therein).

Table 2 - Geochronology of the Paleoproterozoic A-type granites of the Carajás region

Pluton	Method	Analized material	Age
SERRA DOS CARAJÁS GRANITE SUITE			
Cigano	U-Pb	Zircon	1883 ± 2 Ma (1)
Serra dos Carajás	U-Pb	Zircon	1880 ± 2 Ma (1)
Pojuca	U-Pb	Zircon	1874 ± 2 Ma (1)
ESTRELA DEPOSIT			
Qz-Dior Porphyry	U-Pb	Zircon	1881 ± 5 Ma (6)
Episyenite	U-Pb	Monazite	1875 ± 1.5 Ma (6)
BREVES DEPOSIT			
Granite	U-Pb	Zircon	1879 ± 6 Ma (7)
Biotite Granite	U-Pb	Zircon	1879 ± 11 Ma (8)
Fayalite Granite	U-Pb	Zircon	1853 ± 8.6 Ma (8)
JAMON GRANITE SUITE			
Musa	U-Pb	Zircon	1883 +5/-2 Ma (1)
Jamon	Pb-Pb	Zircon	1885 ± 32 Ma (2)
Seringa	Pb-Pb	Zircon	1893 ± 15 Ma (3)
Redenção	Pb-Pb	Whole rock	1870 ± 68 Ma (4)
Felsic dikes	Pb-Pb Pb-Pb	Zircon Zircon	1885 ± 4 Ma (5) 1885 ± 2 Ma (5)

Data source: (1) Machado et al. (1991), (2) Dall'Agnol et al. (1999c), (3) Avelar et al. (1999), (4) Barbosa et al. (1995), (5) D. C. Oliveira (written communication, 2003), (6) Lindenmayer et al (2006), (7) Tallarico et al. (2004), (8) Botelho et al. (2006).

Considering differences in magnetic susceptibility (MS), geochemistry, petrogenesis, and metallogenesis, the granites of this group were subdivided in three sub-groups (Dall'Agnol et al. 2005, Dall'Agnol & Oliveira 2006): (7a) The high MS, magnetite-bearing, oxidized granites of the Jamon suite, with wolframite mineralization Javier Rios 1995); (7b) the moderately reduced granites of the Serra dos Carajás Suite, with Cu, Au, and Mo mineralization (Javier Rios et al. 1995a,b, Lindenmayer et al. 2006, Botelho et al. 2006); (7c) the low MS, reduced granites of the Velho Guilherme Suite, with tin-mineralization (Dall'Agnol et al. 1993, Teixeira 2001, Teixeira et al. 2002). The Velho Guilherme Suite is located to the western domain of the Carajás Metallogenic Province and will not be visited during the present field trip.

Petrographic, geochemical and petrological characteristics of the Archean granitoids (groups 1 to 6, except for the group 5): a brief summary

The main petrographic and geochemical characteristics of the Archean granitoids of groups 1, 2, 3, 4, and 6 are summarized in some selected diagrams (Figs. 3 to 5).

The modal compositions of representative granitoid suites or complexes are presented in Figure 3. The TTG granitoids (groups 1 and 3) are concentrated in the tonalite/trondhjemite field, with the more evolved rocks passing to the granodiorite field; those of the sanukitoid series (group 2) are concentrated in the granodiorite field, with the more evolved rocks occupying the monzogranite field and the mafic and intermediate rocks the quartz monzodiorite, quartz diorite, monzodiorite, and diorite fields; the potassic leucogranites (group 4) are formed dominantly by monzogranites with subordinate syenogranites and granodiorites. The subalkaline granites (group 6) vary from monzogranite to alkali-feldspar granite.

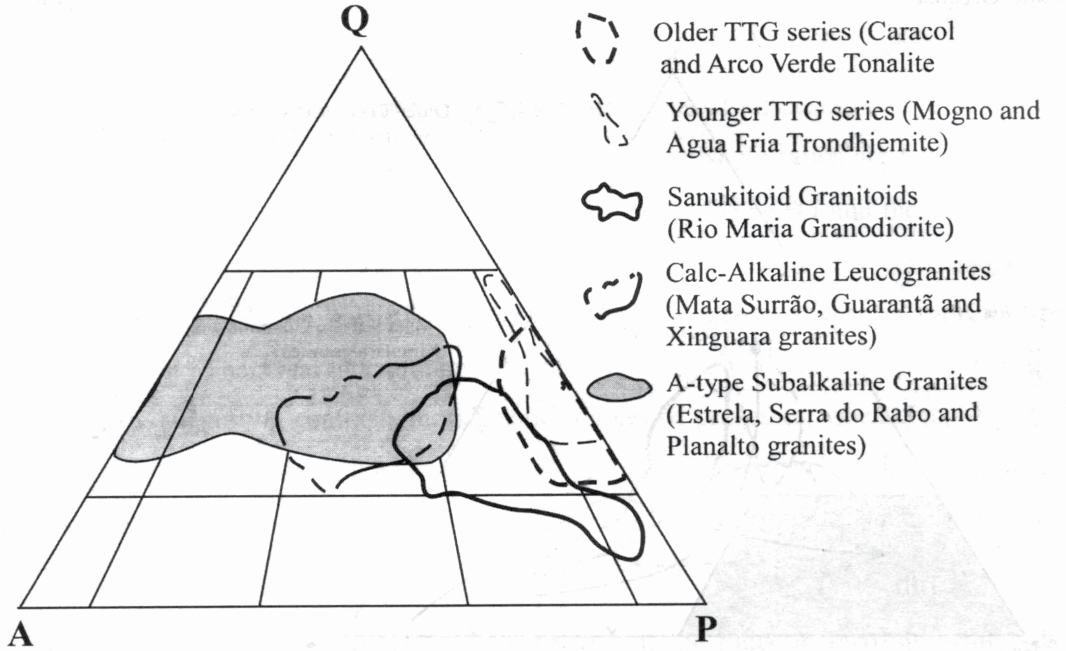

Figure 3 - Modal composition and petrographic classification of the Archean granitoids of the Rio Maria Granite-Greenstone Terrane. Fields from Streckeisen (1976).

There are significant contrasts in modal compositions between the granitoids of the distinguished groups. Except for the TTG granitoids of groups 1 and 3, the other granitoid groups show distinct modal fields in the QAP diagram. The TTGs are characterized by dominance of tonalite and trondhjemite, a classical feature of these series. In the Rio Maria sanukitoid series, granodiorites are largely dominant over other rocks, but the whole series show larger compositional variation than the other groups. The potassic leucogranites are composed essentially of monzogranites with scarce associated granodiorites and syenogranites. Finally, the subalkaline granites are the more evolved granite group, being composed only of granite *stricto sensu*, including in some plutons alkali-feldspar granites.

The An-Ab-Or normative (Figure 4) and the K-Na-Ca diagrams (Figure 5) show also the strong geochemical contrasts between the different groups of granitoids.

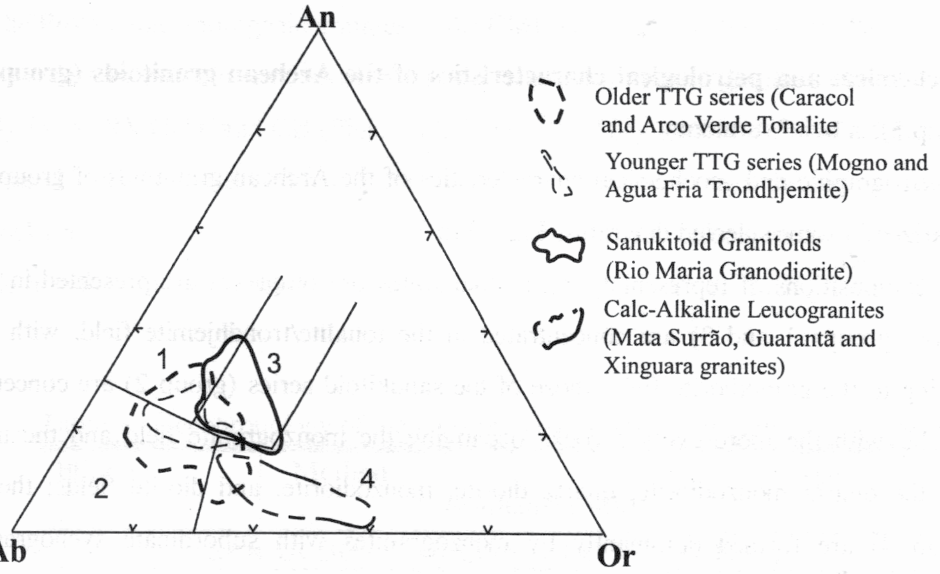

Figure 4 - An-Ab-Or normative diagram showing the distribution of the Archean granitoids of the Rio Maria Granite-Greenstone Terrane. Fields from Barker (1979): 1 - tonalite; 2 - trondhjemite; 3 - granodiorite; 4 - Granite.

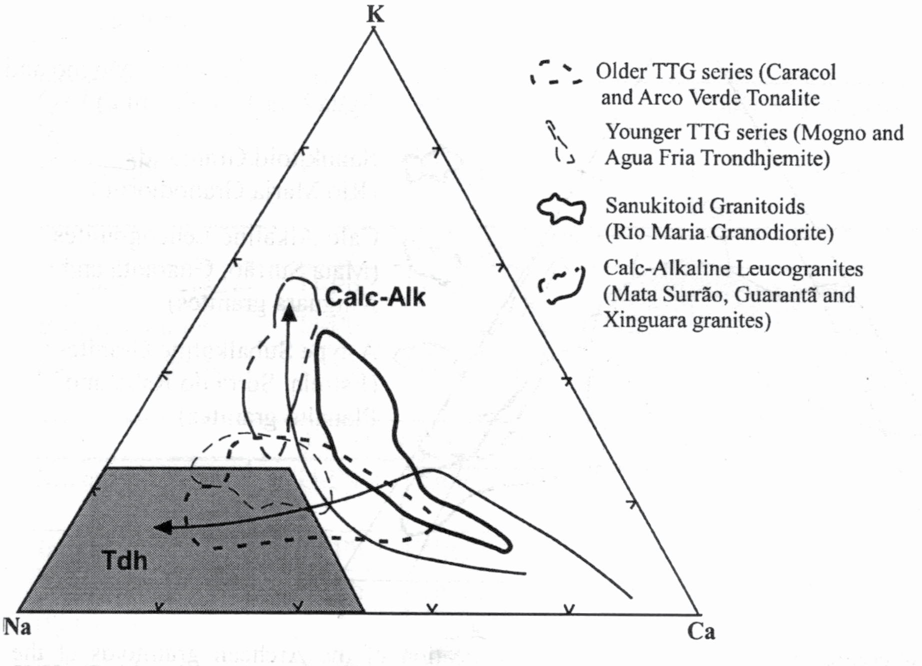

Figure 5 - K-Na-Ca plots (Nockolds & Allen 1953) showing the distribution of the Archean granitoids of the Rio Maria Granite-Greenstone Terrane. Fields from Barker & Arth 1976.

The TTG granitoids display the characteristics of the trondhjemitic series, being relatively enriched in Na_2O and impoverished in K_2O and Rb. Their REE patterns are generally devoid of significant europium anomalies, strongly fractionated and HREE depleted, suggesting the retention of HREE in the source or in fractionated phases (presence of garnet in the melt residue or simultaneous fractionation of plagioclase and amphibole). Althoff et al. (2000) and Leite (2001) assumed that the TTGs derived by partial melting of garnet amphibolites, with the initial magma evolving by fractional crystallization. A similar model was proposed to explain the origin of the dacitic volcanics of the Identidade greenstone sequence, geochemically similar to the TTG granitoids (Souza 1994).

The RMGD and associated mafic and intermediate rocks follow the calc-alkaline series trend in some diagrams. However, they display lower Al_2O_3 and CaO and larger MgO, Cr, and Ni contents compared to calc-alkaline series, approaching geochemically the sanukitoids series (Althoff et al. 2000, Leite 2001, Oliveira 2005). Layered mafic rocks associated with the RMGD occur in the secondary road linking Rio Maria and Bannach towns (Oliveira 2005). Compared to the TTG granitoids, the Rio Maria Granodiorite is enriched in Ca, Mg, K, Cr, and Ni. Its REE pattern is also devoid of significant europium anomalies and strongly fractionated but the depletion in HREE is commonly less pronunciated than in the TTG granitoids. The ubiquity of mafic enclaves associated to the RMGD is seen as an evidence of magma mingling processes, involving the RMGD magma and coeval mafic magmas (Souza 1994, Dall'Agnol et al. 1997, Althoff et al. 2000, Leite 2001, Oliveira 2005). The sources of the RMGD magma are not established. The origin of these rocks could possibly involve: (1) the anatexis of mafic rocks of the greenstone sequences (oceanic crust) in subduction zones with the initial magma interacting with enriched mantle and sialic crust to explain the high contents of some incompatible and transition elements in the actual rocks (Dall'Agnol et al. 1997); or (2) the partial melting of an enriched mantle wedge (Leite 2001). In fact, the origin of these rocks remains an open question.

The potassic leucogranites have, compared to the other granitoids discussed before, lower contents of Na_2O, CaO, MgO, and Sr and higher K_2O and Rb contents. K_2O/Na_2O ratios are higher than the unity. Their Al_2O_3 contents are relatively high (ca. 14 wt.% for SiO_2 near 70 wt.%) and they have calk-alkaline affinities (Sylvester 1994). The Xinguara and Mata Surrão granites have very similar REE patterns, showing only moderate HREE fractionation and a remarkable negative europium anomaly, reflecting important plagioclase fractionation. The Guarantã granite was poorly studied but available data indicate a quite different REE pattern, suggesting contrasts in magmatic sources or processes, when compared to the other mentioned leucogranites. The relatively homogeneous petrographic and geochemical characteristics shown by most of these leucogranites, as well as their evolved compositions, suggest that their magmas were derived by a low degree of melting of crustal granitoid sources (Leite & Dall'Agnol 1999, Leite 2001).

