The Central Brazil Shield Reviewed

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A decade or so ago the Central Brazil Shield south of the Amazon Basin was a single color on regional geological maps. Though this vast area is still poorly known, there has been much progress thanks largely to the Radambrasil project, and the region is now the focus of much attention because of new mineral finds. There have been "rushes" for gold and cassiterite, and the discovery and development of the world-class deposits of the Carajás area. In this review, the authors show that the region developed during the Archean and Early Proterozoic, became consolidated in the Trans-Amazonian Cycle around 1950 Ma, and was reactivated during several thermal-tectonic episodes from the Middle Proterozoic onwards. (Ed.)

Figure 1: NASA SIR-A image of Central Brazilian Shield just NW of Serra dos Carajás. Xingu River on left. Approximate scale - 1:700,000.

Figure 2: Broad tectonic framework of South America. Heavy line is the western edge of the Paraguay-Araguaia fold belt and divides the South Amazonian and Eastern domains of the Central Brazil Shield.

Introduction

The Central Brazil Shield is the basement to that part of the South American Platform situated between the foredeep of the Central Andes and the Amazon, Parnaíba and Paraná sedimentary basins (Figs. 1 and 2). It is mostly located in central and western Brazil, but also extends into Bolivia and in the extreme south into Paraguay. About a quarter of the approximately 2.4 million km² of the Central Brazil Shield is covered by Phanerozoic sedimentary rocks, with some associated basalts, which reach total thicknesses up to a few hundred metres. Two sectors or domains can be distinguished on the basis of lithology and structure, as shown on Figure 2.

The eastern sector constitutes the Ceres Mobile Belt (or Tocantins structural province - Ed) in which exposures of Archean granite-greenstone and high-grade terrains can be identified, surrounded by sedimentary and volcano-sedimentary belts formed, folded and metamorphosed during three Proterozoic tectonic cycles (Almeida, 1981). These are the Trans-Amazonian (2.2-1.9 Ga), the Uruaçuano (1.4-1.0 Ga), and the Brasiliano (900-500 Ma), which collectively gave rise to a complex geological framework outside the scope of this review (see Hasui et al., in Almeida and Hasui, 1984).

The western sector of the Central Brazil Shield is the southerly extension of the Amazonian Platform (Suszczynski, 1970) south of the Amazonian sedimentary basin. This South Amazonian Domain has at times been referred to as the Guaporé Shield or craton (e.g. Gibbs and Barron, 1983) and corresponds to the Tapajós structural province (Almeida et

al., 1981; Almeida and Hasui, 1984). It is bordered on the east by the Paraguay-Araguaia fold belt of the Tocantins province.

In recent years the South Amazonian Domain has been the site of a "mineral rush," prompted by discoveries of cassiterite, gold, iron, copper, bauxite and other deposits in Rondônia, in the Tapajós River valley and in the Serra dos Carajás area. However, it is also a region where human occupation is just beginning and where most access is by river or helicopter.

The dense vegetation (e.g. Fig. 1), the extreme weathering of the rocks and tropical diseases are natural barriers to geological surveys, and the available information, mostly acquired over recent years, is still at the reconnaissance level. This is contained in a few hundred publications and reports, produced mainly for the Brazilian Ministry for Mines and Energy, the Projeto Radambrasil and the Companhia de Pesquisa de Recursos Minerais (CPRM). In Bolivia the main source has been the reports of Projeto Precámbrico, developed by the U.K. Institute of Geological Sciences and Servicio Geológico de Bolivia (see Berrangé, 1982). Syntheses of this work have been published by Issler (1977), Montalvão et al., (1979), Montalvão and Bezerra (1980), Santos (1981), Litherland and Bloomfield (1981), Ianhez et al., (1982), Santos et al. (1982), Santos and Loguércio (1984), Almeida (in Almeida and Hasui, 1984), Amaral (ibid), and Lima (1984).

The South Amazonian Domain consists of a basement formed mainly at the end of the Early Proterozoic, on which later sedimentary and volcanic covers developed, accompanied by intrusions of varied composition. The different lithological and lithostratigraphic units recognized are shown in Table 1, and the distribution of the various rock types is illustrated in Figure 3.

