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The Growth of the Brazilian Shield

by Umberto G. Cordani, Wilson Teixeira, Colombo C.G. Tassinari, Koji Kawashita and Kei Sato

With its several orogenic belts spanning the entire Proterozoic, the Brazilian Shield is one of the best places to study late Precambrian tectonic regimes and the role of accretion versus reworking in crustal growth. In this review, the authors draw on a huge volume of data, many as yet unpublished, to show that some 45% of the present continental crust in the Shield was formed at the end of the Archean and about 80% by the end of the Early Proterozoic. (Ed.)

Introduction

Granitic rocks in the broadest sense are the main constituents of the continental crust. They include not only the common magmatic suites ranging from granodiorites and tonalites to real granites, but also medium to high-grade regional metamorphic terrains, which are granitic in mineralogy and which make up the gneissic-migmatic-granulitic complexes so common in all shield areas. Their geological evolution can be tracked, in part, through the study of the Rb-Sr systematics.

There is general agreement that a regime of global tectonics has governed lithospheric processes since at least the late Precambrian, about 900 Ma ago (e.g. Kröner, 1981). For older terrains, where the diagnostic features of the present regime such as ophiolites and blueschists have not been found, two main schools of thought have developed. One postulates uniformitarian development right through geological time by inferring some type of a "primitive form" of plate tectonics since the Archean, and the other accepts possible changes in the internal behaviour of the Earth and suggests that the mechanisms governing crustal formation and growth may have changed through time.

The Growth of Continents

It has been widely accepted that growth of continental crust was faster in the Archean than in later time, and also that a major part of the present crustal material had already separated from the mantle by the end of the Archean. Figure 1 shows model curves of several authors relating continental crust production to time. Excluding extreme cases involving entire reworking of a primitive sialic crust (Fyfe, 1978; Armstrong, 1981) or a very large accretion in the last 1000 Ma (Hurley, 1968, Hurley and Rand, 1969), the general preference is for models in which a large proportion of continental crust was formed in Archean times but significant crustal growth also occurred during Proterozoic and Phanerozoic. For example, recent textbooks by Windley (1984) and Condie (1982) estimate that around 70-80% of the continental crust was already formed in Archean times.

The curve by Reymer and Schubert (1984) was based on an extrapolation back to the Archean-Proterozoic boundary of the rate of production of continental crust at modern magmatic arcs (e.g. Japan) and in the late Precambrian Hijaz magmatic arc (Saudi Arabia). For these authors, continental growth during Archean times was indeterminate and could have started right at the beginning of geological time. In any case, the crust formed in the Archean at fast rates and would be essentially juvenile, whereas that formed in later times at much lower rates would be dominated by recycling of previous crustal material.

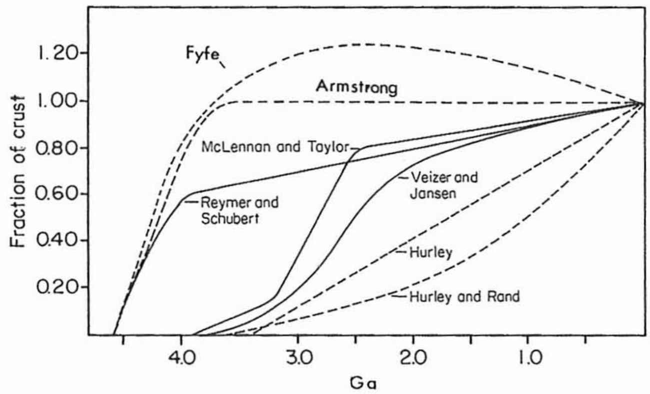

Figure 1: Crustal growth curves, adapted from Taylor and McLennan (1985).