Petrographic, geochemical and petrological characteristics of the Paleoproterozoic granitoids (group 7): a brief summary

Petrography: The modal compositions of representative anorogenic granites are plotted in the Q-A-P and Q-A+P-M' diagrams (Figure 6a). Monzogranites and syenogranites are dominant in the studied complexes and the subordinate occurrence or absence of alkali-feldspar granites, granodiorites and quartz syenites and syenites is noteworthy. Biotite, sometimes partially replaced by chorite or muscovite, is the principal mafic mineral. Iron-rich, calcic amphiboles are found in the less evolved facies of several complexes. Alkaline amphiboles and pyroxenes are systematically absent. The granites display generally medium, even-grained textures. Plagioclase mantled alkali-feldspar have been described in many massifs and are particularly common in the coarse-grained varieties of the Serra dos Carajás and Redenção plutons. *Geochemistry:* The granites are alkaline to subalkaline, metaluminous to mildly peraluminous and have high K_2O/Na_2O and $FeO_t/(FeO_t+MgO)$ ratios (Figure 6b, c). They are enriched in Rb, Zr, Y, Nb, F, and HREE and the more evolved facies have generally very low Sr and Ba contents. In the REE patterns (Figure 7a), negative europium anomalies are enhanced and HREE show gradual increasing with magmatic differentiation. These granites plot in the within-plate field in Pearce at al. (1984) diagrams and have geochemical affinities with the A-type granites (Whalen et al. 1987). Their $FeO_t/(FeO_t+MgO)$ ratios (Figure 6c, d; see Dall'Agnol et al. 2005, Dall'Agnol & Oliveira 2006) are compatible with those of typical A-type granites (Frost et al. 2001). Nevertheless, there are clear contrasts in this ratio between the oxidized (Jamon suite), the moderately reduced (Serra dos Carajás suite) and reduced granites (Velho Guilherme Suite; Figure 6c, d; see Dall'Agnol et al. 2005; Dall'Agnol & Oliveira 2006). The A-type geochemical signature and the affinity with rapakivi granites (Rämö & Haapala 1995) are more evident in the Serra dos Carajás and Velho Guilherme suites. The oxidized granites of the Jamon suite are similar to the magnetite series A-type granites of Central and SW United States (Figure 6d; see Dall'Agnol & Oliveira 2006, Anderson & Morrison 2005). The contrast between oxidized and reduced A-type granites of the Carajás province is also clearly shown by variations in biotite and amphibole compositions in these granites (Figure 7b, c; Dall'Agnol et al. 2005).

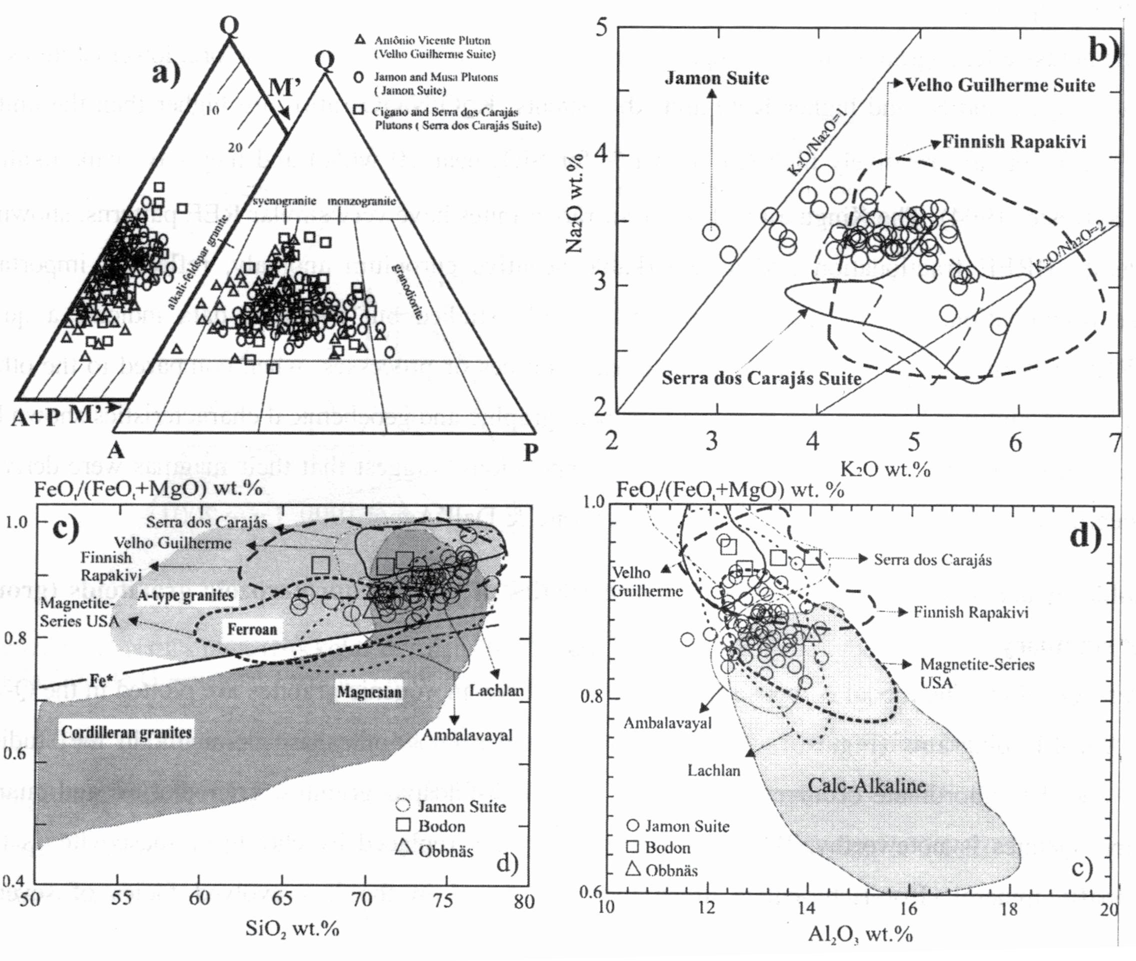

Figure 6 - a) QAP and Q–(A+P)–M' plots for the A-type granites of Carajás. (Dall'Agnol et al. 2005 and references therein).Whole-rock (b) Na2O versus K2O, (c) FeOt/(FeOt+MgO) versus SiO2 diagrams showing composition of A-type granites of Carajás. Fe* line, A-type, and Cordilleran granite fields in c are from Frost et al. (2001). (Dall'Agnol et al., 2005 and references therein). (d) FeOt/(FeOt + MgO) versus Al2O3 diagram showing composition of representative oxidized and reduced A-type granites compared with calc-alkaline granites. Calc-alkaline fields based on Sierra Nevada and Tuolumne granitoids with > 60 wt. % of SiO2, from the data set of Frost et al. (2001). From Dall'Agnol and Oliveira, in press and references therein.

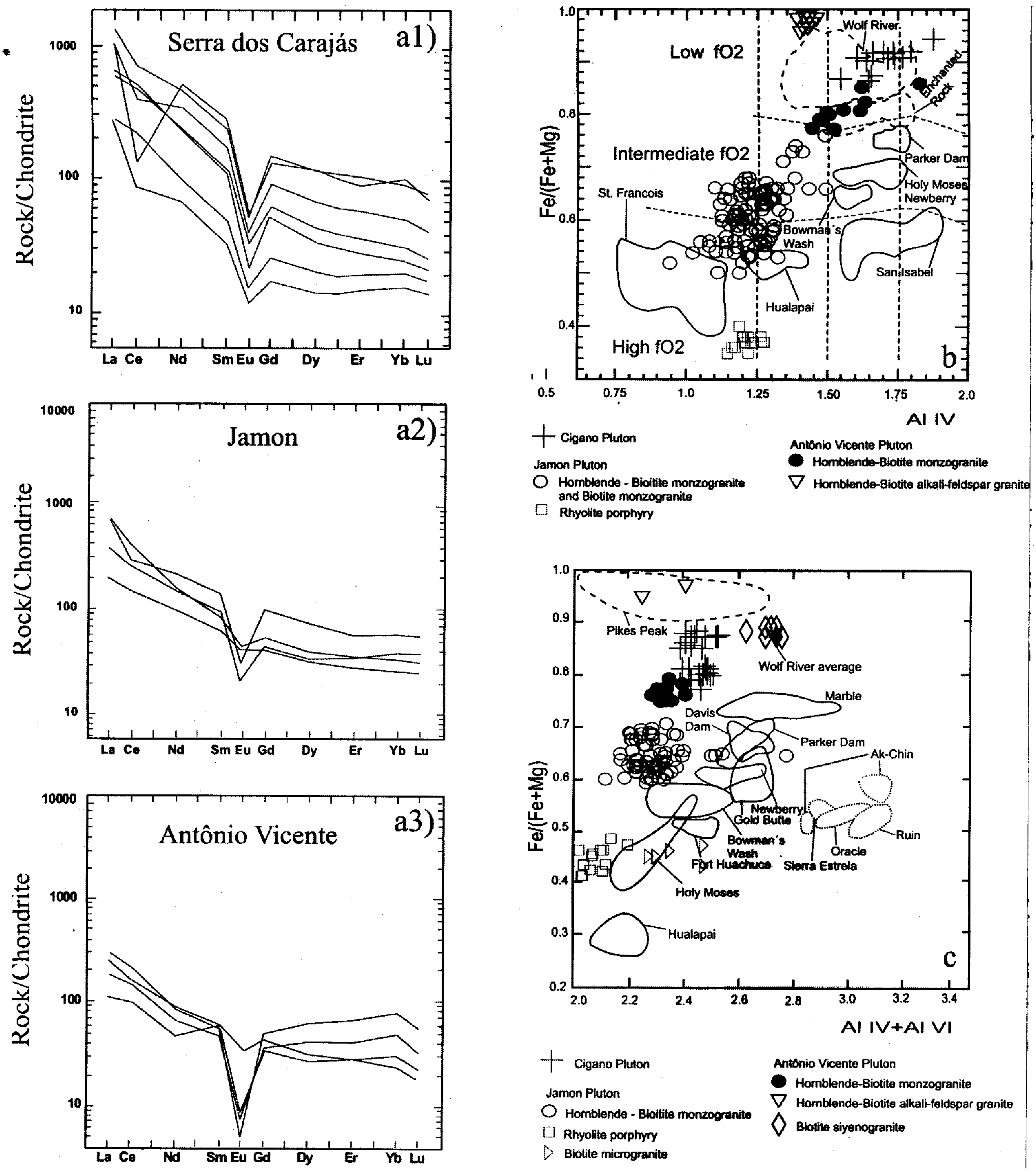

Figure 7 - a) Chondrite-normalized (Evensen et al., 1978) REE patterns for representative granites of the Serra dos Carajás (a1), Jamon (a2), and Velho Guilherme (a3). Source:.Dall'Agnol et al., 2005 and references therein. b) Fe/(Fe+Mg) versus Al IV diagram showing composition of amphibole in the A-type granites of Carajás (Dall'Agnol et al., 2005 and Rämö et al., 2002) and A-type mid-Proterozoic granites of the United States (Anderson and Smith, 1995; Frost et al., 1999) and Fenno s ca ndia (Obbnäs and Bodom plutons; Kosunen, 2004). Continuous fields —

oxidized magnetite-series granites; dashed fields—reduced granites. (c) Fe/(Fe+Mg) versus Al IV+AlVI diagram showing composition of biotite in the A-type granites of Carajás (Dall'Agnol et al., 2005) and A-type mid-Proterozoic granites of the United States (Anderson and Bender, 1989: continuous fields–magnetite-series granites; dashed fields–ilmenite-series granites; dotted fields–two-mica granite; Barker et al., 1975: Pikes Peak; Anderson and Cullers, 1978: Wolf River; Frost et al., 1999: Sherman batholith) and Fennoscandia (Obbnäs and Bodom plutons; Kosunen, 2004).

Petrogenesis: The anorogenic granite magmas are probably derived by the partial melting of lower crustal Archean sources (Dall'Agnol et al. 1994, Dall'Agnol et al. 1999b,c). A evidence favoring this hypothesis is given by the Nd isotope data that indicate Archean T_{DM} mantle depleted ages and strongly negative εNd (-7 to -12) for the studied granites (Rämö et al. 2002, Dall'Agnol et al. 2005). Contrasts in the nature of the sources, as well as in the melting temperatures, water contents and oxygen fugacity of the magmas should explain the differences observed between the distinguished granite sub-groups.

GEOLOGY OF THE AREAS TO BE VISITED DURING THE FIELD TRIP

Introduction

A general location map of the region to be visited during the field trip is given in Figure 8. The geology of the areas included in the field trip will be described and discussed gradually. The descriptions follow the sequence to be respected during the field trip, beginning with those of the RMGGT and ending by those of the Carajás Basin. The location of the stops is indicated generally in the local geological maps and eventually in the regional geological maps. The first day field trip will be employed for the travel from Marabá to Redenção. Arriving to Redenção, after installation in the hotel, before dinner, it will be done a short presentation and discussion about the geology of the Rio Maria Granite-Greenstone Terrane.