Figure 3: Geology of the South Amazonian Domain. After Berrangé (1982) and Almeida and Hasui (1984). 1 - sedimentary sequences (Pacaás Novos, Dardanelos, Cubencranquém, Prainha, Mutum-Paraná, Tucuruí, Prosperança-Acari, Couto Magalhães, Aguapeí, Sunsas, Vibosi, Huanchaca, Gorotire, Beneficente, Uatuma, Rio Fresco); 2 - basic volcanics (Arinos, Nova Floresta); 3 - bimodal volcanics (Serra do Rio Branco); 4 - acid to intermediate volcanics (Uatumã); 5 - alkaline intrusives (Canamã, Teotônio); 6 - basic intrusives (Cachoeira Seca, Ciriquirei, Crepori); 7 - acid intrusives (Rondônia, Velho Guilherme, Teles Pires, Serra da Providência, Serra dos Carajás, Maloquinha); 8 - volcanic-plutonic suites (Costa Marques, Caripunas, Amoguijá, Centurión); 9 - low-grade supracrustal sequences (Grão-Pará, Jacareacanga, Comemoração, Inajá, Quatro Meninas); 10 - medium to high-grade sequences (Salobo, Alto Tererê, San Luís); 11 - basic-ultrabasic intrusions (Cocoal); 12 - granitoid suites (Parauari, Juruena, Jamanxim, Aviaquário, Mucajá); 13 - high-grade complexes (Cuiú-Cuiú, Chiquitania, Lomas Maneches); 14 - Xingu and Apa complexes. C - Carajás, Cn - Concepcion, Cr - Corumba, PV - Porto Velho, SdP - Serra dos Parecis, SdB - Serra do Bodoquena.

The Oldest Basement

For the most part, the oldest basement, generally described in Brazil as the Xingu and Apa Complexes, is still poorly known, though some granitoid batholiths, basic and ultrabasic suites and volcano-sedimentary belts have been differentiated. The Xingu Complex includes acid and basic orthogneisses, various kinds of migmatite, and a great volume of granite, granodiorite, adamellite, trondhjemitic, diorite, and

TABLE 1:

Age (Ma)	LITHOLOGIC AND LITHO-STRATIGRAPHIC UNITS OF SOUTH AMAZONIAN DOMAIN	
500	Diabase dikes. Alto Paraguai Group Corumbá, Araras, Murciélagos, Itapocumi and Tucavaca groups. Boqui, Jacadigo and Bauxi groups; Puga Formation (glacial units).	
	Diabase dikes, Arinos and Nova Floresta basic volcanics, Cachoeira Seca basic intrusives, Canamã and Teotônio alkalines, Costa Marques and Caripunas plutonic volcanics, Rondônia granites. Ciriquirei basic intrusives, Serra do Rio Branco bimodal volcanics	Pacaás Novos and Dardanelos formations. Cubencranquém and Prainha formations, Mutum-Paraná and Tucuruí groups. Prosperança-Acari and Couto Magalhães formations; Aguapeí, Sunsas, Vibosi and Huanchaca groups.
1400		
1430-		
1550	Velho Guilherme, Teles Pires and Serra da Providência granites	
1640	Crepori basic intrusive suite. Gorotire Formation and Beneficente Group.	
1700-	Serra dos Carajás and Maloquinha granite suites.	Amoguijá Suite and
1850	Uatumã Supergroup (Irirí, Sobrero and Roosevelt formations).	Centurión Group
	Rio Fresco Formation (Gemaque and Serra Pelada formations, Azul and Naja members).	
	Low-grade supracrustals: Grão-Pará Group; units of the northeastern area; Jacareacanga and Comemoração complexes; Inajá and Quatro Meninas groups. Medium/high grade supracrustals: Salobo and Alto Tererê complexes, San Luís Group. Granitoid suites: Parauari, Juruena, Jamanxim, Aviaquário, Mucajá. >1900 Basic-ultrabasic suites: Cocoal, Ingarana. High-grade complexes: Cuiú-Cuiú and Chiquitania complexes, Lomas Maneches Group. Xingu and Apa Complexes.

tonalite. There are also local occurrences of metasediments, metabasic and ultrabasic rocks and granulites. The latter occur sparsely and constitute the two granulite belts of Rondônia (Candeias) and Central do Pará (Bacajá; Hasui, 1984; Lima, 1984). Mineralogical readjustments in low-grade metamorphisms and the effects of mylonitization and cataclasis have been recognized in the Xingu Complex. The Apa Complex, in the south of the domain, is mainly made up of gneisses and granitoids.