A reasonable estimate of the time when a particular material was incorporated from its mantle source into the continental crust can be achieved by examining its "signature" in terms of radiogenic isotopes. Natural processes can not modify isotopic ratios in order to "clean" a rock unit of its acquired radiogenic components, and a complete isotopic rejuvenation of Sr, Pb and Nd is unrealistic. Thus, ancient continental crust cannot be completely concealed, whatever its geological evolution. Moreover, from isotopic evidence its age of formation can be usually revealed or estimated within certain limits (e.g. Moorbath and Taylor, 1981).

As in the case of Pb and Nd isotopes, Sr isotopes are thus very important, for they may help in determining the type and intensity of accretion and reworking processes. The initial $^{87}Sr/^{86}Sr$ ratio for a suite of cogenetic igneous or metamorphic rocks has long been used as a petrogenetic indicator of source material, and when applied to granitoid rocks, it can be of significant value in determining their tectonic setting and origin. In general, values below 0.703 are indicative of mantle-derived juvenile material, and values above 0.710 indicate anatexis or metamorphic transformation of a crustal protolith. Intermediate values are more difficult to interpret, since they may be due to mixing of different source materials, derivation from crust with relatively low Rb/Sr ratios, crustal contamination of mantle-derived magmas, or formation from anomalous mantle sources with higher radiogenic Sr (Faure, 1986).

In recent years, with the increasing evidence from isotopes of Sr, Pb and Nd, the evolution curves can be estimated separately for each continental mass. Calculations employing especially Nd isotopes have indicated crustal ages younger than those that would be derived from such curves. For example, a growth curve for Australia was presented by

Page and others (1984) in which Proterozoic crustal accretion was considered significant. In Canada and in the Baltic Shield also, Nd isotope studies are demonstrating that the crust can be generally younger than previously thought (De Paolo, 1980, 1981; O'Nions et al., 1979). As shown in the following, Sr isotopes indicate that for South America Proterozoic crustal evolution was predominant, with the addition of juvenile material in this period even exceeding the crustal material produced in the Archean.

Precambrian Geologic Evolution in South America

The Brazilian Shield can be divided into crustal domains with internally coherent structural evolution and geochronological pattern (Fig. 2) using several criteria. First, the principal tectonic provinces can be distinguished following the work of Almeida and others (1981), and Hasui and Almeida (1985). The São Francisco and Amazonian cratons can be further subdivided using the boundaries suggested by Brito Neves and others (1980), and Cordani and Brito Neves (1982) respectively. Within the late Precambrian tectonic provinces, crustal domains follow the areal extent of associated folded belts and exposed rejuvenated basement (e.g. Schobbenhaus et al., 1984). Where Precambrian basement is concealed beneath Phanerozoic sediments, primarily in the Amazonian, Parnaiba and Paraná basins and below the extensive Tertiary-Quaternary cover of central Brazil, crustal domains can be extrapolated into "basement" areas with the help of drill-core data (Brito Neves et al., 1984).

The westernmost outcrops of the Brazilian Shield were taken as the western limit of the area covered by this study. The extension of the Precambrian basement beneath the Andean foredeeps (Llanos, Beni, Chaco, Pampas) was thus excluded from our estimates, because of complete lack of information. To the north and east, the present coastline was used as a boundary, since the thinning of the continental crust at the shelf areas is not completely known. The area considered in Figure 2 (9.3×10^6 km^2) includes the whole of Brazil, French Guiana, Guyana and Surinam, a large part of Venezuela, significant areas of Bolivia and Uruguay, and small areas of Paraguay and Argentina.

