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Nd AND Pb ISOTOPE STUDIES BEARING ON THE CRUSTAL EVOLUTION OF SOUTHEASTERN BRAZIL

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ABSTRACT Nd- and Pb-isotopes have been determined on composite samples of selected granites, gneisses, and metasediments from SE Brazil, which range in age from Archaean to Late Proterozoic (Brasiliano). A brief introduction to Sm-Nd systematics is followed by discussion of the Sm-Nd isotope data on the composite samples which yield model Nd ages of 3.3-1.3 Ga. Pb isotope compositions are consistent with those model ages, and Nd- and Pb-isotopes together indicate that, as in southern Africa, the main period of crustal growth was in the Late Archaean and Early to Middle proterozoic. The Brasiliano event appears to have been characterized by relatively little new continental crust.

RESUMO São apresentadas 15 análises pelos métodos Sm-Nd e Pb-Pb em amostras do Cinturão Dom Feliciano e do Cráton Rio de la Plata dos Estados de Santa Catarina e do Rio Grande do Sul. A discussão dos resultados obtidos é precedida por uma apresentação dos fundamentos metodológicos e interpretativos dos métodos geocronológicos, com aplicação, em função de sua novidade, do sistema Sm-Nd. Os terrenos do Cráton Rio de la Plata forneceram idades arqueanas entre 3,3 e 2,6 Ga, tanto em Santa Catarina como no Rio Grande do Sul, enquanto os metassedimentos do Grupo Brusque (SC) e granitóides associados (Suíte Valsungana) forneceram valores ao redor de 2,0 Ga. Os terrenos graníticos das porções internas do Cinturão Dom Feliciano indicaram idades entre 1,4 e 1,7 Ga em ambos os Estados. Os resultados obtidos permitiram a caracterização de dois períodos principais de acreção de material diferenciado do manto à crosta. Os valores de 2,0 Ga podem ser alternativamente caracterizados como produtos híbridos dos dois intervalos citados ou representar um outro período de diferenciação do manto. Merece destaque a formação da crosta continental em épocas pós-arqueanas (Proterozóico Médio) na região sul do Brasil.

INTRODUCTION The continental crust preserves a record of geological processes over some 3.5 million of years. Geochronologic studies have identified areas of different ages, and in older terrains relict cratonic nucleii are typically surrounded by a complex succession of younger mobile belts. However, different age provinces may reflect different processes ranging from those associated with the generation of new continental crust, to those involved in crustal anatexis and intracrustal remobilization. Here we offer a brief introduction to Nd-isotopes and present the results of a preliminary study aimed at evaluating the major period(s) of crustal growth in south-east Brazil.

South Brazil contains three major geotectonic units: the Rio de la Plata Craton (Almeida *et al.* 1973), the Dom Feliciano Belt. The Dom Feliciano Belt is of Late Proterozoic the Paraná Basin. The first consists of old granulite-migmatite terrains of Archaean to Early Proterozoic age, which then acted as a stable foreland during the evolution of the Dom Feliciano Belt. The dom Feliciano Belt is of Late Proterozoic age, its present exposure is ~150 km wide, and the main structural fabric is orientated NNE-SSW with the dominant vergence beingtowards the NW. Thus the main geological events took place in the Archaen (~3.2 - 2.6 Ga), the Early Proterozoic (2.0 Ga) and the Late Proterozoic (_ 0.60 Ga), and it is these we seek to evaluate in terms of which events were primarily responsible for the generation of new crust in southern Brazil.

Nd-ISOTOPES Within the rare earth group of elements (REE), ^{147}Sm decays to ^{143}Nd. The decay takes place very slowly (the *half-life* is approximately twice as long as that for ^{87}Rb), and the range of Sm/Nd in rocks and minerals is much less than that for Rb/Sr. Thus the present range of the relevant isotope ratio ($^{143}Nd/^{144}Nd$) is very small, 0.5% compared with over 200% for $^{87}Sr/^{86}Sr$, and routine measurements only became possible in the mid 1970's (*e.g.* Lugmair *et al.* 1975).

The isochron equation is written:

$$\frac{^{143}Nd}{^{144}Nd} = \frac{^{147}Sm}{^{144}Nd}(e^{\lambda t} - 1) + \frac{^{143}Nd}{^{144}Nd_0} \quad (1)$$

This is the pratical equation for calculating the age *t* and $^{143}Nd/^{144}Nd_0$ from measurements of present day $^{143}Nd/^{144}Nd$ and $^{147}Sm/^{144}Nd$ ratios. λ is the *decay constant,* which is expressed as the probability that an atom will decay in unit time, and for $^{147}Sm = 6.54 \times 10^{-12} a^{-1}$. It can also be shown that the half-life (T 1/2) is simply related to the decay constant (λ) by T 1/2 = (ln2/ λ) $^{143}Nd/^{144}Nd_0$ is the Nd-isotope ratio of a sample *at the time of its formation* and is called the *initial* Nd-isotope ratio.