More than 200 isotopic age determinations have been made on this basement (e.g. Amaral, 1974; Darbyshire, 1979; Santos and Reis Neto, 1982; Teixeira and Tassinari, 1984). In the northeast some ages between 1.4 and 1.75 Ga have been obtained, and one of 3.28 Ga that requires confirmation. In the central part of the domain only one old date of 2.75 Ga is known (Tassinari and Basei, 1980), while others correspond to the end of the Early Proterozoic and to the Middle Proterozoic. The Early-Middle Proterozoic boundary is here placed at 1.95 Ga and that between the Middle and Late Proterozoic at 1.0 Ga. In the southwest and south, most reported ages are in the 950 Ma-1.5 Ga range with others between 1.8 and 2.2 Ga. These dates are either K-Ar or Rb-Sr determinations on isolated samples or model ages based on reference isochrons on not necessarily co-genetic samples, and their reliability may be questioned.

Figure 4: General view of Carajás district. (Photo by K. Wirth).

Some workers interpret the Proterozoic dates as the result of rejuvenation during various thermo-tectonic episodes (e.g. Issler, 1977; Almeida, 1978; Lima, 1984; Santos and Loguercio, 1984; Hasui et al., 1984). Others, however, view these dates as the true age of formation of these rocks (e.g. Cordani et al., 1979; Litherland and Bloomfield, 1981; Cordani and Neves, 1982). In the latter approach, part of the region is said to have evolved as successive mobile belts, and the overall orogenization is regarded as of terminal Middle Proterozoic age.

Low-Grade Volcanic-Sedimentary Sequences

Low-grade supracrustal sequences have been identified in some areas. The best known of these is the Grão-Pará Group, which forms the Carajás Range, a broad synclinorium with a WNW-trending axis (Figs. 4 and 5). This structure is bordered by the Xingu and Salobo complexes and contains in its core an upper sequence attributed to the Rio Fresco Formation. The Group consists of two levels of basic metavolcanics separated by the Carajás Formation (Beisiegel et al., 1973). The latter is a 100-300 m sequence of fine-grained to conglomeratic quartzites and phyllites, with important levels of jaspilites and itabirites, which weather to form the huge reserves of high-grade iron ore of Serra dos Carajás. The Grão-Pará Group is interpreted as a shallow marine deposit

with basic volcanic contributions, though whether the iron is sedimentary or volcanogenic is debatable. K-Ar determinations provide ages of around 2.0 Ga (Gomes et al., 1975), which may be related to the greenschist facies metamorphism of the Group or to a Trans-Amazonian imprint on Archean rocks.

Other supracrustal sequences (Table 1), metamorphosed to greenschist and locally to amphibolite facies, consist of basic, ultrabasic and some acid metavolcanics associated with clastic metasediments interbedded in places with meta-cherts and banded iron formation (Fig. 6). They are locally gold bearing. In the northeastern part of the domain, these sequences include the Inajá Group, the unnamed sequences of the Andorinhas Range and Gradaús Range (Fig. 5), and those of the Rio Novo, Sapucaia and Itatá regions (Ilanhez et al., 1980; Cordeiro, 1982; Gama et al., 1982; Cordeiro et al., 1982; Hirata et al., 1982; Silva, 1984). Also grouped here are the Jacareacanga Complex, in the central part of the domain, and the Comemoração Complex and the Quatro Meninas Group in the southwestern part (Santos and Loguercio, 1984; Saes et al., 1984). In the sequence of the Sapucaia region, spinifex textures have been noted (Hirata et al., 1982).

These volcano-sedimentary sequences are interpreted as greenstone belts infolded within the Xingu Complex. These form NW-, WNW- and NE-trending belts intruded or surrounded by granitoid bodies. The only age determination available on these sequences is 2.75 Ga on the Inajá Group.

Medium- and High-Grade Units

Some supracrustal sequences metamorphosed to amphibolite-granulite facies have also been defined. In the northeast the Salobo Complex has been defined and correlated with several other metamorphic sequences around Serra dos Carajás (Fig. 5). This complex has been studied in detail because of its copper deposits. It consists of biotite gneisses, amphibolites, amphibole schists, quartzites, basic and intermediate metavolcanic rocks and banded iron formations (Farias and Saueressig, 1982; Martins et al., 1982). An age of 2.7 Ga was obtained for this sequence, and micro-granite intrusions cutting it have been dated at 1.8 Ga (Tassinari et al., 1982).

In the central part of the South Amazonian Domain is the Cuiú-Cuiú Complex, cut by the 1.8 Ga Ingarana Gabbro and metamorphosed to amphibolite and locally granulite facies and migmatized.

In eastern Bolivia, the Lomas Maneches Group (Berrangé, 1982) has been described as mainly granulite rocks, locally migmatized, and passing transitionally to the Chiquitania Complex. This latter is composed of migmatized paragneisses, quartzites, tremolite schists, leptytes, amphibolites and calc-magnesian rocks (Bloomfield and Litherland, 1979), and locally constitutes the basement for the rocks of the San Ignacio Group. In the area of Concepción, some Chiquitania paragneisses are known to grade laterally into psammite members of the San Ignacio Group. The latter consists of mica and graphite schists, quartzites, calc-silicate rocks, paragneisses, basic metavolcanics, iron formation and basic-ultrabasic sills, all metamorphosed to medium grade.