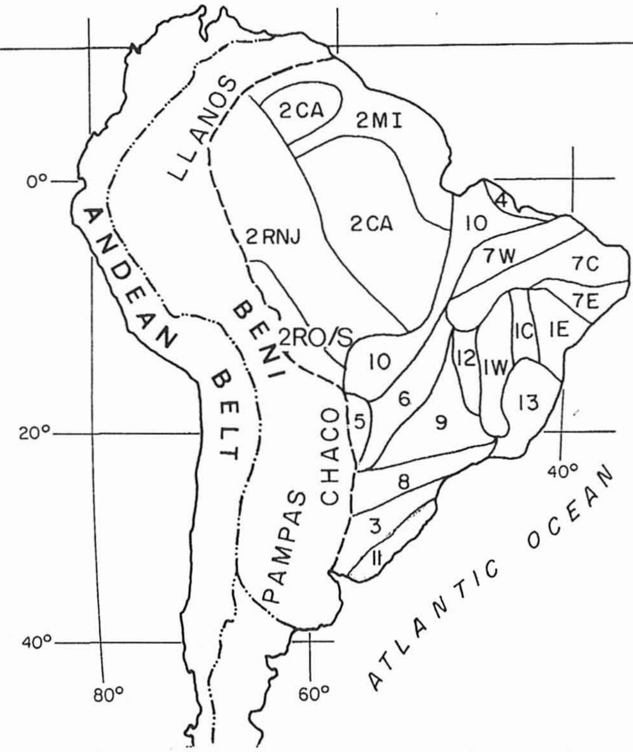

Figure 2: Crustal domains of the Brazilian Shield. 1: São Francisco Craton (E-Eastern, C-Central, W-Western), 2: Amazonian Craton (CA-Central Amazonian, MI-Maroni-Itacaiunas, RNJ-Rio Negro Juruena, RO/S-Rondonian/Sunsas), 3: Rio de la Plata and Luis Alves cratonic fragments, 4: São Luis Craton, 5: Rio Apa cratonic fragment; 6: Central Goiás Complex, 7: Borborema Province (E-East, W-West, C-Central, including NE Goiás State), 8: Curitiba crustal fragment, including São Roque Belt, 9: Araxá, Alto Rio Grande belts, including Amparo Complex, 10: Paraguay-Araguaia/Tocantins belts, 11: Dom Feliciano Belt, 12: Brasília Belt, 13: Jequitinhonha Belt.