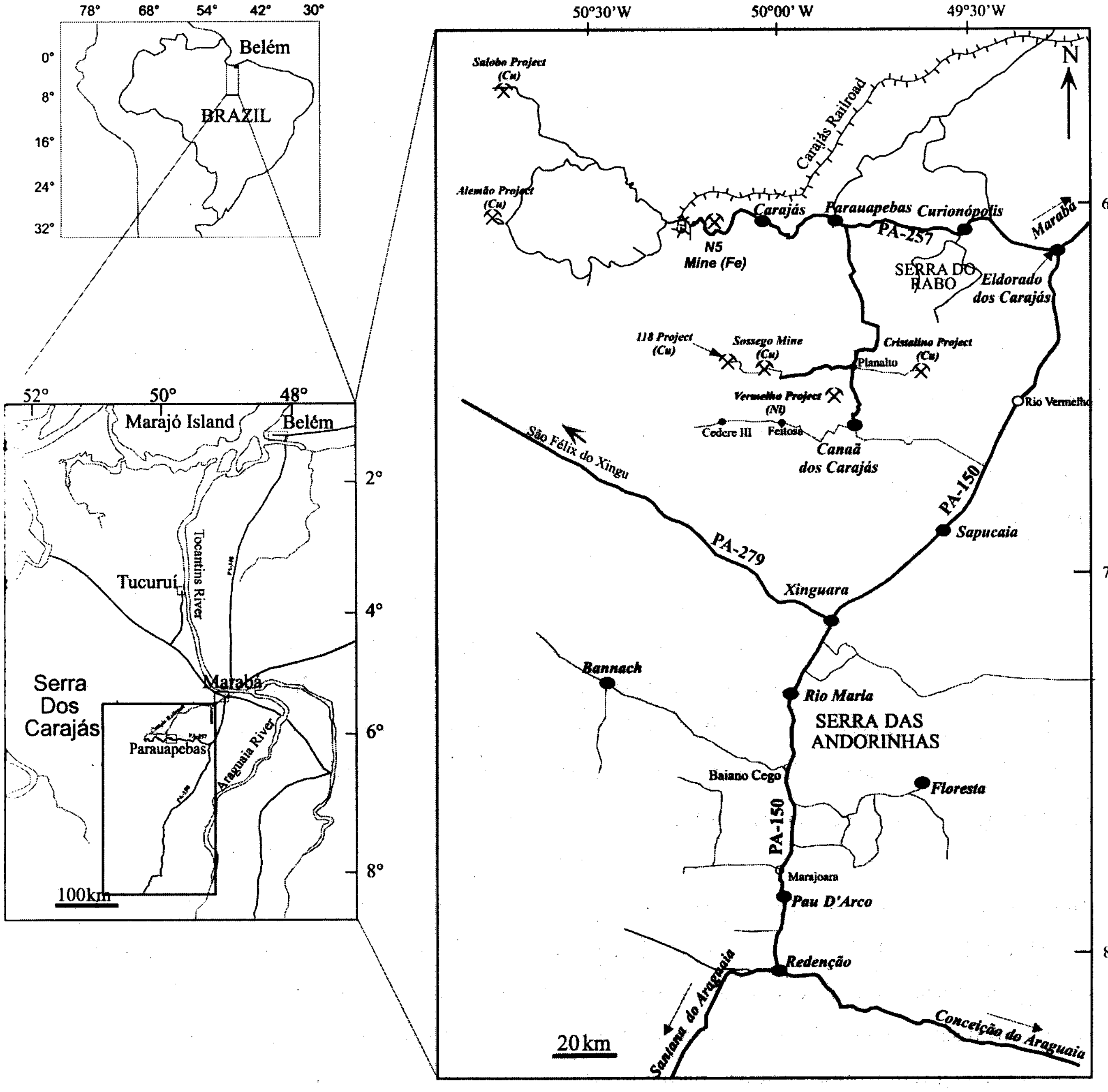

Figure 8 - Location map of the area to be visited during the field trip.

Rio Maria Granite-Greenstone Terrain (RMGGT)

The Redenção and Vila Marajoara Area

F. J. Althoff, D. C. Oliveira, R. Dall'Agnol, M. A. Oliveira, J. A. C. Almeida

The Redenção and Marajoara area will be the first to be visited during the field trip. It corresponds to the southernmost area of the RMGGT to be visited. In this area (Figure 1, 9) are situated the sites where the Arco Verde Tonalite and Guarantã Granite were originally described (Althoff 1996 and references therein). It has also a domain of occurrence of the Rio Maria Granodiorite, several Archean granitic stocks correlated to the Mata Surrão Granite and the Redenção and Marajoara Paleoproterozoic anorogenic granite plutons.

General Aspects of the Granitoids

Arco Verde Tonalite (AVT; 2.98 to 2.94 Ga; Table 1; Group 1) - The AVT is a grey, medium-grained rock; biotite (3-14 modal volume %) is the dominant mafic mineral. The AVT displays a tonalitic or trondhjemitic character in normative Q-Ab-Or diagrams and corresponds to the K-poor calc-alkaline series, similar in mineralogical and geochemical aspects to the Archean TTG series ($K_2O/Na_2O<0.5$; strongly fractionated REE patterns, 6 <La/Yb< 93; and low Yb_N contents, 2.1 - 14.3). The AVT includes centimetric quartz diorite enclaves. A large micaschist xenolith found in the AVT suggests that an older crust existed long before the tonalite crystallization (Althoff 1996). The AVT magma was probably derived by partial melting of amphibole- and garnet-bearing tholeiitic sources (Althoff 1996). The initial magma evolved by fractional crystallization leaving a residue composed of plagioclase (70%), hornblende (24%), biotite (5%) and ilmenite (1%).

Rio Maria Granodiorite (Group 2) - A granodioritic body situated a few kilometers to the north of Redenção (Figure 1, 9) has mineralogical, geochemical and structural characteristics similar to those of the Rio Maria Granodiorite (RMGD; 2874 + 9/-10 Ma; Table 1) and was correlated to that of type-area located in the Rio Maria region (to be visited during the third day of the field trip). The granodiorite is a greenish grey, medium- to coarse-grained rock, containing hornblende and biotite as dominant mafic minerals and common centimetric, mafic enclaves. It has a sanukitoid character, K_2O/Na_2O ratios > 0.5, relatively high MgO (mg > 0.45), FeO_t, CaO and transition-trace element contents (Cr and Ni).

Mata Surrão and Guarantã Granites (MSG and GG; ~2.87 Ga and ~2.93 Ga, respectively; Table 1; Group 4) - The GG and MSG crosscuts the AVT. The Mata Surrão Granite Suite assembles heterogeneous monzogranite facies with mineralogical and structural similarities, that occurs in two major domains and in several small satellite bodies. It is a pink, hololeucocratic, coarse-grained and locally porphyritic (microcline) rock, containing rare dioritic enclaves. Biotite is the main mafic phase. These leucogranites are included in the group 4 granitoids and are representative of the more evolved K-rich calc-alkaline

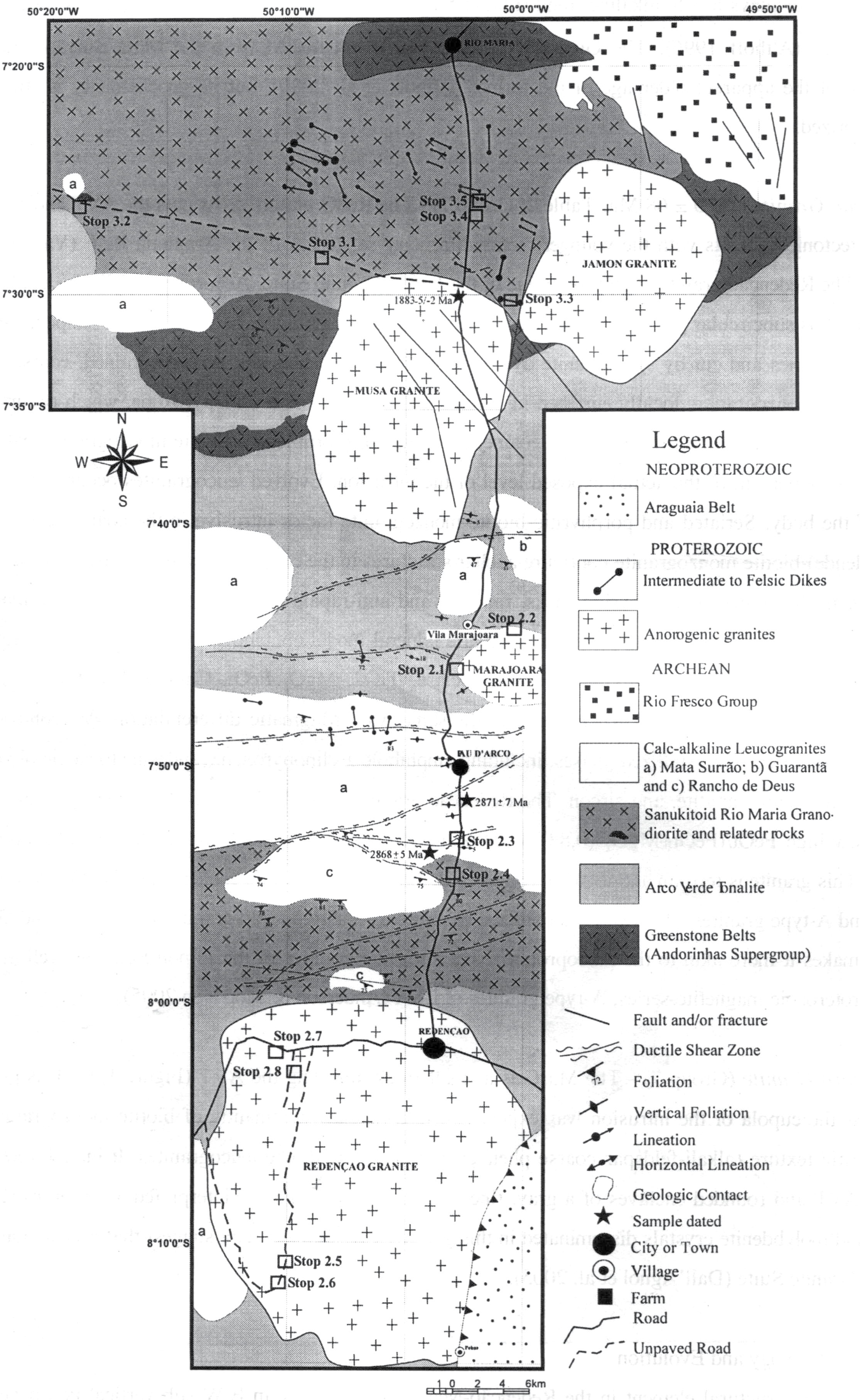

Figure 9 - Geological map of the Redenção-Rio Maria Area (Modified from Gastal 1987, Medeiros 1987, Duarte 1992, Althoff 1996, Oliveira 2001, Oliveira 2005).

series. They displays a calk-alkaline trend (Figure 5), K_2O/Na_2O ratios > 0.8 and Yb_N values ranging from 12.1 to 9.1 (Althoff 1996). The Guarantã Granite was distinguished from the Mata Surrão Granite in function of the apparent older age of the former (Althoff et al. 2000), but its geochemistry is still poorly characterized.

Redenção Granite (1870 ± 68 Ma, Table 2; Group 7) - The RedG pluton cross cuts the AVT and MSG and shows tectonic contacts with the younger metasedimentary sequences of the Araguaia Belt (Vale & Neves 1994). The Redenção granite is representative of the Jamon Granite Suite. According to Oliveira et al. (2005, in prep.), this subcircular granitic pluton (Figure 10) is formed essentially of monzogranites disposed in near-concentric zones and cut by syenogranite dykes. The less evolved facies is an even-grained, coarse biotite-hornblende monzogranite, locally enriched in cumulatic (?) amphibole ± clinopyroxene, which occurs in the southern part of the pluton. It grades to a coarse, even-grained (hornblende)-biotite monzogranite that covers roughly fifty percent of the actual exposed level of the intrusion. Evolved leucogranites occur in the central part of the body. Seriated and porphyritic biotite monzogranite facies intrusive in the coarse- even-grained (hornblende)-biotite monzogranite configure anellar structures in the central and southern areas of the pluton. Locally, in the coarse or porphyritic rocks, rapakivi and anti-rapakivi textures are present. The magmatic zoning is marked by a systematic decrease of mafic mineral modal content, plagioclase/potassium feldspar, amphibole/biotite and anorthite content of plagioclase. TiO2, MgO, FeOt, CaO, P2O5, Ba, Sr, and Zr decrease, and SiO2, K2O, and Rb increase in the same way. Magmatic differentiation was controlled by fractionation of early crystallized phases, including amphibole ± clinopyroxene, andesine to calcic oligoclase, ilmenite, magnetite, apatite, and zircon. The Redenção granite is subalkaline, metaluminous to peraluminous and show high FeOt/(FeOt+MgO) (0,83 to 0,95) and K2O/Na2O (1 to 2) and moderate K/Rb (100-300) ratios. This granite is ferroan alkali-calcic (Frost et al. 2001) and displays geochemical affinities with within-plate and A-type granites. However, the oxidized character of the Redenção granite (Dall'Agnol and Oliveira 2006) makes it more akin to the Paleoproterozoic anorogenic granites of the Jamon Suite, as well as to the Mesoproterozoic magnetite-series, A-type granites of USA (Anderson & Morrison 2005).

Marajoara Granite (Group 7) - The MarG is a small stock intruding the AVT (Figure 1, 9). It is probable that just the cupola of the intrusion was exposed. It is composed dominantly of biotite monzogranite with porphyritic texture (alkali-feldspar coarse phenocrysts) and subordinate leucogranites. It includes xenoliths of the AVT and rounded enclaves of a gray, fine-grained quartz porphyry, interpreted as autoliths. Locally are found molybdenite crystals disseminated in this granite. Geochemical data suggest that it is similar to the Jamon Granite Suite (Dall'Agnol et al. 2005).