Litherland and Bloomfield (1981) interpret the San Ignacio Group as representative of the (post-Trans-Amazonian) San Ignacio orogenic cycle which ended around 1.3 Ga. The unconformity between the San Ignacio Group and the Chiquitania (in part) and Lomas Maneches complexes of so-called Trans-Amazonian age has, however, only been recorded in the San Ignacio type-area, perhaps because of migmatization of the assemblages elsewhere.

K-Ar dates on these Bolivian rocks give results from 1.991 Ga to 597 Ma, which certainly correspond to minimum ages. Two results for the Lomas Maneches Group (2.279 and 3.601 Ga) were considered anomalous (Darbyshire, 1979). The reference Rb-Sr isochrons obtained do not permit reliable age

determinations. The 1.297 Ga date for the San Javier Granite, associated with the San Ignacio Group, and that of 1.961 Ga for the Lomas Maneches Group indicate incomplete isotopic homogenization or later disturbances in the system, thus casting doubt on the link of these units to the San Ignacio and Trans-Amazonian Cycles.

It is probable, thus, that the rocks in question are part of the older basement and that the geochronological pattern, similar to that determined in other parts of the domain, can be interpreted in a different way. There is the same kind of doubt about the Alto Tererê Complex in Brazil and its extension into Paraguay, known as the San Luis Group. The Alto Tererê appears on the eastern slope of the Bodoquena Range in the southern portion of the domain. It is made up of fine-grained quartzites, mica schists, amphibole schists and granitoids (CPRM, 1976) and is intruded by granites from the Amoguijá Suite (1.7 Ga). The sequence is covered by the Late Proterozoic Corumbá Group. The San Luis Group consists mostly of folded and sheared schists and quartzites, with low to medium grade metamorphism. Contacts with the gneissic basement seem to be obscured by faults.

Old Intrusive Rocks

Although more or less gneissic granitoids are an important part of the Xingu Complex, only a few of them have yet been mapped. Among these, in the central region, are the batholiths of Parauari, Jamanxim and Juruena, of pre-Uatumã age (1.947 Ga), and those of Aviaquário and Mucajaí in Rondônia. The domain also contains a large number of small metamorphosed basic and ultrabasic intrusives.

Middle Proterozoic

After the Trans-Amazonian thermal-tectonic event, intense erosion, marine and continental sedimentation, and volcanism and intrusions of various types occurred. The remains of the volcanic and sedimentary covers can be found all over the Shield, but as yet their correlation and depositional environments have not been properly determined. Although several hundred isotopic dates have been obtained, mainly by K-Ar and Rb-Sr (conventional ages and reference isochrons), there is still much doubt about their interpretation. Table 1 lists the recognized formations and groups in the order - often assumed - in which they succeeded one another.

Volcanic and Sedimentary Sequences

The acid to intermediate volcanism of the Uatumã Supergroup probably affected no less an area than 2 million km² of the Amazonian Craton, in the interval from 1.85 to 1.55 Ga. The Uatumã constitutes a major stratigraphic unit, allowing the distinction of rocks of earlier and later Middle Proterozoic age.

The pre-Uatumã platform cover appears in the northeastern part of the domain as clastic marine sediments of the Rio Fresco Formation. Possible correlatives include the Gemaque unit and the Serra Pelada Formation, known for its gold occurrences (João et al, 1982). The Rio Fresco Formation reaches as much as 3,000 metres in thickness and includes some limestones and a coal horizon. Like its correlatives, it was folded and affected by low-grade metamorphism.

Figure 5: Geology and mineral deposits of the Serra dos Carajás region. After Hirate and others (1982). Dashed lines indicate roads. Rio Fresco sequence: RFa - Azul Member, RFn - Naja Member, RFs - Serra Pelada Formation, RFg - Gemaque Formation. Greenstone belts: RN - Rio Novo, SA - Sapucaia, GR - Gradaus, AN - Andorinhas. Mineral deposits: 1 - Salobo 3A, 2 - Pojuca (MML), 3 - Buritirama, 4 - Azul, 5 - Sereno, 6 - Serra Pelada, 7 - Andorinhas, 8 - Gradaus, 9 - Vermelho, 10 - Puma, 11 - Onça, 12 - Velho Guilherme.