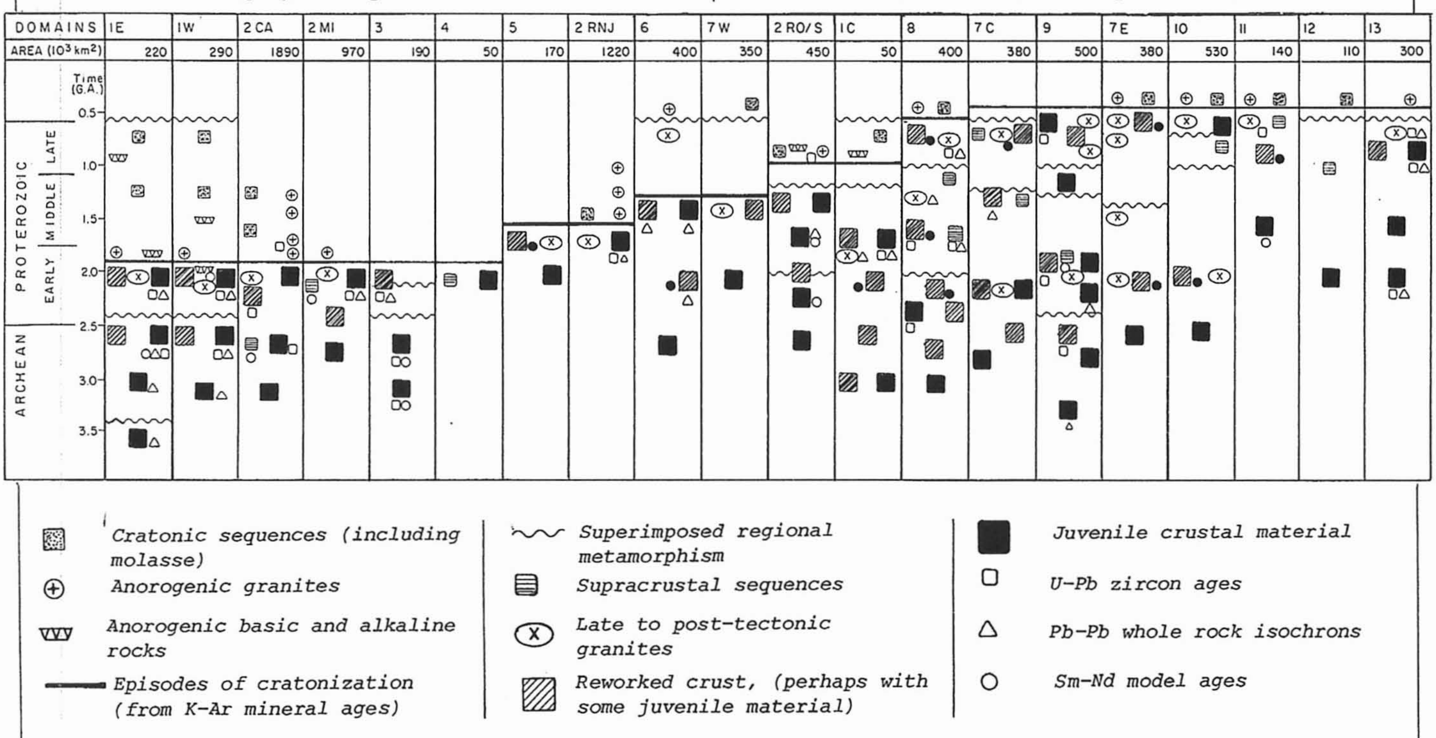

Figure 3: The geological evolution of the main geotectonic domains of the Brazilian Shield. Radiometric control mainly by Rb-Sr whole rock isochrons. See text for explanation.

Figure 3 illustrates, with the aid of available isotopic determinations, the geotectonic evolution of each domain thus defined. Since episodes of crustal accretion or crustal reworking in a given tectonic domain are generally spread over an interval of time with durations of up to a few hundred million years ("orogenic" episodes), some kind of a conventional time-scale had to be employed for our exercise. The Precambrian in Figure 3 has, therefore, been divided into nine time intervals in order to report the sequence of orogenic events in each of the crustal domains.

The principal regional "orogenic" sequences, tectonic units, main granitic intrusions, and regional events (metamorphic episodes, cratonization and regional cooling) are shown on Figure 3, with emphasis on episodes of crustal formation. Initial Sr ratios were used to estimate the main periods of accretion, low values being assumed to indicate direct mantle derivation. Intermediate to high values, together with the average Rb/Sr ratios were used to estimate either the possible age of juvenile protoliths, in case of reworking, or the relative proportion of added juvenile material, when mixing and crustal contamination processes were involved. When available, other radiometric data was also used, and in most cases concordant or nearly concordant apparent ages were obtained, thus supporting the validity of the Rb-Sr measurements.

The information used in compiling Figure 3 is, of course, extemely varied, and it is not possible to refer to all the sources employed. In general, the work is based on about 10,000 Rb-Sr determinations of individual rock samples, and the examination and interpretation of more than 500 isochron diagrams. Part of this material is included in some 100 scientific publications, many of which are regional works primarily of local interest. Comprehensive syntheses also exist (e.g. Brito Neves et al., 1980; Cordani and Brito Neves, 1982; Cordani et al., 1985; Litherland et al., 1986; Iyer et al., 1987; Dall'Agnol et al., 1987; Tassinari, 1988; Teixeira et al., in press).

Also used was unpublished data from on-going work at the Institute of Geosciences of the University of São Paulo. Most of the U-Pb, Pb-Pb or Nd isotopic work referred to was carried out in collaborative research projects at foreign laboratories. More importance was given in this compilation to isochrons with good geological control, such as cogenetic samples collected at single outcrops, or clearly related and nearby outcrops of the same rock units. Nevertheless, we must emphasize that in such a compilation and synthesis it is not possible to avoid subjective and personal bias.