Structural Geology and Evolution

The principal structural element in the Redenção-Marajoara region is an E-W sub-vertical non penetrative foliation. Alike other structures, this foliation is well developed in the Arco Verde Tonalite and potassic

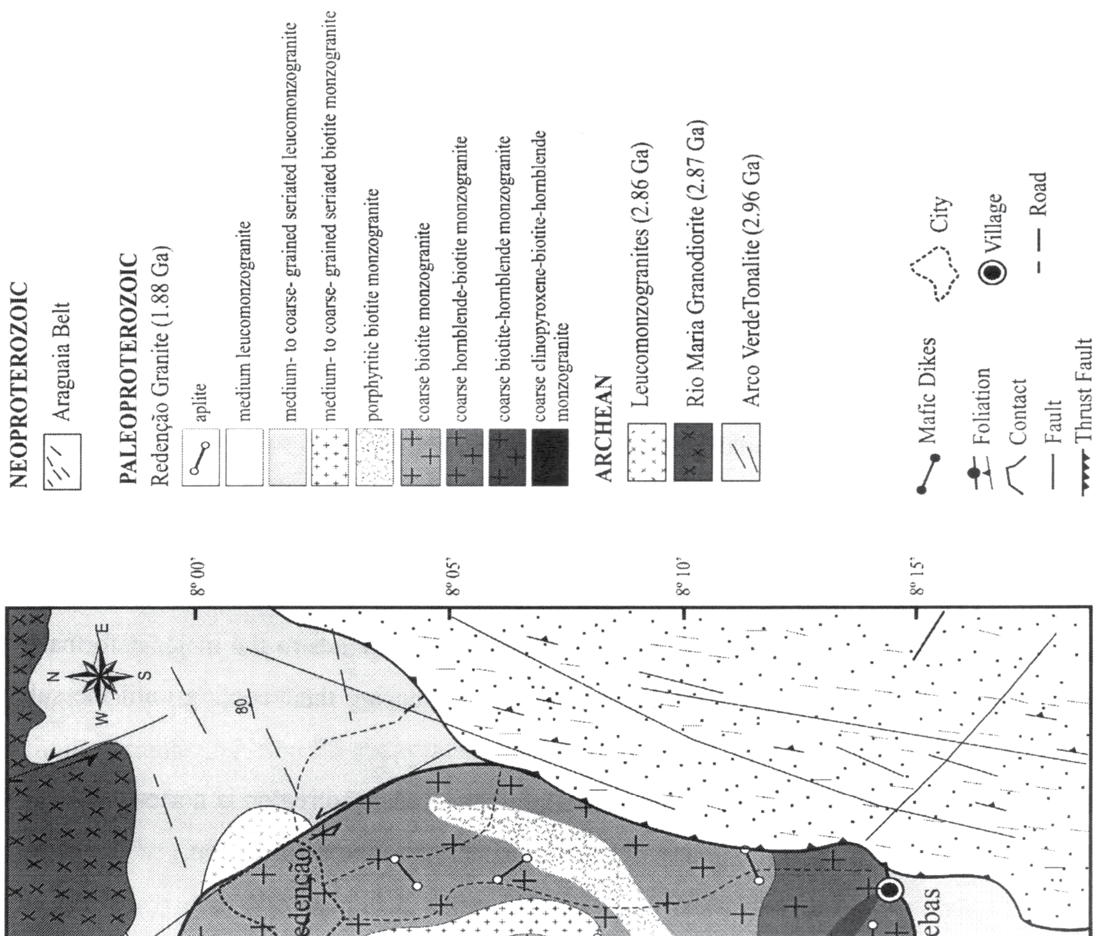

Figure 10 Geological map of the Redenção pluton showing the areal distribution of the different facies (Oliveira et al. submitted).

leucogranites. The structures identified are: (1) magmatic stage - vertical layering and locally preserved, syn-magmatic shear zones; (2) subsolidus stage - vertical schistosity, weak horizontal lineation and conjugate vertical shear-zones, veins, tension gashes. These structures suggest that these granitoids suffered a strong regional shortening under conditions ranging from high-T (near solidus and subsolidus ductile deformation; strong quartz and feldspar recrystallization) to low-T (low grade brittle deformation). The structures were acquired mostly during the cooling of the igneous plutons, under a decreasing T-gradient within a regional stress field.

These structures are almost absent in the Rio Maria Granodiorite that, excepting rocks affected by local shear zones, is generally little deformed (weakly recrystallized quartz, undulose extinction in feldspars). It shows, locally, a foliation and weakly shortened mafic enclaves.

The structures registered in the three granitoids point to strong horizontal shortening oriented N10-20E in the region. The finite strain analysis (Panozzo method) shows that the AVT and GG where submitted to flatenning. These two granitoids were very probably affected by a same deformation event synchronous with their emplacement. The 2.87 emplacement age of the RMGD dates the end of the shortening processes. In this evolution two points need to be emphasized: (1) the flattening is not a late event in the regional story. It is synchronous with the emplacement of the granitoids and corresponds to the major deformation; (2) the deformation did not affect gneissic rocks but magmatic rocks during their cooling until the submagmatic stage.

The absence of tangential structures in the Marajoara-Redenção region is norteworthy. This feature can be due to a predominant ductile response of the Archean crust to the deformation.

Selected points to be visited:

Stop 2.1 - ca. 32.5 km to the north of Redenção, on the eastern side of the PA-150 road, small secondary way conducting to the top of a hill. After ~300 m in the SE direction, flat outcrop and associated boulders of the Arco Verde Tonalite in the southern side of the way.

The tonalite is a medium-, even-grained rock, with biotite as the main mafic phase. It shows a slightly undulated banded structure, alternating comparatively more mafic or felsic bands orientated around 100 to 110° Az. It includes quartz dioritic enclaves with evidences of local resorption. Locally there are blocks of gray, medium- to coarse-grained granites related to the Mata Surrão granite.

Stop 2.2 – ca. 2 km to the north of stop 2.1, arriving at Vila Marajoara, it should be taken a secondary way to the east, conducting to an older, abandoned quarry. It is exposed on this quarry the contact between the Marajoara Granite (Jamon Suite) and the Archean Arco Verde Tonalite (Group 1 granitoids).

The Marajoara granite is a light rose biotite monzogranite with porphyritic texture, showing coarse phenocrysts of K-feldspar in a medium-grained matrix. This granite includes globular enclaves of light gray porphyritic quartz porphyry, with dropped phenocrysts of K-feldspar and plagioclase in a fine-grained matrix. Similar enclaves are also common in other areas of the pluton. Textural and field evidence suggest that these enclaves are coeval with the granite. They probably represent partially molten bubbles of a magma that coexisted with the Marajoara monzogranite magma during its emplacement. There are local occurrences of molybdenite and pyrite associated with the Marajoara granite.

The Marajoara granite display sharp discordant contact with the Arco Verde Tonalite. In the quarry, it is possible to observe the interaction between both rocks with different degrees of resorption and corrosion of the tonalites along the contacts. The tonalite is a foliated rock while the Marajoara granite is a isotropic rock. Locally there are large mica crystals (siderophyllite?) concentrated along the contacts of later granite veins and the country rocks. A nice picture obtained in this quarry shows the Marajoara granite including an ellipsoidal enclave of quartz porphyry that, at its place, encloses irregular centimetric xenoliths of the Arco Verde tonalite.

The Marajoara Granite is geochemically similar (D.C. Oliveira, unpubl. data) to the Jamon Suite granites, with low Al_2O_3 and CaO, high $FeO_t/(FeO_t+MgO)$ and moderate K_2O/Na_2O (>1). The associated granite porphyry has a monzogranitic composition and is less evolved compared to the Marajoara varieties, as indicated by the lower SiO_2 and higher FeO_t, MgO, TiO_2, CaO, P_2O_5, Ba, and Sr, contents of the former. The Marajoara evolved leucogranites are extremely impoverished in Sr and Ba and enriched in Rb.

Stop 2.3 – Returning in the direction of Redenção along the PA-150 road, 16.4 km to the south of Vila Marajoara, in the west side of the road, crops out the Mata Surrão Granite. Near 2 km to the west of this point, a similar granite yielded a Pb-evaporation age on zircon of 2868 ± 5 Ma (CPRM in press).

The granite is a porphyritic monzogranite with coarse, K-feldspar phenocrysts in a medium- to fine-grained matrix. The granite displays a penetrative 100-110° Az foliation, interpreted as related to regional shortening caused by near N-S dominant stress. It has been affected in a second moment by intense dextral shear deformation (115 ° Az shear zones), as revealed by deformed K-feldspar phenocrysts.

Stop 2.4 - At ca. 3.6 km to the south of the stop 2.3 or at ca. 15 km to the north of Redenção, along the PA-150 road. In the western side of the road, it is exposed a large outcrop of boulders of the Rio Maria Granodiorite.

Except for the fact that its modal amphibole contents are comparatively higher, the Rio Maria Granodiorite exposed in this area is extremely similar to that of the type locality to be visited tomorrow. It displays the typical greenish-gray color and coarse- to medium-grained granular hipidiomorphic texture characteristic of this granitoid. The greenish tonality is due to the intense saussuritization of the plagioclase. The granodiorite includes here fine-grained, centimetric, mafic enclaves formed essentially by hornblende, biotite, and plagioclase. Scarce quartz-feldspathic veins, ocassionally with sulfides, cut the granodiorite.

The granodiorite is massive or shows steep, EW-trending foliation, outlined by amphiboles and little shortened enclaves. Scattered quartz filled, tension gashes, perpendicular to the foliation, and decimeter-scale shear zones can be observed. In the Redenção-Marajoara area, the RMGD is later than the major Archean deformation that affected the AVT and the GG.

Stop 2.5 – Returning to Redenção along the PA-150 road, it will be turned to the west just before to arrive to Redenção, following towards Santana do Araguaia. The road is situated along a flat area that corresponds to the coarse biotite monzogranite domain of the pluton. Looking to the south, it is possible to see the salient relief of the Redenção pluton, corresponding to the domains of the seriated biotite monzogranite and seriated leucogranite (Figure 10).

At ca. 10 km to the west, it will be taken a secondary road towards the south. The secondary road is located on a valley flanked to the east by the domain of leucomonzogranites and to west by the porphyritic biotite monzogranite. Along the valley are exposed coarse biotite monzogranites. The outcrop to be visited is located at ca. 20 km south, near the southwestern border of the Redenção pluton (Figs. 9, 10). It is situated on the western side of the secondary road.

In the south part of the pluton, the less evolved, relatively mafic-enriched (clinopyroxene)-biotite-hornblende monzogranites are largely dominant. The rock exposed at this site is a rose to reddish, coarse-even-grained hornblende-biotite monzogranite, showing sparse centimetric plagioclase mantled K-feldspar crystals and clusters of mafic minerals. This kind of rapakivi texture is common in the Redenção pluton.

Stop 2.6 – Towards south along the same road, about 800 m after stop 2.5 on the northwestern side of the road.

Relatively large blocks and boulders of coarse- even-grained biotite-hornblende monzogranite, similar in texture to the monzogranite observed in the stop 2.5, but comparatively enriched in mafic minerals and plagioclase. Associated to it, a coarse- to medium-grained seriated monzogranite and a fine-grained leucogranite are found, both showing evidences of interaction with the biotite-hornblende monzogranite. The field and textural relationships between the different rocks suggest the coexistence of magmas in a partially molten state and their interaction by means of magma mingling processes. Aplitic dikes are commonly found cross-cutting the less evolved facies.

Stop 2.7 – Return to the PA-150 road, turning to the west towards Santana do Araguaia. At ca. 4 km, turning in a small way towards the southern side of the road, it is found at ~500 m, a small abandoned quarry.

The facies largely dominant in the quarry is a rose to reddish, coarse-grained, biotite-monzogranite, showing sparse and conspicuous centimetric rose alkali feldspar crystals mantled by white or gray plagioclase (rapakivi texture). This rock is representative of the coarse biotite monzogranite dominant in the northern area and in the whole pluton. It is generally weathered in the outcrops and is generally exposed in the areas of lowest relief.

Stop 2.8 – Returning ~2 km from stop 2.7 along the PA-150, a secondary road is located on the southern side of the PA-150 road. After ~3 km on this road, a small quarry is found.

Along the road, it is possible to see a relatively high relief area, corresponding to the seriated biotite monzogranite domain, contrasting with the flat domain occupied by the coarse biotite monzogranite. The quarry is located on the base of a hill that is formed dominantly by a reddish-gray, coarse- to medium-grained seriated biotite monzogranite associated with a coarse biotite monzogranite. A remarkable feature is the evidence of magma mingling processes involving the mentioned rocks. This is suggested by the presence in the seriated biotite monzogranite of K-feldspar megacrystals in a medium-grained matrix. These megacrystals display generally rapakivi texture and give a local porphyritic aspect to the seriated biotite monzogranite. These megacrystals were interpreted as coarse crystals of the biotite monzogranite dropped into the medium-grained monzogranite (Oliveira et al. submitted). These rocks, as well as those exposed in the point 2.7, have been exploited for ornamental stone purposes.

The Rio Maria Area

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The Rio Maria area (Figs. 1, 9; Medeiros et al. 1987, Huhn et al. 1988, Huhn 1991) is characterized by the occurrence of several greenstone belts appertaining to the Andorinhas Supergroup (Lagoa Seca, Babaçu, Pedra Preta and Serrinha sequences). They are intruded by the Rio Maria Granodiorite and partially covered by the sedimentary rocks of the Rio Fresco Group. The type locality of the Rio Maria Granodiorite is the section along the PA-150 road to the south of Rio Maria. The first 2.87 Ga U-Pb zircon ages (Table 1) of the RMGD were also obtained in samples from this area, but they were reproduced more recently in samples from other areas of RMGGT (cf. Table 1). The Archean units are intruded by the Paleoproterozoic (1.88 Ga; Table 2) Jamon and Musa granites, as well as by basic, intermediate and felsic dikes, all included in the Jamon Suite.

The Greenstone sequences (Andorinhas Supergroup)

The Andorinhas Supergroup comprises the Babaçu and Lagoa Seca Groups (Huhn et al. 1988). The Igarapé Encantado Formation is the basal unit of the Babaçu Group. It is composed dominantly of talc and/or chlorite ultramafic schists and serpentinites, with subordinate banded iron formations, mafic and felsic metavolcanics. Spinifex textures are sometimes preserved and chemical analysis defined the komatiitic character of the ultramafic rocks. The Mamão Formation, the other stratigraphic unit of the Babaçu Group, is better exposed to the south of the Serra das Andorinhas, where it corresponds to the basal sequence. Massif metabasalts, locally intercalated with metatuffs, talc schists and metamorphosed chemical sediments, are the dominant rocks.

The Lagoa Seca is the upper sequence of the Andorinhas Supergroup. It comprises the Fazenda do Quincas Formation, formed predominantly by metamorphosed graywackes and siltstones, and the Recanto Azul Formation, composed by metamorphosed andesites, dacites and rhyolites, intercalated with clastic sediments and thin levels of mafic and ultramafic metavolcanics.

Important gold and sulfide mineralizations have been found in the contact between the basaltic komatiites and the banded iron formations of the Babaçu Group. The gold deposit is related to several small ore bodies located in a major shear zone striking NE and dipping 45° to the north. The ore bodies are disposed parallel to down dip stretching lineation along the shear zone. There are also small gold deposits associated to the shear zones developed in the mafic-ultramafic rocks of the Lagoa Seca Group.