The Uatuma Supergroup includes volcanic rocks from the Iri, Sobrero and Roosevelt formations and is synchronous with the Amogujá Complex (southern part of the domain) and Centurión Group of Paraguay. The components are rhyolites, rhyodacites, dacites, andesites, latites, trachytes, tuffs, breccias and volcanic agglomerates, and ignimbrites, ranging from 1.845 to 1.55 Ga (e.g. Bezerra et al., 1982).

Post-Uatuma sequences, whether continental or marine, formed through erosion of pre-existing volcanic rocks, shortly after, or even during the final episodes of the volcanism itself. One of the oldest of these sequences, the Beneficente Group, covered a large part of the central and western regions of the domain with marine clastics, locally including limestones which may contain stromatolites. The Gorotire Formation, apparently constituted during the same time span as the Beneficente Group, has continental characteristics. Both sequences are deformed by faults. The Gorotire Formation has been correlated with the Roraima Group of the Guiana Shield (Gibbs and Barron, 1983). It is cut by the Crepori sill, which is dated at 1.64 Ga; dikes associated with the Crepori also intruded the Beneficente Group, attesting to the antiquity of both.

Also resting on the Uatuma volcanics is the Prosperança Formation made up of clastic sediments intercalated with limestones and dolomites of the Acari Formation and intruded by basic dikes dating from 1.1 to 1.4 Ga. The Couto Magalhães Formation, well developed in the Ceres Mobile Belt, is transgressive on the eastern portion of the domain where it forms a thin tabular cover (Hasui and others, in Almeida and Hasui, 1984). Its minimum age is 860 Ma.

Figure 6: Small-scale folding in banded iron formation, Carajas. (Photo by K. Wirth).

In the southern portion of the domain, the Aguapeí Group (Souza and Hildred, 1980; Santos and Loguércio, 1984) represents the remains of an extensive platform cover of marine clastics less than 600 metres thick. Low-grade metamorphism and pronounced deformation occur in a zone of intense faulting, away from which the layers are subhorizontal. A basic intrusion into this unit has been dated (K-Ar) at 936 Ma.

The Sunsas, Vibosi and Huanchaca groups of eastern Bolivia (Bloomfield and Litherland, 1979; Berrangé, 1982) have clastic lithologies similar to those of the Aguapeí Group, but with thicknesses of thousands of metres and metamorphism up to high amphibolite facies. The mafic-ultramafic Rincón del Tigre Complex, more than 4,600 metres thick, intrudes into the Vibosi Group, and has been dated at 992 Ma (Darbyshire, 1979). The WNW-trending fold belt of the Sunsas and Vibosi groups has been interpreted as an ensialic orogenic belt that developed between 1.3 Ga and 950 Ma during the Sunsas Cycle.

The subhorizontal Cubeneranquém Formation, probably of continental origin, occurs in a broad area of the central part of the domain. It is younger than the alkaline rocks (1.175 Ga) of the Sucunduri Dome. The Prainha Formation, recognized in the north-central part seems to be synchronous with Cubeneranquém, as does the Mutum-Paraná Group which is exposed in Rondônia. In the northeast, the Tucuruí Group consists of basalts at the bottom and fine-grained graywackes at the top. It was upthrust by the Couto Magalhães Formation from the Paraguay-Araguaia fold belt (Hasui and others, in Almeida and Hasui, 1984) and is regarded as late Middle Proterozoic age.

The Dardanelos and Pacaás Novos formations are represented by arkoses, sandstones and continental conglomerates, which occur in grabens at the western part of the domain. The former is intercalated with basaltic flows (Arinos Formation), whereas the latter covers a similar unit (Nova Floresta Formation). These alkaline volcanics have been dated at approximately 1.0 Ga.

Finally, reference must be made to the bimodal volcanic rocks that appear at the headwaters of the Paraguay River. These are the basalts, rhyolites, dacites, andesites and granophyres of the Serra do Rio Branco Suite. The acid volcanics are dated at 1.13 Ga, and the basic rocks have K-Ar ages of from 850 Ma to 1.45 Ga (Teixeira and Tassinari, 1984).

Intrusive Rocks

Many stocks and batholiths with varied forms, some of sub-volcanic type, appear throughout the South Amazonian Domain (Dall'Agnol, 1982). The Uatuma Supergroup has associated intrusions of biotite granite, alaskite, rapakivi granite, adamellite, granophyre, quartz monzonite, quartz syenite, and diorite. These constitute the Maloquinha Suite, whose age spans the interval from 1.77 to 1.55 Ga. In the northeast, there are many intrusive bodies cutting the old basement and the Rio Fresco Formation. These are known as Serra dos Carajás-type granite (Fig. 5), dated at 1.82 Ga (K-Ar).