The objective parameters involved are the areal extent of the tectonic units under examination, and the variations observed in Rb/Sr ratios and initial $^{87}Sr/^{86}Sr$ ratios. In several cases, the choice is between a tectonic model of lateral accretion (e.g. magmatic arc-type regime) and one involving vertical growth (e.g. rift-type or ensialic orogenic regime), with obvious consequences for estimates of volumetric proportions of crustal material. In other cases it was necessary to estimate from Sr isotope evidence alone (occasionally, with Nd model ages) the possible ages and relative amounts of juvenile protoliths in regions of reworked crustal material. Finally, and again from isotopic evidence alone, some estimates had to be made of the proportions of juvenile material added to a granitoid-migmatite terrain with a mixed origin.

Growth of the Brazilian Shield

Assuming a uniform crustal thickness for the Shield, the relative areas of the domains can be taken as representing crustal volumes. From the estimated proportions of accreted material for each domain, the relative amounts of continental crust accreted in each time interval can be obtained for the entire Shield (Fig. 4). Three time intervals were attributed to the Archean (with boundaries arbitrarily chosen at 3100, 2800 and 2500 Ma), and six to the Proterozoic (with boundaries at 2100, 1800, 1500, 1200, and 900 Ma). The nine resultant time-intervals (A_1, A_2, A_3; EP_1, EP_2; MP_1, MP_2, LP_1, and LP_2) were employed for the crustal growth calculations (Fig. 4).

It must be emphasized that in these calculations, significant weight is given to the very large domains of the Amazonian craton (e.g. Central Amazonian 2CA, Maroni-Itacaiunas 2MI, Rio Negro-Juruena 2RNJ, see Fig. 2), where geological information is very preliminary, and geochronological control is far from adequate. Nevertheless, the results of these calculations are plotted in Figure 5. For comparison, the Reymer and Schubert (1984) curve (from Fig. 1) is also indicated here.

The main periods of crustal growth in the Brazilian Shield are immediately evident. As expected, Archean (A_2 to A_3 - 3100 to 2500 Ma), Early Proterozoic (EP_2 - 2100 to 1900 Ma - the Transamazonian Orogeny) and mid-Proterozoic (MP_1 - 1800 to 1600 Ma - the Rio Negro-Juruena magmatic arcs) stand out as the main periods for continental crust accretion. On the other hand, even if they are very important tectonically, the Late Proterozoic orogenies were mainly ensialic in character, bringing only a minor

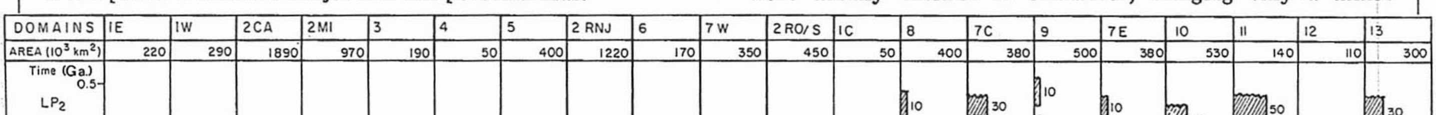

Figure 4: Growth of the continental crust for the Brazilian Shield. Domains keyed to Figure 2 and time events to Figure 3. The numbers within the columns for each domain indicate the percentage of crustal growth during that time period.

contribution to the growth of continental crust. Moreover, the growth curve does not show significant early Archean contributions, perhaps reflecting in part the lack of appropriate (U-Pb, Sm-Nd, Pb-Pb) radiometric data on ancient material.

It appears thus that about 45% of the present continental crust was already formed at the end of the Archean, and about 80% at the end of the Early Proterozoic Trans-amazonian Orogeny. Accretion during the Proterozoic was clearly more important in quantitative terms (55%) than during the Archean.