The Rio Maria Granodiorite (RMGD, Group 2)

The RMGD was studied in its type area by Medeiros (1987), Medeiros & Dall'Agnol (1988) and Huhn et al. (1988). It shows a very typical greenish gray color and a medium to coarse even-grained texture. Foliation is weakly developed, except in local shear zones. Mafic enclaves are common and small bodies of basic rocks were identified to the east of Bannach town (to the west of the area of Figure 9; see Oliveira, M.A. 2005; Oliveira, M.A. et al. submitted). Monzogranites are dominant along the road from Rio Maria until the crossing to Babaçu and Lagoa Seca, while the typical granodiorites are better exposed in the southern and western areas of the batholith (Figure 9). Near the contacts with the anorogenic granites the RMGD is strongly affected by contact metamorphism. The originally green saussuritized plagioclase is recrystallized to granoblastic, mosaic-shaped andesine or calcic oligoclase (Soares 1996, Oliveira, M.A. 2005) and the rock color changes to rose gray. Magnetite grains are formed during metamorphic reactions and magnetic susceptibility values increase remarkably in the rocks affected by contact metamorphism (Magalhães & Dall'Agnol 1991, Soares 1996). The RMGD has been exploited as an ornamental stone.

The intermediate to mafic rock bodies associated with the Rio Maria Granodiorite will not be visited during the field trip, except for a special occurrence of layered igneous amphibole-rich mafic rocks described in the following (stop 3.2). It is worthwhile to say, however, that the characterization of these intermediate and mafic rocks was of great relevance to define the Rio Maria granitoids as a diversified sanukitoid series (Oliveira, M.A. 2005). The presence of these rocks, associated to the omnipresence of abundant coeval mafic enclaves in all occurrences of the Rio Maria Granodiorite (Althoff et al. 2000, Souza et al. 2001, Leite 2001, Oliveira, M.A. 2005), indicate that mafic rocks played an essential role in the evolution of these granitoids.

The Rio Fresco Group

The Rio Fresco Group (RFG) is exposed in the Serra das Andorinhas (Figs. 1 and 9). It is a transgressive, clastic sequence, composed dominantly of quartzites which grade upwards to siltstones and chemical sediments. Huhn et al. (1988) and DOCEGEO (1988) consider that the stratigraphic relationships between the RFG and the Andorinhas Supergroup characterize an unconformity. Moreover, Macambira (1992) studied detrital zircons of the RFG and suggested that they were derived from the greenstone belts and the Archean Arco Verde Tonalite and Rio Maria Granodiorite. These data suggest that the RFG is younger than the mentioned units and possibly coeval of the Águas Claras Formation of the Carajás Basin (Figure 2).

The Jamon and Musa Granites (Group 7)

These granite bodies have similar petrographic and geochemical characteristics and are included in the Jamon Suite (Dall'Agnol et al. 2005). The Jamon Granite (JG) was studied by Dall'Agnol et al. (1999b, c) and the Musa Granite (MuG) by Gastal (1987). The JG is formed essentially by four monzogranite facies. The less evolved have hornblende associated to biotite and the more differentiated only biotite. Geochemical modeling suggest that the JG magma was derived by partial anatexis of Archean rocks similar to quartz diorites associated to the Rio Maria Granodiorite and the initial magma evolved by fractional crystallization (Dall'Agnol et al. 1999b). Experimental studies carried on a hornblende-biotite monzogranite sample of the JG demonstrated that this granite crystallized in a temperature interval of 900°C to ca. 700°C at relatively high oxygen fugacity conditions (Dall'Agnol et al. 1999c). Nd isotope studies (Rämö et al. 2002, Dall'Agnol et al. 2005) demonstrated that the granites of the Jamon Suite have Archean T_{DM} ages (depleted mantle model) and display systematically strongly negative Nd (-7 to -11, with an average of -9), These data indicated that the Jamon Suite granites derived from Archean igneous crustal protoliths.

The MuG has syenogranite facies associated to monzogranites very similar to those of the JG. It differs a little from the JG in the REE and Y behavior, suggesting a stronger influence of amphibole fractionation during the MuG evolution. The source for the MuG is probably very similar to that of the JG (Dall'Agnol et al. 1999b, 2005).

Proterozoic Dikes

Proterozoic dikes trending preferentially WNW-ESE or eventually NE-SW or near N-S are commonly found cutting the Archean rocks and locally the MuG (Gastal 1988, Silva Jr. 1996, Silva Jr et al. 1999, Dall'Agnol et al. 2002., Oliveira, D.C. in prep). These dikes have a maximum width of 15 to 20 meters and locally can be followed by several hundred meters. Diorites and quartz diorites are dominant, but basic and felsic dikes (dacites and granite porphyries) have also been described. The geochemical data suggest that the basic and intermediate dikes are not cogenetic. The felsic dikes yielded equivalent ages (Table 2) and are similar in mineralogy and geochemistry to the Jamon Suite granites. It was concluded that granites and felsic dikes should have a related origin and they were all included in the Jamon suite. The basic dikes were not dated so far, but the recent find of a composite dike of diabase and granite porphyry (stop 3.3 of the field trip), indicate that at least some of the mafic dikes are coeval of the felsic magmatism. This composite dike cuts the Rio Maria Granodiorite and there is evidence of coexistence in the partially molten state of both basic and acid magmas (enclaves of diabase in the granite porphyry showing feldspar phenocrysts interpreted as dropped crystals from the granite porphyry).

Selected points to be visited during the field trip:

Stop 3.1 – From the PA-150, ca. 60 km to the north of Redenção, turn to the west on the Baiano Cego locality; the selected point is located at ca. 10.3 km to the west, on the southern side of the road towards

Bannach town. The road is located near the northern border of the Musa pluton and looking to south it is possible to see some hills formed by this granite. Leaving the Musa granite domain, it is found a flat area where it is exposed the Rio Maria Granodiorite.

In the site choosen for visitation, the abandoned Marajoara's quarry, there is a good exposition of the typical Rio Maria Granodiorite, displying its greenish gray color and including many mafic enclaves. These are strongly flattened enclaves, orientated in the ~E-W direction and vertically disposed. Brittle to ductile shear zones orientated N60°E and N20°W are observed. Fractures are locally filled by epidote + quartz + chlorite.

Stop 3.2 – 18 km to west from the stop 3.1, on the northern side of the road towards Bannach town, ~100m of the road.

In the Bannach region, to the west of the point to be visited, small bodies of intermediate and mafic rocks (IMR) associated to the Rio Maria Granodiorite were identified for the first time. The whole rock assemblage defines a diversified sanukitoid series. In the present site, layered mafic rocks, genetically related to the sanukitoid association, are exposed. These layered rocks occur as isolated blocks. The igneous layering is indicated by the succession of darker, near horizontal levels of centimeter-sized amphibole crystals-rich coarse rocks, alternating with gray color, comparatively finer grained layers. The layering is sub-horizontal, deeps at low angle to the east and there is no evidence of significant superimposed deformation. The anomalous concentration of generally quadratic or short prismatic coarse idiomorphic amphibole crystals in these rocks, associated with other textural features, indicated a particular magmatic evolution, involving crystal accumulation processes (Oliveira 2005). Following this reasoning, a cumulatic origin is admitted for the mafic layered rock, with the amphibole megacrystals corresponding to cumulus phases, which were enveloped by mesocratic intercumulus material.

Stop 3.3 - After return to the Baiano Cego locality, turning south on the crossing with the PA-150 road, the northeastern hills of the Musa pluton can be observed. After a cut in the road, turn to east in a secondary way conducting to the Maçaranduba farm. Following the way toward the east, it will be exposed the northeastern domain of the Musa pluton. After ca. 3.5 km, the way inflects to south and it will be find a domain of the Rio Maria Granodiorite intensely affected by intrusive granite phases related to the Musa pluton. Looking to the south, it is possible to see in the western side of the way the northeastern border of the Musa pluton. Turning to the eastern side, the southeastern hills of the Jamon pluton are exposed. In this area, a fringe of the Rio Maria Granodiorite is situated in between the two mentioned plutons and was submitted to intense intrusive contact effects.

The Musa granite exposed in the hills to the west is a coarse-grained amphibole-biotite monzogranite. Approaching the border of the pluton and along the contact zone, a porphyritic or fine- to medium-grained hololeucocratic granite dominate. This granite cross-cut the granodiorite and angular xenoliths of the later are involved by the leucogranite. The contacts are sharp and indicate a high viscosity contrast between the leucogranite magma and the granodiorite. This is consistent with the difference on age between both rocks and the admitted high level of intrusion of the Musa granite (2 to 3 kbar). Along the contacts, sometimes there are enrichment in feldspars crystals and orientated micas.

The granodiorite has a rose gray color, distinct of the greenish gray color dominant in most areas. This aspect is attributed to the metamorphic contact effects. Detailed studies in the contact aureole demonstrated that the saussuritized plagioclase of the granodiorite is replaced by fine recrystallized mosaic-textured oligoclase-andesine, accompanied by fine magnetite grains. Biotite was also recrystallized, showing clear Ti enrichment, and the amphibole apparently remained stable (Soares 1996). The contact effects inducing the neoformation of magnetite caused an important increase in the magnetic susceptibility of the granodiorite along the contact aureole (Magalhães & Dall'Agnol 1991, Soares 1996).

In the western side of the way, it is easily identified a dike of diabase that initially follow and finally traverse the way. This mafic dike has associated a granite porphyry dike both with the same general direction 290° Az and defining a composite dike that cross-cuts the Rio Maria Granodiorite. The dike has a 7m apparent width and the diabase, with an estimated width of 4m, was the first rock to intrude. The granite porphyry has an apparent width of 3m and it intrudes the diabase, normally with sharp contacts, leaving a thin fringe of diabase separating it from the granodiorite. Enclaves of the mafic rock are included by the granite porphyry and the former display sparse megacrysts in a dark matrix. These megacrysts are interpreted as dropped crystals from the granite. This feature and evidences of interaction between the granite porphyry and the diabase suggest that both magmas coexisted in the molten state and were modified by mingling processes. The granite porphyry dike was dated by Pb-evaporation on zircon and an age of 1885 ± 4Ma was obtained (Table 1; D.C. Oliveira, unpublished data). This age is coincident with that of the Jamon Suite granites and demonstrates that the felsic dikes and granites are coeval. This hypothesis is reinforced by a similar age furnished by a second dated dike (Table 1). Admitting that the basic dike was emplaced simultaneously with the granite porphyry it implies that the basaltic and granitic magmatism are coeval. This evidence gives some indirect support to the model of mafic underplating in the lower crust as the heat source for melting and generation of granite magmas (Dall'Agnol et al. 1994, 1999b, 2005). There are apparently some analogies between the features observed in this area and the rapakivi related composite dikes described in Finland (Rämö 1991, Rämö & Haapala 1995).

Stop 3.4 - At 7.5 km to the north of the Baiano Cego locality, on the right side of the PA-150 road. A small abandoned quarry where large decametric boulders of the RMGD were exploited in the past for ornamental stone production.

The monzogranitic variety of the RMGD is the dominant rock in the outcrop. It has lower mafic content compared to the dominant granodiorite and structures are very difuse. Mafic enclaves are very rare, but some felsic enclaves of leucogranites are relatively common. The origin of theses enclaves is not known (older leucogranites correlated to the Guarantã Granite? See Table 1).

Stop 3.5 - At 9.9 km to the north of the Baiano Cego locality, it is situated the crossing of the PA-150 road with the secondary road to Lagoa Seca and Babaçu. Turning to the east, the stop is situated at ca. 0.9 km of this point, on the secondary road.

Two Proterozoic dikes are exposed at this site. They are semi-paralel, trending near N50°W and N70°W. The first one is a basic dike, comprising a fine- to medium-grained diabase, which grades laterally towards the border of the dike, to a porphyritic rock showing white phenocrysts of corroded plagioclase in a dark, aphanitic mesostasis. Associated with the diabase dike is found a rose, medium-grained granite, corresponding probably to a metamorphosed variety of the Rio Maria Granodiorite. The second dike is formed by intermediate dioritic rocks. In the center of the body, the diorite is fine- to medium-grained, with rare plagioclase phenocrysts. In the border zone, the rock has a fine-grained texture and phenocrysts of mafic phases are common. The relationships between these intermediate dikes and the Jamon Suite are not defined. The age of the dikes is now being determined (Oliveira, D.C. in prep.). Their geochemistry contrasts with that of the mafic dikes and also with the felsic dikes and granites and an independent origin for these intermediate dikes is possible.

The Geology of the Xinguara Area

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Introduction

The Xinguara area is situated in the northern sector of the Rio Maria Granite- Greenstone Terrane (Figure 11). The Identidade and Sapucaia greenstone belts, and the following Archean granitoids are exposed in it: the Tonalitic Caracol complex (Group 1), the Rio Maria Granodiorite (Group 2), the Água Fria Trondhjemite (Group 3) and the Xinguara Granite (Group 4). The Proterozoic anorogenic granites are represented by the Manda Saia Granite (Group 7). The Caracol tonalitic complex (CTC) shows enclaves of the greenstone belts; the Água Fria Trondhjemite (AFTR) is intrusive in the Sapucaia greenstone belt and in the Caracol tonalitic complex, and coeval with the Xinguara Granite (XGG); the Rio Maria Granodiorite (RMGD) is younger than the CTC and older than the Agua Fria Trondhjemite and Xinguara Granite. The later includes many decametric to centimetric enclaves of the Caracol tonalitic complex and centimetric ones of the Rio Maria Granodiorite.

Structural Aspects

The dominant regional structures follow a WNW-ESE trend. The Identidade greenstone belt is elongated in the WNW-ESE direction and has an apparent thickeness of 4 km. Its structural pattern was interpreted as the result of one event of dextral transpression related to a NW-SE shortening direction (Souza 1994). Based on the shape of xenoliths, basaltic pillows, enclaves, and plagioclase and quartz phenocrysts, Souza (1994) suggested that there are variations in the intensity of deformation and also the shape of the strain ellipsoid across and along the belt, as well as towards the contacts with the granitoids. A mean shortening of ca. 60% and elongation around 150-200 % in the WNW-ESE direction was estimated.