The granites included in the Teles Pires Suite intrude the edges of the Serra do Cachimbo Graben in the central region (Fig. 7). They are dated at 1.55 Ga (Rb-Sr isochron). East of the graben, granites, alaskites, granodiorites and trondhjemites of the Velho Guilherme type are dated at 1.43 Ga, whereas to the west, the rapakivi granites of the Serra da Providência granite type are approximately 1.53 Ga old. In Bolivia, the San Javier granites described by Bloomfield and Litherland (1979) have been dated at 1.38 Ga.

The Rondonian granites in the western part of the domain comprise porphyritic granite, leucogranite, microgranite and rapakivi granite (Kloosterman, 1968) and are associated with cassiterite-bearing greisens and acid to intermediate volcanics. Recent age determinations yield Rb-Sr isochron ages at 1.26 Ga ($R_i=0.715$; Teixeira and Tassinari, 1984), much older than the 980 Ma dates obtained by Priem and others (1971). Some workers regard these granites as having formed at about 1.5-1.6 Ga, like other cassiterite-bearing granites of the central and southwestern shield, with younger dates being the result of isotopic rejuvenation.

The granites of this suite are related to the volcanics (rhyolite, rhyodacite, andesite and dacite) of the Caripunas Suite, exposed in the Madeira River valley of western Rondônia. In southern Rondônia, rhyolites, rhyodacites, andesites, trachytes and tuffs of the Costa Marques Suite (1.02 Ga) also appear, associated with Rondônia-type intrusives.

Precambrian alkaline intrusive rocks are uncommon in the South Amazonian Domain. The syenites, aegirine monzonites and aegirine granites of the Porto Velho region (Teotônio) have preliminary ages from 950 Ma to 1.25 Ga. The so-called Canamã Syenite, grouping alkali syenites, nepheline syenites and phonolites (circa 1.175 Ga), forms scattered dikes and stocks to the west of the Cachimbo Graben.

Basic dikes are scattered throughout the domain. Many of them in the central and northeast parts have been dated at 900-1050 Ma and 500 Ma, and others of Mesozoic age occur in the northeast. In the west, basic and ultrabasic rocks of the Ciriquiqui Complex have been dated at 1.37 Ga. From 1250 to 950 Ma in the central part of the Domain, there were frequent basic and some alkaline intrusives of the Cachoeira Seca magmatics. Small anorthosite massifs dated at 1.24 Ga and associated with gabbro, quartz monzonite and granophyre are also known.

Late Proterozoic

Within the southern edge of the domain in Brazil, Bolivia and Paraguay, there are some sedimentary sequences less than 1.0 Ga old, which are assigned to the interval between the Proterozoic and the Llandovery. For the most part these represent a westward extension into the foreland of deposits from the Paraguay-Araguaia fold belt. The oldest of these sequences are the Boqui and Jacadigo groups, which are probably coeval, consisting of immature sandy and conglomeratic sediments, with pelitic intercalations, and chert, jaspilitic iron and limestone beds. The Boqui Group of southeastern Bolivia rests discordantly on the basement, as does the Jacadigo Group of the Corumbá region and vicinity, famous for its vast deposits of jaspilitic iron ore and manganese oxides.

The Bauxi group is a sequence of coarse to fine elastics, locally with low grade metamorphism. Some workers correlate it with the Aguapeí Group whereas others regard it as younger. The post-Boqui Tucavaca Group (Berrangé, 1982) is a unit about 2,000 m thick, which in Bolivia fills a WNW faulted zone 400 km long. It shows incipient local metamorphism and rests on the Sunsas Group.

An extensive thick sequence of limestone and dolomite with intercalated fine-grained elastics extends inwards from the edge of the craton where it was deformed by the Brasiliano orogeny, especially in Bolivia (Berrangé, 1982). These sequences include the Corumbá and Araras Groups of Brazil, Murciélago in Bolivia, and Itapocumi in Paraguay. Locally at the base are glacial deposits of the Puga Formation consisting of up to 100 m of diamictites, sandstones, silts and shales. The dolomites in the sequence contain stromatolitic structures. In the upper limestones remains of an apparently new Scyphozoa (*Corumbella wernerii*) have been found; this would be the first Precambrian animal macrofossil to be found on the continent. Together with the associated algae (apparently *Bavlinella faceollata*), this would indicate that these rocks date from the Riphean/Early Cambrian (Walde et al., 1984), but this age is cast in doubt by Fairchild (1984).