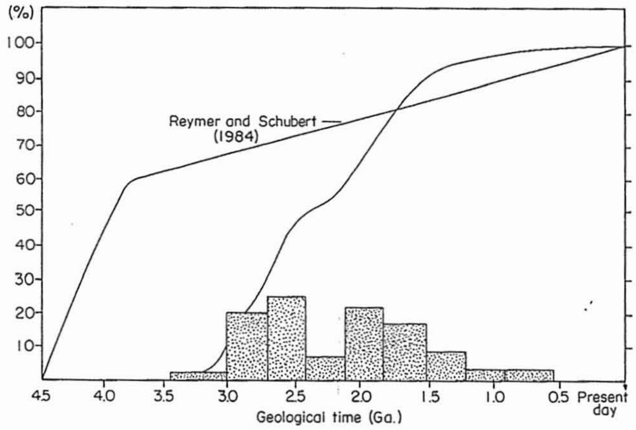

Figure 5: Histogram and cumulative curve illustrating the growth of the continental crust of the Brazilian Shield.

This analysis and similar ones produced for other continents all show a limited amount of continental crust formed prior to 3.5 Ga. This is in line with the fact that outcrops of early Archean rocks are very rare on all continents. It does not necessarily mean that continental crust was not being formed then, but most probably that the extremely active Archean mobile regimes allowed complete recycling into the mantle, precluding the survival of stable continental crust. Moreover, our estimates for the Archean continental growth of the Brazilian Shield appear to be substantially lower than those of other models for the Archean (see Fig. 1). This predominantly Proterozoic accretion may be a situation peculiar to South America, or it may be, in part, due to the different ways in which crustal growth is assessed.

Finally, if the area we have synthesized (see Fig. 2) is extrapolated to include the whole of the South American continent, three main additional crustal provinces must be taken into account. For the foredeeps of the Andean mountain chain, their basement is an extention of the Brazilian Shield and should not modify significantly the proportions indicated in Figure 5. However, the crustal substratum of Patagonia seems to have had a very significant Phanerozoic orogenic history, and, of course, in the Andean chain itself juvenile material in substantial proportions was added to the continent during the present tectonic regime, active since Jurassic times, and connected with typical subduction processes. Thus, a growth curve for the entire South American continental crust would differ from Figure 5 essentially in that Archean and Proterozoic proportions would be somewhat reduced, to allow for significant accretionary components in Phanerozoic times.

Prof. U.G. Cordani is Director of the Institute of Geosciences at the University of São Paulo (USP, CP 20899, 01498 São Paulo, Brazil), and widely known for his work on the geochronology of South America. The new President of IUGS, Prof. Cordani was profiled in the last issue of Episodes.

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Dr. K. Kawashita is Director of the Geochronology Research Centre and Assistant Professor in the USP Institute of Geosciences. Originally trained in physics and nuclear engineering, he has been working since 1963 in geochronology and isotope geology.

K. Sato is a member of the technical staff of the USP Geochronology Research Centre. With his background in X-ray fluorescence and mass spectrometry, he is responsible for keeping the analytical work going at the Centre.

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Late Proterozoic-Early Paleozoic of South America – a Collisional History

by Victor A. Ramos

The southern portion of South America is a complex collage of cratonic blocks that were brought together along the southwestern Gondwanaland margin in late Precambrian to early Paleozoic times. An enormous amount of recent work especially in northern Argentina and Chile, reviewed here, has led to many new ideas and models for the development of this region in terms of plate interactions and orogenic cycles. (Ed.)

Introduction

The hypothesis that continental drift caused the destruction of Gondwanaland was accepted early on by many South American geologists because of the striking similarities and correlations between the Paleozoic history of South America and southern Africa (e.g. Keidel, 1917). Most tectonic studies have assumed a fixed ensialic or ensimatic origin for the orogenic belts that predated the breakup of Gondwanaland. However, increasing evidence on the distribution of mafic and ultramafic oceanic rocks, ancient magmatic arcs, and the metamorphic and sedimentary sequences of these old orogenic belts suggests that a complex collage of earlier collisons and amalgamations between lithospheric plates formed Gondwanaland in Late Proterozoic to early Paleozoic times.

Many workers on the Phanerozoic Cordillera of South America have long avoided the vast and complex Precambrian problems of the continent.