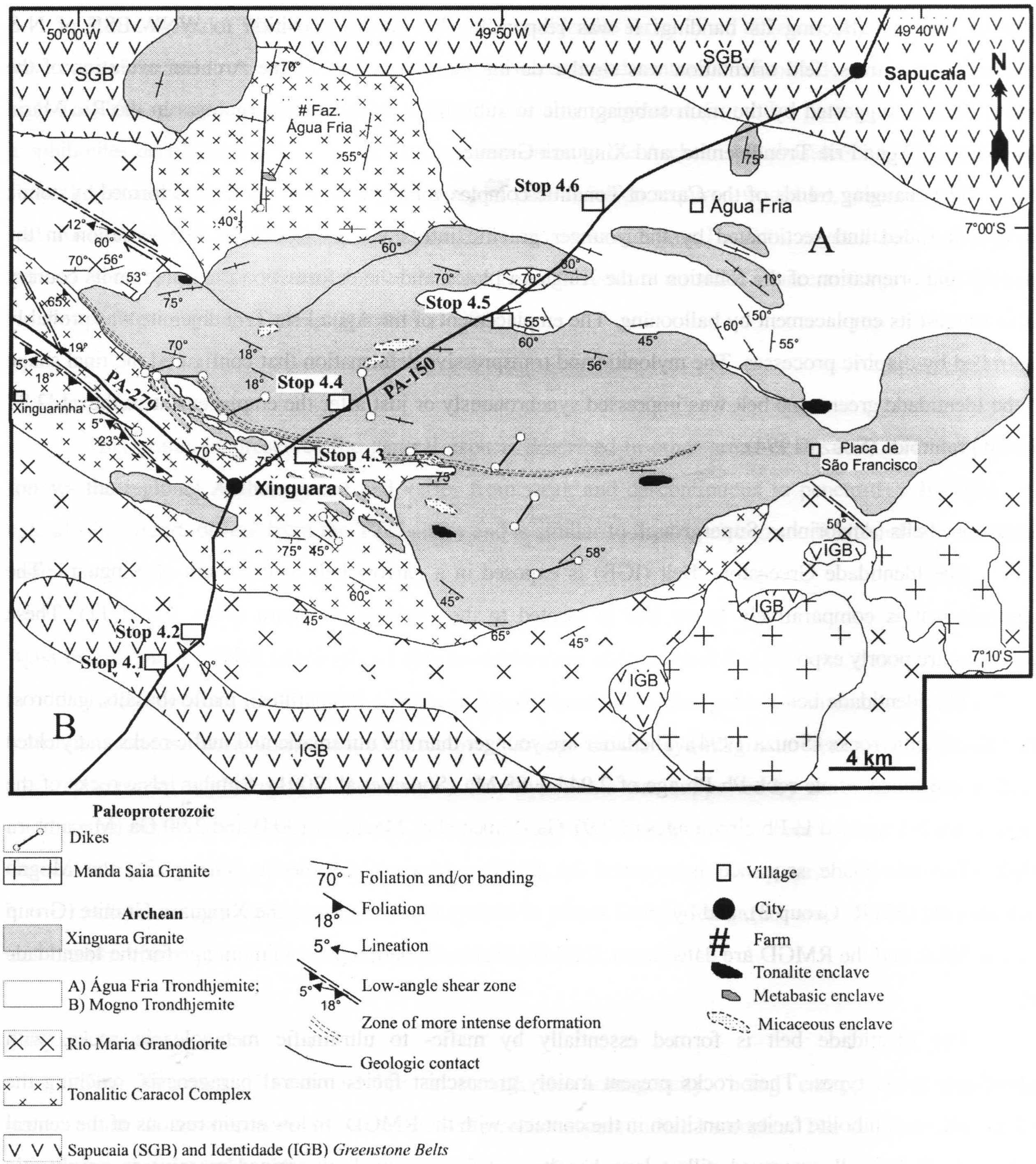

Figure 11 - Geological map of the Xinguara Region (Modified from Leite 2001).

The Caracol tonalitic complex preserves N-S banding in its NW sector, but this structure is transposed to the WNW-ESE regional trend (Leite 2001). The Rio Maria Granodiorite shows strongly flattened mafic enclaves and the Água Fria Trondhjemite displays a magmatic banding. The Xinguara pluton has an elongated shape and the leucogranites display a weak foliation, subhorizontal at the center and dipping at high angles along the borders of the intrusion (Figure 11). The σ1 axis of the regional stress during the intrusion of the granitoids was horizontal and trending N40E. The regional stress remained active during the submagmatic stage of the Caracol tonalitic complex evolution, as indicated by the presence of folds or boudins affecting its banding. It was responsible by the transposition to WNW-ESE of N-S structures. The stress field orientation was similar during the two phases of the Archean evolution of the region. This is suggested by the main submagmatic to subsolidus deformation structures in the Rio Maria Granodiorite, Agua Fria Trondhjemite, and Xinguara Granite.

The changing trends of the Caracol Tonalitic complex foliation suggest that it was formed by domic plutons, intruded and sectionated by the younger granitic intrusions (Leite 2001). The variation in the intensity and orientation of the foliation in the Xinguara pluton and the deformation imprinted on its country rocks suggest its emplacement by ballooning. The emplacement of the Agua Fria Trondhjemite was probably controlled by diapiric processes. The mylonitic and transpressive deformation that configured the final shape of the Identidade greenstone belt was impressed synchronously or just after the emplacement of the ca. 2.87 Ga old granitoids (Souza 1994).

Greenstone belts (Andorinhas Supergroup)

The Identidade Greenstone Belt (IGB) is exposed in a narrow belt to the south of Xinguara. The Sapucaia belt is comparatively larger and is located to the north of Xinguara (Figs. 1 and 11). These sequences are poorly exposed and their contacts were observed only locally in the field.

The Identidade belt is composed of metamorphosed ultramafic (komatiites), mafic (basalts, gabbros) and felsic dacitic rocks (Souza 1994). The latter are younger than the ultramafic and mafic rocks and yielded a little constrained whole rock Pb-Pb age of 2.944 ± 88 Ma (Souza et al. 2001). Similar felsic rocks of the Lagoa Seca belt yielded U-Pb zircon ages of 2.97 Ga (Pimentel & Machado 1994) and 2.90 Ga (Macambira 1992). The Identidade sequence is crosscut by the Rio Maria Granodiorite (Group 2), the Mogno Trondhjemite (MTR, Group 3), and by small stocks of leucogranites similar to the Xinguara Granite (Group 4). The MTR and the RMGD are dated at ca. 2.87 Ga (Table 1), defining a minimum age for the Identidade belt.

The Identidade belt is formed essentially by mafic- to ultramafic metavolcanic rocks, with subordinate felsic types. Their rocks present mainly greenschist facies mineral paragenesis, reaching the greenschist - amphibolite facies transition in the contacts with the RMGD. In low strain regions of the central part of the belt, well preserved pillow-lava basalts and fine- to medium-grained massive to porphyritic dacites are exposed. The ultramafic schists have a typical nematoblastic texture due to acicular amphibole, with subordinate amounts of talc and chlorite. Metabasalts and metagabbros have variable proportions of amphibole, saussuritized plagioclase, titanite, opaques, and chlorite. The amphiboles are transitional from actinolite to Mg-hornblende in the metabasalts, actinolite in metagabbros, and tschermakite in the ultramafic rocks (Souza 1994). As a consequence of the low strain imposed over these rocks, some relicts of plagioclase phenocrysts, as well as spinifex-like textures are yet recognized.

Caracol Tonalitic Complex

It is a typical TTG similar to the Archean trondhjemite series. Two different geochemical signatures have been identified in this granitoid on the basis of accentuated contrasts in La_N/Yb_N ratios. The dominant, high La_N/Yb_N group crystallized from a liquid probably originated from the partial melting of garnet amphibolites derived from tholeiites similar in composition to the Archean metabasalts or to the metabasalts from the Identidade greenstone belt. The degree of partial fusion required would be, respectively, 25-30% and 10-15% (Leite 2001). On the other hand, the tonalites with low La_N/Yb_N crystallized from a liquid derived from a garnet-free similar source. Nd isotopic data indicate a mantle source and a juvenile character for the tonalites of the first group (Rämö et al. 2002).

Rio Maria Granodiorite

This granitoid preserves the general aspects described in other areas of the RMGGT. Its foliation follows the regional Archean trend and varies from weak and descontinuous to penetrative. It follows the calc-alkaline trend, differs from the TTG series and is similar to the Mg-rich granodiorites of the Sanukitoid series.

Água Fria Trondhjemite

To the north of the Xinguara pluton, the Água Fria Trondhjemite occurs in contact or intercalated with the granites. Both form banded structures, interpreted as syn-magmatic features, suggesting the contemporaneous emplacement of these rocks. This hypothesis was supported by the similar ages obtained for these granitoids (ca. 2.86 Ga; Table 1). The Água Fria Trondhjemite is geochemically similar to the Caracol complex and by extension to the Archean TTG, but it is comparatively enriched in K_2O. The Água Fria Trondhjemite may have been generated by 5-10% partial melting of garnet amphibolites derived from metabasalts, chemically similar to the Identidade metabasalts (Leite 2001).

Xinguara Granite

The Xinguara Granite exhibits a remarkable homogeneity, being composed essentially of monzogranite. It shows a rose or gray color and massive aspect in hand samples. The deformation is better seen in thin sections, where the strong recrystallization of quartz and feldspars is noteworthy. The dominant varieties are metaluminous to slightly peraluminous leucomonzogranites with high SiO_2 and alkali contents, high K_2O/Na_2O ratios, low MgO, and moderate CaO contents (Leite 2001). Evolved pegmatoid granites and leucosyenogranites are subordinate. The pegmatoid granites intrude the dominant monzogranites and also the Caracol tonalitic complex all along the southern contact of the pluton.

Two leucomonzogranite (LMG) facies were identified (Leite & Dall'Agnol 1999), both with similar silica contents, but the LMG2 type showing lower Al_2O_3, MgO, CaO, and Na_2O and higher K_2O, Rb, Zr, and Y contents compared to the LMG1 type. In geochemical diagrams the LMG1 and LMG2 types define contrasting evolutive trends, indicating that they crystallized from two different liquids. The behavior of lithophile elements suggests that a moderate fractionation of potassic feldspar, plagioclase and biotite controlled the small degree of differentiation of Xinguara pluton magmas. The large extent of fractionation of the HREE, the depletion in Y, Ti, and Nb parallel to the enrichment in P and Sr in comparison to the average composition of the upper continental crust, as well as the high values of Rb/Y and Al_2O_3/TiO_2 ratios, indicate a similarity between the Xinguara leucogranites and Archean calc-alkaline leucogranites of type 2 (Sylvester 1994). The two types of Xinguara leucogranites were probably derived by different degrees of partial melting from a same crustal protolith, which is possibly similar to the TTG granitoids.

Manda Saia Granite

Two small stocks of Paleoproterozoic anorogenic granites intrusive in the greenstone sequences and Rio Maria Granodiorite were identified (Araújo et al. 1994, Leite & Dall'Agnol 1999). The limited available data indicate petrographic and geochemical characteristics similar to those of the Jamon and Musa granites (Leite 2001).

Tectonic Evolution

The geochemical features of the mafic and ultramafic rocks suggest a back arc or oceanic plateau environment for the greenstone belts (Souza 1994, Souza & Dall'Agnol 1995). Nothing can be said about the nature of the basement of the greenstone belts, but, in the period of 2.97 to 2.87 Ga, it seems reasonable to admit that the continental crust was almost entirely formed, as indicated by the volcanic arc characteristics of the felsic metavolcanics and granitoid plutons (Souza 1994), as well as by the presence of 2.97 Ga old detritic zircons in metagraywackes of the greenstone belts and in quartzites of the Rio Fresco Group (Macambira 1992). Souza et al. (2001) argue that the deformation that affected the Identidade region was related to the generation of a continental island arc and closure of marginal basins, which were coeval of the main event of granitoid emplacement. The low metamorphic grade attained during regional metamorphism and the interpretation of geophysical gravimetric data suggest a relatively high crustal level for plutonic intrusion and indicate that this deformation was impressed in a tectonic environment with a not very high geothermal gradient.

The Archean geologic evolution of the Xinguara region probably occurred in two stages (Leite 2001). The first stage starts in the interval of <2.95 to 2.93 Ga and is apparently similar to those of the Pilbara and Darwhar cratons. The second stage starts at 2.88 Ga and it is coincident with a sharp change in crustal behavior. At this time, the increasing thickening and stabilization of this Archean crustal domain turned more effective the processes of plate subduction and convergence. In this tectonic context, the partial melting of an enriched mantle wedge would generate the parental magma of the Rio Maria Granodiorite and the partial fusion of garnet amphibolites derived from the subducted ocean crust would generate the Água Fria Trondhjemite magma (Leite 2001). Finally, the upward movement of the Água Fria Trondhjemite and Rio Maria Granodiorite magmas would induce the melting of the TTGs in the lower crust, thus generating the granitic magmas of the Xinguara pluton.

Selected points to be visited during the field trip

Stop 4.0 (Optional stop) - At ca. 11.3 km to the south of Xinguara, along the PA-150 road. At the west side of the road, there is an outcrop of the Mogno Trondhjemite.

Relatively large blocks and boulders of trondhjemite, showing dextral S-C structures, similar to those observed in the granites of stop 4.3. The trondhjemite is a gray rock, containing little, generally chloritized biotite. The XZ horizontal and the N-S, vertical planes of the finite strain ellipsoid can be observed. In other points, the trondhjemite is richer in mafic minerals and includes enclaves of metabasalts, which are admitted to be related to the Identidade greenstone sequence.

Stop 4.1 - At ca. 7.4 km to the south of Xinguara, along the PA-150 road. Stop in front of the *Fogão a Lenha* restaurant. At ca. 50 m to the west of the road, near a house of peasants, large block of metabasalts of the Andorinhas Supergroup.