The Alto Paraguai Group represents the thick filling of a molasse foredeep extending from the adjacent fold belt, where it is strongly deformed, to the cratonic foreland as a tabular cover only deformed by faults. The shales in the top of the sequence have been dated at 547 Ma (Rb-Sr), presumably indicating the age of sedimentation.

Main Phanerozoic Events

As already mentioned, more than 25% of the South Amazonian basement is covered by marine and continental rocks and by Phanerozoic volcanics associated with the Paraná and Amazon basins. The most important cover sequences belong to the Serra Do Cachimbo Graben and the Parecis-Xingu Basin (Fig. 7). These are attributed mainly to the Silurian and Permian (Santos and Loguercio, 1984), and the thickness exceeds 1,350 m. In Rondônia, the Pimenta Bueno Formation, consisting of clastic sediments, subordinate limestones and coal lenses, is considered to be Paleozoic but has not yet been properly dated.

Near the southeast edge of the domain are important remains of the sediments and volcanics correlated with those of the Paraná Basin. This Jurassic-Cretaceous volcanism gave rise to basalt flows, sills and many dikes, several of which have been dated. Dozens of kimberlite intrusions are also present, the source of placer diamonds mined at Rondônia and Mato Grosso (Svisero et al., 1984). Alkaline intrusions also exist in Paraguay (Palmieri and Velasquez, 1982) and Bolivia (Fletcher and Litherland, 1981).

The Late Cretaceous is represented by the Parecis Formation of Rondônia and Mato Grosso, which constitutes clastic layers up to 210 m. thick (Santos et al., 1978). In the upper

Figure 7: Major structures of the South Amazonian Domain. After Berrangé (1982) and DNPM maps.

basin of the Xingu River in the north of Mato Grosso, there is also an extensive thin sand-clay cover, dated as Cenozoic. Quaternary sedimentation is limited to river valleys, with the most impressive development in the Guaporé River basin along the Brazil-Bolivia border.

Structures

The structures of the South Amazonian Domain are poorly known. Folds, foliations, faults and lineaments have been reported, but most have been inferred from radar and satellite imagery without precise definition (Fig. 7). In the older basement, the lithologic belts, foliation and large folds mostly trend from NNW to E-W, and there are scattered domal features. However, there is insufficient information to systematize deformation patterns and styles.

Folds and foliation can also be recognized in part of the Proterozoic volcanic and sedimentary cover. In Brazil, such features are interpreted as related to shear zones, intrusions and local stresses. In Bolivia, the folds and metamorphism of the Sunsas and Vibosi Groups are attributed to a mobile belt of the Sunsas Cycle (Litherland and Bloomfield, 1981; Berrangé, 1982).

The most pronounced features are the lineaments interpreted as large shear zones (Issler, 1977, Lima, 1984), mostly with NW and NE trends. These zones are related to normal and transcurrent displacements, which divide up the region into blocks or grabens and horsts. The outstanding grabens are those of the Serra do Cachimbo, Pimenta Bueno, Uopione and Pacaás Novos. The displacements are considered to be mainly of late Middle Proterozoic age, but they may have developed earlier and undergone reactivation throughout the Proterozoic. Later faults that cut Paleozoic sediments, are also known.

Geological Evolution

The lack of detailed data about the origin, age, correlation and transformation of the old basement makes unreliable the models proposed for the geological evolution of the shield. However, there are already sufficient data to prove continuity between the Guiana Shield and that part of the Central Brazil Shield south of the Amazon.

In 1970, Suszczyński presented a preliminary essay on regional interpretation, in which three major provinces within the Amazonian Platform were distinguished. Considering the radiometric dates then available, Amaral (1974) related these provinces to successive Middle Proterozoic tectono-magmatic events. He argued that the Trans-Amazonian Cycle was an event of crustal remobilization, accompanied by anatexis, gneissification and migmatization between 2.2 and 1.9 Ga, following which the region stabilized. The tectono-magmatic events he recognized are the Paraense (1.7–1.55 Ga), the Madeirense (1.4–1.25 Ga), and the Rondoniense (1050–900 Ma). These events are believed to have migrated from NE to SW in broad adjacent NW-SE trending zones.

In 1978, Almeida drew attention to the remarkable tectonic, sedimentary and magmatic similarities between the Middle Proterozoic of the Baltic Shield and the South Amazonian Domain. Amaral (in Almeida and Hasui, 1984) has recently supported the analogy by comparing his three Middle Proterozoic events with those recognized by Grigoryeva (1979) in the Baltic region.