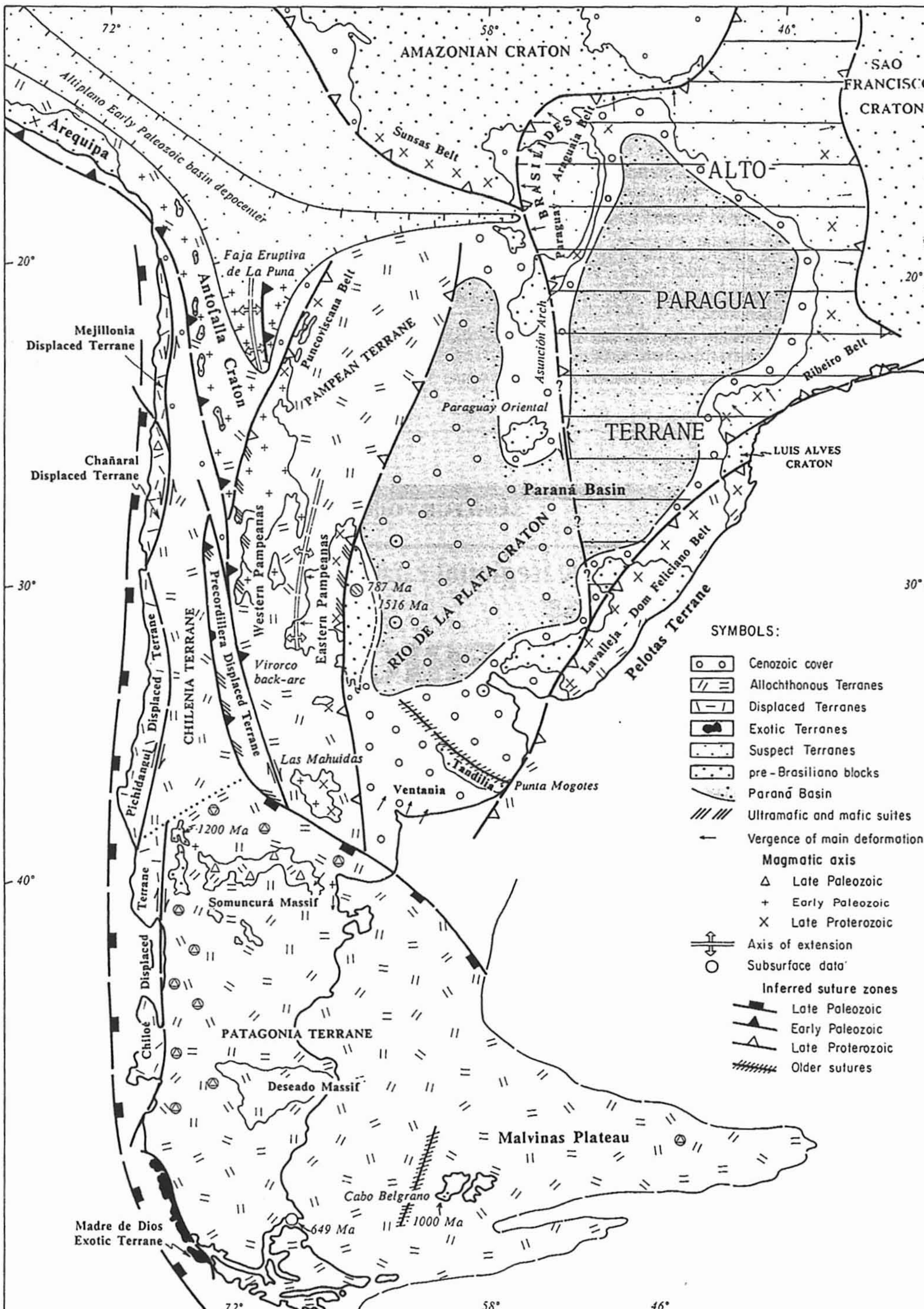

Figure 1: Main cratonic blocks and allochthonous terranes of southern South America. Horizontal lines indicate the extent of the Alto Paraguay Terrane.