At this site, it is situated the best preserved outcrop of basaltic pillows of the Andorinhas Supergroup exposed in the Identidade area. It was originally described by Cordeiro & Martins (1984). The top of the pillows are orientated to NE and they have the form of tubes (Souza 1994). In the inner part of the pillows, they display a homogeneous, very fine-grained texture, showing evidences of quenching. Actinolitic hornblende and epidote are dominant over chlorite, titanite, and opaque minerals.

The preservation of these mafic pillows in the Amazonian region is intriguing and this could be a subject of an interesting discussion about the possible paleoclimatic evolution of this region. Why do you have relatively fresh rocks exposed along the Rio Maria Granite Greenstone Terrane? It represents also strong evidence against some prejudices and oversimplifications stating that it is impossible to find fresh rocks in the Amazonian region. This can be true or not.

Stop 4.2 - At ca. 6 km to the south of Xinguara, along the PA-150 road. Arriving to a small church, take the secondary road to the west. At ca. 400 m to the west, outcrop of the Rio Maria Granodiorite in the northern side of the road.

This outcrop is situated just to the north of the not exposed contact between the RMGD and the Identidade metabasalts. The more important aspect here is to observe the strong similarity between the granodiorite exposed at this point and the RMGD of the type locality visited yesterday. The petrographic and structural analogies are noteworthy. The granodiorite includes many centimetric hornblende diorite or quartz diorite enclaves, with subordinate biotite and sometimes clinopyroxene relicts. The granodiorite and the associated enclaves show a syn-magmatic foliation dipping to the south.

Stop 4.3 - Returning to Xinguara and going ~2 km to the NE along the PA-150, it is attained a secondary way to the east conducting to some hills; at ~500 m there is an active quarry being exploited to produce gravel for road pavement.

All people must be extremely carefull in this site because there are lots of unfixed blocks of rocks along the quarry walls and it must be imperatively avoid to work near the walls. Big trucks are also moving constantly in the area. To reduce risks, the visit of the quarry should be done during the stop for lunch of the workers, at 12:00 o'clock, and the time available for the quarry examination will be of half an hour only. It is possible, however, to see the walls from a distance of a few meters and there are lots of disrupted blocks that allow detailed examen of the different rocks and their relationships. The blocks are concentrated in front off the walls and also in a lower level in the side of the way conducting to the principal quarry.

The quarry is located along the contact zone between the Xinguara Granite and the Caracol Tonalitic Complex (Figure 11). All along the contact, there are complex relationships between the tonalites and the evolved pegmatitic granites associated with the Xinguara pluton. The pegmatitic leucogranites intrude the tonalitic rocks and occur intercalated with them in some places (Leite 2001). The term pegmatitic is employed here in a more textural descriptive way, meaning extremely coarse-grained rocks with centimetric k-feldspar crystals. In some other places, these rocks show graphic intergrowths between quartz and feldspars.

Along the quarry wall, tonalitic rocks intruded by a sub-horizontal ~4 m thick layer of pegmatitic leucogranite are exposed. The contact between both rocks is sharp. In the disrupted blocks, it is possible to observe that the leucogranite cuts discordantly the foliation and/or banding of the tonalite. Te later generally displays a banded structure and has associated veins and pockets of more leucocratic trondhjemite. Apparently the trondhjemite is intruding the tonalite and both rocks are folded. The pegmatitic leucogranite veins and injections do not show evidence of folding, suggesting that it is later than the tonalite and trondhjemite. There also evidence of reaction along the contacts between the latter rocks and the leucogranite. Locally, there are zones of mafic enrichment (biotite ± epidote) in the tonalite, associated with folded veins of trondhjemite. The trondhjemite could represent local felsic injections or segregations derived from the Caracol tonalitic magma or, alternatively, from a younger magma similar to that forming the Água Fria Trondhjemite.

Stop 4.4 - At ca. 20 km to the north of Xinguara, along the PA-150 road, outcrop in the west side, about 100 m from the principal road, along a secondary way.

Typical exposition of the Água Fria Trondhjemite found to the north of the Xinguara pluton. The trondhjemitic rocks display a remarkable compositional banding, also concordant with the regional WNW-ESE trend. The banding is affected by folds and locally by shear bands. Locally the banding is deflected around metric tonalitic or quartz dioritic enclaves, probably related to the Caracol Tonalitic Complex.

Stop 4.5 - At ca. 15 km to the north of Xinguara (five km south of stop 4.4), along the PA-150 road, outcrop in the east side, about 300 m from the road, near a house. Outcrop of the Água Fria Trondhjemite associated with the Xinguara Granite.

The trondhjemite shows a light gray color and a medium or coarse, even-grained texture and is weakly foliated (WNW-ESE). Leucomonzogranites and pegmatoid granites related to the Xinguara

Granite are common. They are disposed either concordant or discordant to the foliation trend. The discordant leucomonzogranites are variably folded, while the concordant ones alternate with the trondhjemites defining a compositional banding. The trondhjemites include some elongated enclaves, disposed concordantly to the foliation. These enclaves are similar to the Caracol tonalite, suggesting that the trondhjemite exposed in this outcrop is later than the Caracol tonalite, which was confirmed by geochronological dating (Table 1; Leite et al. 2004).

Stop 4.6 - At ca. 6 km to the north of Xinguara, along the PA-150 road, big boulders in small hill in the west side of the road.

In this site, it is found an exposition of a very homogeneous, weakly foliated or massive leucomonzogranite of the Xinguara Granite. It is a medium- even-grained, rose colored granite, displaying scattered biotite plates. Locally, it is possible to recognize a WNW-ESE trending, weak foliation. Tonalitic and quartz dioritic enclaves of variable size, included by the granite, are disposed concordantly with the main regional trend. The general disposition of the Xinguara pluton is also concordant with the trend of the country rocks.

Carajás Basin

It is beyond the scope of this guide to present a synthesis of the geology of the Carajás Basin. A general ideal of its stratigraphy and the areal distribution of main units can be obtained in figures 2 and 13. The more relevant geochronological data, with emphasis in granitoid rocks, are given in Tables 1 and 2. It will be given in the following just a brief description of the most important granitoid groups exposed in this tectonic domain.

Subalkaline Foliated Granites (Group 6)

Estrela Granite Complex

C.E.M.Barros, P. Barbey & R. Dall'Agnol

Introduction

The Estrela Granite Complex, exposed to the south of Curionópolis (Fig. 12), is representative of the subalkaline foliated granitoids of the Carajás Basin.

Stratigraphy

The Estrela Granite Complex (EGC) outcrops to the east of the Carajás range as a composite batholith elongate nearly in the E-W direction. Pb-Pb evaporation on zircon dating yielded an age of 2763±7 Ma for the EGC (Barros et al., 2001). The EGC intrudes the metavolcano-sedimentary sequence of the Itacaiúnas Supergroup (DOCEGEO, 1988) dated at 2.76 Ga (U-Pb zircon age; Wirth et al., 1986; Machado et al., 1991).

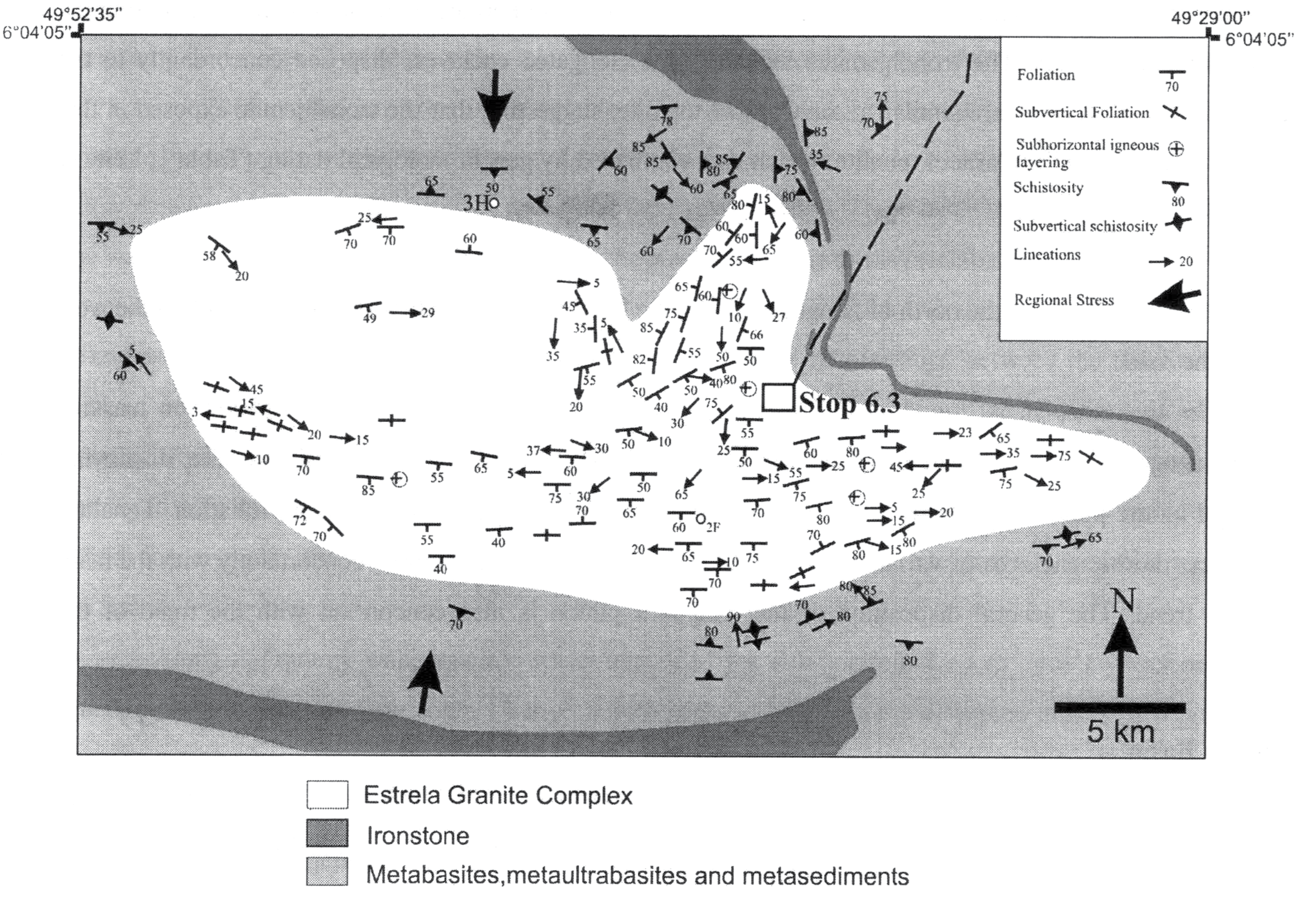

Figure 12 - Geological map of the Estrela Granite Complex (Barros et al. 2001)

Petrography

The EGC is characterized by light-grey fine-to-medium grained rocks. Monzogranites predominate widely over syenogranites, granodiorites and tonalites. The main minerals of the EGC are quartz, moderately perthitic microcline, plagioclase (An_{10} to An_{47}), bluish-green ferro-pargasitic hornblende and ferro-pargasite [Mg/(Mg+Fe)= 0.04-0.21], biotites with high Fe/(Fe+Mg) ratios (0.86-0.97) and, locally, clinopyroxenes [hedenbergite with FeO/(FeO+MgO)= 0.74-0.77]. On the basis of the mafic mineral contents, the monzogranites can be subdivided in several facies: hb-, hb±cpx-, hb±bt-, bt±hb- and bt-monzogranites. The hornblende-rich varieties are mainly located in the eastern part of the batholith, whereas the others are situated in its western domain. Accessory minerals are allanite, zircon, apatite, and ilmenite.

Pegmatite dykes with hornblende megacrysts and aplite veins are commonly found cutting the monzogranites.

Chemistry

The EGC has moderate K_2O+Na_2O (6.19%-8.62%) and high FeO/(FeO+MgO) (0.93-0.99). Two groups of monzogranites can be distinguished on the basis of alumina contents: a metaluminous (Al_2O_3 ca.

11.5%) and a weakly peraluminous group (Al_2O_3 ca. 13.5%). The first one comprises the hornblende-rich monzogranites, whereas the latter one comprises the biotite-enriched monzogranites.

The monzogranites present moderate to very high Y (13-404 ppm), Nb (17-45 ppm) Zr (80-652 ppm), and rare-earth elements (REE) (La= 56-281 ppm; Yb= 7-15 ppm), besides high Ga/Al (3.42-4.76). Chondrite-normalized (Evensen et al., 1978) REE patterns display moderately to highly fractionated light REE [$(La/Sm)_N$= 3.04-7.78], large negative Eu anomalies (Eu/Eu*= 0.25-0.65), and slightly fractionated heavy REE [$(Gd/Yb)_N$= 1.04-2.33].

The geochemical characteristics of the EGC are comparable to those of the A-type granites (Whalen et al. 1987); the A2-crustally derived granites (Eby 1992); the ALK-3 Archaean granites and in part to the ALK-1 Phanerozoic granites (Sylvester 1994).

Structures

Satellite image analysis coupled with mapping of foliation trajectories, lithologies and areal distribution of xenoliths allowed different elliptical plutons to be distinguished within the complex, testifying its composite nature. The long axes of most plutons trend EW with an EW/70S average foliation trend (Fig. 12). Conversely, a pluton situated to the north of the complex is oriented NNE-SSW.

The main structural feature is a widespread magmatic foliation characterized by alternating mafic and quartz-feldspathic layers. The foliation has been affected by shortening stresses which produced decimetric-to-metric folds with subhorizontal axes and a sub-vertical axial plane schistosity. In the western end of the EGC, longitudinal leucocratic dykes are injected along the schistosity, originating migmatitic-like features. Lineations are weakly developed and subordinate to the planar structures indicating the predominance of flattening regimes. Locally, mylonitic rocks are observed in decametric-thick strike-slip shear bands.

Interference between regional deformation and granite-emplacement strain produced triple junctions of foliation trajectories (cf. Brun & Pons, 1981) in the host rocks of the EGC reforcing its synkinematic emplacement (Fig. 12).

Conclusions

The Estrela Granite Complex is a Neoarchean composite batholith, geochemically comparable to the A-type granites. Its structural pattern (Fig. 12) denotes syntectonic emplacement under regional N-S shortening followed later by small sinistral strike-slip components. The occurrence of the Estrela Granite Complex and several other geochemically- and structurally- similar granites indicate that the Neoarchean evolution of the Carajás Metallogenic Province was marked by an episode of syntectonic granite [illegible] of alkaline affinities.