Another model of the geological evolution of the Amazonian Platform, based on geochronological data, has been proposed by Cordani and others (1979) and Cordani and Neves (1982). Their interpretation is based on lateral and vertical accretion processes occurring through successive mobile belts trending NW-SE. These belts are said to have evolved around an Archean cratonic block (Xingu Block), constituted by granite-greenstone terrains. To the northeast, in the area shown on Figure 4, they recognize the Maroni-Itacaiunas Mobile Belt (2.1–1.8 Ga), to the west the Rio Negro-Juruena Mobile Belt (1.75 to 1.5 Ga) and to the southwest, the Ron-

dônia Belt (1.4–1.0 Ga). All these belts are regarded as ensialic but involving the formation of supracrustal rocks and the addition of mantle-derived materials.

In eastern Bolivia, Litherland and Bloomfield (1981; see also Berrangé, 1982) recognize two Middle Proterozoic ensialic orogenic cycles: San Ignacio (around 2.0–1.3 Ga) and Sunsas (1,300–950 Ma). The former developed a NW-trending orogenic belt accompanied by granitoid formation, while the latter constituted an orogenic belt with a NNW trend and associated granitoid and basic-ultrabasic intrusions.

A new approach is now possible in the recognition of major structures and crustal units. This utilizes gravimetric and magnetic data provided by satellite, gravimetric data from the Amazon Basin and Bolivia, partial aeromagnetic data, density values for rock samples collected by Projeto Radam-brasil, and existing geological data. Four large blocks of granite-greenstone terrains, separated by high-grade belts, have now been delineated, representing the regional structures developed in the Archean (Hasui et al., 1984). The major lineaments active during the Middle Proterozoic coincide with or run parallel to the high-grade belts, and old lines of crustal weakness seem to have had a pronounced influence on the Proterozoic evolution of the region. The tectono-magmatic and sedimentary processes, which occurred from the Middle Proterozoic onwards, apparently did not occur in regular belts but were rather the result of isotherm elevations, crustal swellings and tensional regimes operating over large areas.

Mineral Resources

Finally, many mineral deposits have already been found and the probability of new discoveries is high. The outstanding example is the iron ore of Serra dos Carajás (Fig. 5). More than ten deposits are now known, adding up to reserves of nearly 18×10^9 tonnes of high-grade ore with 66% Fe (Santos, 1981). A large-scale mining, dressing and transportation project (involving a 890 km railway and a marine loading terminal) is in the final stages of implementation. The sedimentary iron deposit of Urucum, associated with the Jacadigo Group, is also impressive.

Seventy-five percent of the gold mined in Brazil in 1983 came from the South Amazonian Domain, panned from placers apparently derived from volcano-sedimentary sequences of greenstone belts. These areas include Comemoração in Rondônia, Jacareacanga in the Tapajós valley, the sequences of the eastern region shown in Figure 5, and Itatá south of Altamira. The case of Serra Pelada is different, because the gold here is associated with a sedimentary sequence correlated with the Rio Fresco Formation (Meirelles et al., 1982).

Significant cassiterite deposits have been discovered in Rondônia and, more recently, in Pará. These are placers derived from the Middle Proterozoic granites, and the 1983 production totaled 76 tonnes of cassiterite.

The Salobo Complex in the northeastern part of the domain contains copper deposits of stratiform and stratabound type, with the sulphides disseminated in ferruginous schists. The Salobo 3A deposit has reserves estimated at 1,100 million tonnes (MT) with 0.86% Cu, and associated Mo, Au and Ag (Santos, 1981). Other deposits shown on Figure 3 are still being evaluated.

Manganese is found in several areas. The Azul deposit in the Rio Fresco Formation (44.5 MT with 42.2% Mn), the Buritirama deposit related to the Salobo Complex (3 MT with 40% Mn), and the Sereno deposit are the most impressive in the Carajás Range region. In the Jacadigo Group, the Urucum deposit has 14 MT of sedimentary ore with 44.27% Mn.

South of the Carajás Range, basic-ultrabasic bodies contain nickel deposits in the form of disseminated sulphides and laterites (Bernardelli et al., 1982; Alves et al., 1984). The

most important four are Vermelho (44 MT with 1.5% Ni), Puma (24 MT with 2.2% Ni), Jacaré (23 MT with 1.2% Ni), and Onça (18 MT with 2.2% Ni).

The bauxite of the Carajás Range is related to the laterization of metabasic rocks of the Grão-Pará Group and the estimated reserve is 40 MT with 44% Al_2O_3 , 24% Fe_2O_3 and 2% SiO_2 (Bernardelli et al., 1982).

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