Planalto Granite

M.A. Oliveira, A.C.B. Gomes, R. Dall'Agnol, A.S. Sardinha

In the Canaã dos Carajás area (Fig. 13), several stocks composed of subalkaline granites have been described. These granites are included in a granite suite, denominated Planalto Granite. Its type area corresponds to a small stock located to the east of Planalto village (Oliveira, M.A. 2003). A representative sample of that stock yielded a Pb-evaporation on zircon age of 2747±2 Ma (Huhn et al. 1999; Table 1). Several other stocks exposed to the east of Canaã dos Carajás have been correlated with the Planalto Granite (Gomes 2003, Gomes et al. 2004). These stocks were formerly correlated with the Plaquê Suite. A representative sample of a granite of that area defined a Pb-evaporation on zircon age of 2734±4 Ma (Sardinha et al. 2004; Table 1). The Planalto Granite is also exposed to the west of Canaã dos Carajás around Feitosa village (Sardinha 2005, Fig. 12). The Planalto Granite is composed of monzogranites to syenogranites with alternating modal dominance of hornblende or biotite. The rocks are coarse- to medium-evengrained and display rose or red colors. They are generally foliated and locally mylonitic rocks are formed. The granites are metaluminous to mildly peraluminous and display the general geochemical characteristics of A-type granites, as described in the case of the Estrela Granite Complex.

Anorogenic Granites

R. Dall'Agnol, J.A.C. Almeida, M.A. Oliveira

Cigano Granite (CIGG; Group 7)

The CIGG (1.88 Ga; Table 2) outcrops a few kilometers to the north of Parauapebas town, to the Northeast of the Serra dos Carajás and to the northwest of the Estrela Granitic Complex (Fig. 2). It is intrusive into the Archean units and hornfelses were described in the southern contacts of the pluton (Gonçalez et al., 1988). Amphibole-biotite monzogranites and biotite monzogranites and syenogranites are the dominant varieties, microgranites and rhyolite dikes occurring locally. Amphibole-bearing facies are more abundant in the eastern and southwestern borders of the pluton. In the center of the intrusion, medium even-grained, strongly chloritized-, biotite monzogranites are largelly dominant. A summary of the petrographic and geochemical characteristics of this granite is presented in Figures 6 to 7 (see also Dall'Agnol et al. 1994, 2005). This granite is not especialized for tin and there are only local molybdenite, chalcopyrite, and pyrite mineralizations associated to it.

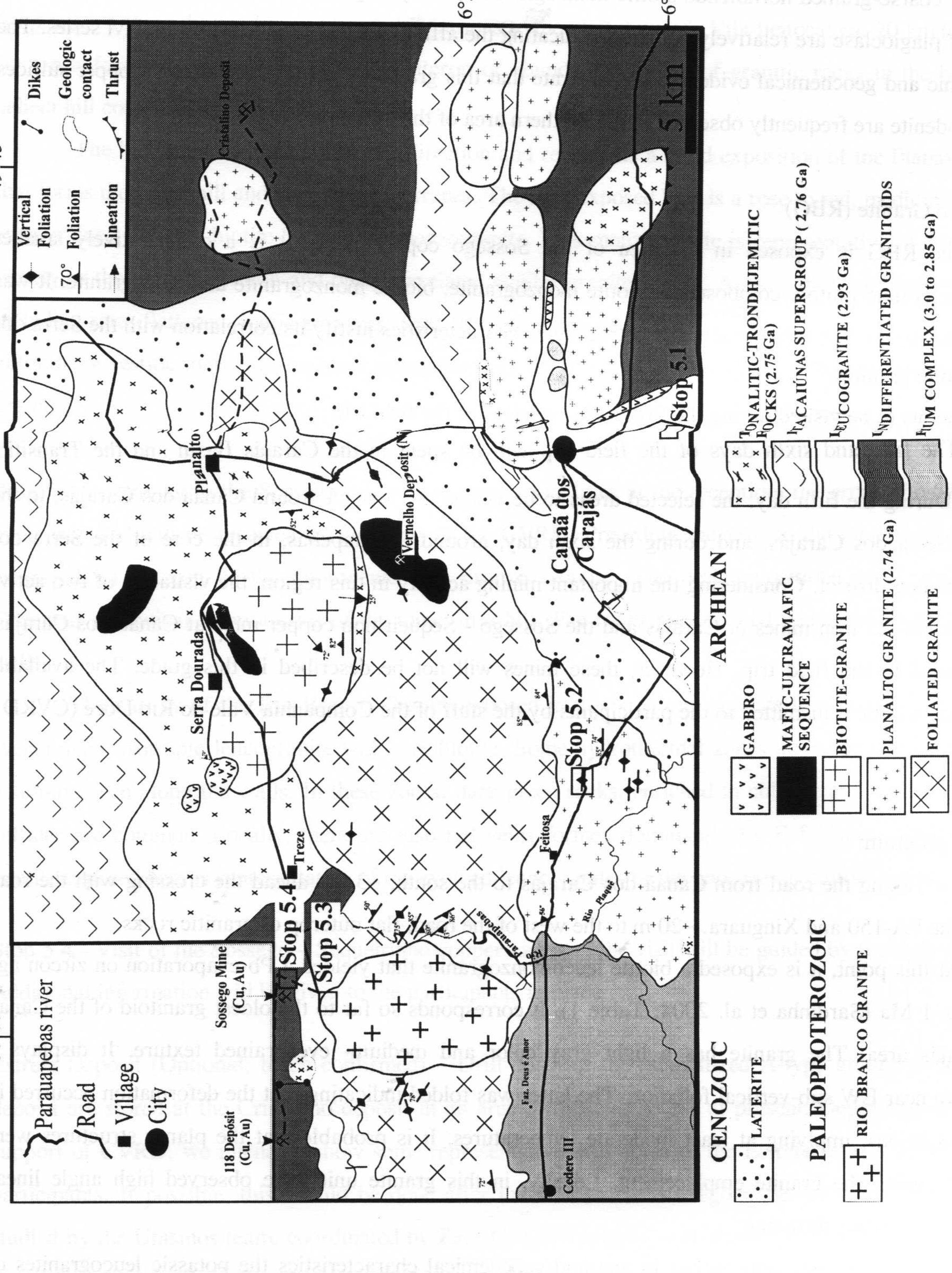

Figure 13 - Geological map of the Canaã dos Carajás region (modified from Soares 2002, Oliveira 2003, Gomes 2004, Sardinha 2005).

Serra dos Carajás Granite (SCG; Group 7)

The SCG (1.88 Ga; Table 2) is a batholith exposed in the central area of the Serra dos Carajás, crosscutting the Archean sediments of the Águas Claras Formation. Only the northern and western areas of the batholith were studied in detail (Javier Rios et al., 1995a,b; Barros et al., 1995). The granite comprises essentially coarse-grained hornblende-biotite monzogranites and syenogranites. Alkali-feldspar crystals with mantles of plagioclase are relatively common, indicating the affinity of this granite with rapakivi series. The petrographic and geochemical evidences demonstrate that this granite is not tin-specialized. Copper sulfides and molybdenite are frequently observed in the northern area of the intrusion.

Rio Branco Granite (RBG)

The RBG is exposed in the area of the Sossego copper mine. It is a comparatively smaller anorogenic granite pluton, composed of biotite monzogranite, biotite monzogranite and leucogranite. It was little studied so far, but field aspects and petrographic characteristics justify its correlation with the Serra dos Carajás Suite granites.

Selected points to be visited during the fifth and sixth days of the field trip

The fifth and sixth days of the field trip will be spent in the Carajás Basin and the Transition Domain. During the fifth day, the selected areas to be visited are located around Canaã dos Carajás, to the south of Serra dos Carajás, and during the sixth day, around Parauapebas, in the core of the Serra dos Carajás mining district. Considering the important mining activity in this region, the visitation of two active mines, the N4-N5 iron mines at Carajás and the Sossego - Sequeirinho copper mine at Canaã dos Carajás, was included in the field trip. However, these mines will not be described in this guide. The available information will be transmitted to the participants by the staff of the Companhia Vale do Rio Doce (CVRD).

Fifth day program:

Stop 5.1 – Taking the road from Canaã dos Carajás to the south, ~3 km ahead the crossing with the road towards the PA-150 and Xinguara. ~20 m to the west of the road, flat outcrop of granitic rocks.

At this point, it is exposed a biotite leucomonzogranite that yielded a Pb-evaporation on zircon age of 2928 ± 1 Ma (Sardinha et al. 2004; Table 1). It corresponds so far to the oldest granitoid of the Canaã dos Carajás area. The granite has a light gray color and medium- evengrained texture. It displays a penetrative near EW sub-vertical foliation. The latter was folded indicating that the deformation occurred in ductile conditions, implying at least moderate temperatures. It is probable that the planar structures were generated during the granite emplacement. Locally, in this granite unit were observed high angle linear structures suggesting thrusting.

This leucogranite approaches in age and geochemical characteristics the potassic leucogranites of group 4, represented by the Xinguara and Mata Surrão granites of the RMGGT. It is evidence that the Transition Domain corresponds to a crustal segment that existed before the formation of the dominant rocks of the Carajás Basin at ~2.76 Ga. It is possible that the RMGGT extended to this domain, but it was certainly intensely affected by the magmatism related to the 2.76 Ga old events of the Carajás Basin. This is demonstrated by the widespread occurrence of foliated subalkaline granites and ~2.75 Ga old TTGs on the Canaã dos Carajás area (Fig. 13).

Stop 5.2 – Taking the road from Canaã dos Carajás to the west, towards Vila Feitosa; ca. 20 km to the west, ~3 km before arriving to Vila Feitosa. Outcrop of abundant boulders of granitic rocks in the border of a salient hill contoured by the road.

The hill extends to the southwest direction and represents a good exposition of the Planalto Granite that forms the entire hill and the adjacent terranes. The rock exposed here is a rose to red, medium- to coarse-even-grained, foliated biotite-hornblende monzogranite. This monzogranite is representative of the dominant variety in the Planalto pluton and other correlated similar granite bodies. At this place, the monzogranite is including rare, flattened, mafic enclaves, with 10 cm of diameter. These enclaves are interpreted as possible autoliths or restitic mafic material and sometimes they are involved by leucogranitic varieties of the dominant granite.

Stop 5.3 – Arriving to the Sossego mine, after some formalities at the reception, the group should enter the mine area and will be received by geologist of the CVRD. Preceding the visit to the mine itself, it will be examined an outcrop of the anorogenic Rio Branco Granite. The best expositions are found near the Chemical Analytical Laboratories of the mine, in a hill. The rocks are exposed inside the road along some walls.

The variety of the Rio Branco Granite exposed in this area corresponds to a cream rose, medium-evengrained, isotropic leucogranite with rare biotite. Some hydrothermal zones attaining a maximum ~1 m width are seen along the walls. In these zones, dark green rocks, enriched in chlorite and with disseminated sulfides are common. Locally, there are also red veins formed dominantly by K-feldspar (adularia?). The granite exposed here is representative of the evolved leucogranites of the anorogenic plutons (group 7).

Stop 5.4 - Visit of the Sossego – Sequeirinho copper mines – The visit will be guided by the staff of CVRD. Additional information will be given to the participants in place.

Estrela Deposit (Optional; to be confirmed) – Drill cores of the mineralized A-type granite of the Estrela deposit are stored at the Cristalino deposit in an area of difficult access at present. Depending of logistical support of CVRD, we intend to show some representative drill cores of the Estrela deposit to the field trip participants. If possible, this should be done after the visit to the Sossego mine. The Estrela deposit was studied by the Unisinos team, coordinated by Zara G. Lindenmayer, and also by Karen Volp (Falconbridge, Australia). Both will participate in the field trip. Z.G. Lindenmayer can introduce the participants to the mentioned deposit. A brief description of it is presented in the symposium abstract volume (see Lindenmayer et al. and Volp abstracts).

Sixth day program:

Stop 6.1 - A large quarry on the northern area of the Serra dos Carajás Granite. Take the road between Carajás town and the Bahia mine. The quarry is situated in a secondary road.

Javier Rios & Villas (1991) and Javier Rios et al. (1995a, b) estudied the quarry in detail. At the end of the 80', amphibole-biotite syenogranites and monzogranites were exposed at the quarry. They were intruded by three distinct microgranites; pegmatitic pods and discrete veins were also common. Three types of veins were recognized: 1) calcite-sulfide veins; 2) quartz - tourmaline - chlorite - epidote - albite - calcite - fluorite - sulfide veins, and 3) sulfide veinlets. The sulfides identified were: chalcopyrite, pyrite, molybdenite, bornite and covellite. Actually, a lower level of the quarry is exposed and it is less-rich in sulfides than the level studied by the mentioned authors. The granite shows a rose color and is coarse-grained. In the wall of the quarry, it is possible to see a strong brittle deformation of the granite, probably related to the effects of the regional Carajás Fault, trending ~NW (Fig. 2). Pegmatitic veins are very common at the present level. Some light green sulfide-bearing greisens and brick red colored, feldspar-rich rocks are also observed along hydrothermally altered zones.

Stop 6.2 – Visit of the N4-N5 iron mines – The visit will be guided by the staff of CVRD. Additional information will be given to the participants on time.

Stop 6.3 (optional) – Taking the road from Parauapebas to Curionópolis, about 2 km before to arrive to Curionópolis, it should be taken a secondary road to the south. After ca. 11 km, it is attained a crossing and it should be followed the road to SW for more 1.8 km. At this point there is an interesting outcrop of the Estrela Granite Complex in a creek.

Hornblende syenogranite showing moderate foliation (N75E/70SE) cross-cut by hornblende-bearing pegmatite dikes. Foliated pegmatite dikes show ondulated contacts and locally syn-magmatic ruptile disruption. Laterally, very little deformed pegmatites showing centimetric hornblende crystals which envelop fine-grained quartz-feldspathic aggregates are found. Diffuse pegmatite bodies and miaroles are also observed.

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