Isochron diagrams The isochron equation is in the form of a straight line. A plot of $^{143}Nd/^{144}Nd$ against $^{147}Sm/^{144}Nd$ is the traditional isochron diagram (Fig. 1a), in which the slope of a straight line is proportional to the age t, and the intercept on the y-axis is the initial Nd-isotope ratio, $^{143}Nd/^{144}Nd_0$. For a suite of samples, as in figure 1, it is envisaged that at the time of their formation t million years ago they had the same $^{143}Nd/^{144}Nd$, but different $^{147}Sm/^{144}Nd$ ratios. Since then the change in $^{143}Nd/^{144}Nd$ depends on the ratio of $^{147}Sm/^{144}Nd$ and the length of time t, such that at the present day the samples all lie on a straight line whose slope is proportional to their age t. A geologically meaningful age is only obtained if the samples were all of the same age, they had the same initial Nd-isotope ratio and

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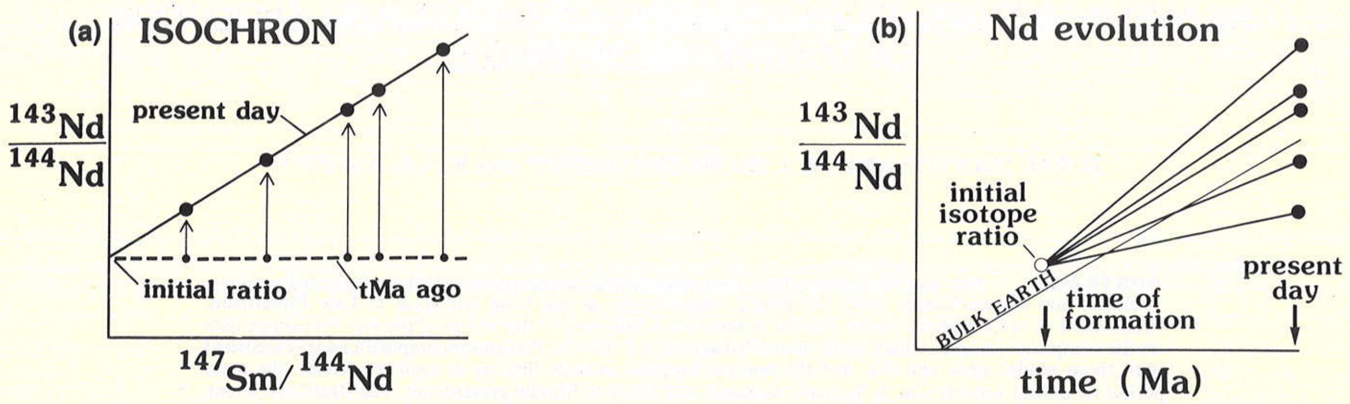

Figure 1 – a. Sm-Nd isochron diagram illustrating how five hypothetical samples evolved from their initial isotope composition to the present day; b. The change in $^{143}Nd/^{144}Nd$ from the time of formation to the present day illustrated on a Nd-isotope evolution diagram

provided that neither $^{143}Nd/^{144}Nd$ nor $^{147}Sm/^{144}Nd$ have been changed by secondary processes (metamorphism, alteration etc) between the time of formation and analysis in the laboratory.

Isotope evolution diagrams The form of the isochron equation is such that plots of $^{143}Nd/^{144}Nd$ against time (t) also yield straight line relationships, in which the slope depends on the ratio of $^{147}Sm/^{144}Nd$. Such diagrams are called isotope evolution diagrams, for they illustrate the changes in isotope ratios with time. The data and interpretations from figure 1a are reproduced on an isotope evolution diagram in figure 1b. Data are collected at the present day and so plot at 0 Ma. The samples formed at t Ma with the same (initial) $^{143}Nd/^{144}Nd$ ratio, and since then they evolved along straight lines with different slopes corresponding to their different $^{147}Sm/^{144}Nd$ ratios.

Model Nd-ages Precise age determinations by the isochron method require samples with a wide range in Sm/Nd. High Sm/Nd ratios indicate that the samples are LREE depleted and for whole rocks such REE patterns tend to be found only in basalts which have sampled mantle similar to that now beneath mid-ocean ridges. Continental rocks, by contrast, are almost invariably LREE enriched. They therefore have low Sm/Nd ratios, which result in little variation in $^{143}Nd/^{144}Nd$ and so make them difficult to date. However, they are well suited to the calculation of model Nd ages.

Model Nd ages are estimates of the times at which continental rocks, or their crustal precursors, were derived from the upper mantle. They are based on the premise that the upper mantle is LREE depleted, or it has chondritic REE ratios, and continental rocks are LREE enriched. Thus the formation of new continental crust is what causes the major change in Sm/Nd – on average a 30% reduction. Any later events within the crust, such as partial melting, or erosion and sedimentation, have relatively little effect on Sm/Nd since the crustal source rocks and the resultant granites and sediments are all LREE enriched. If that is correct then the present day Sm/Nd and $^{143}Nd/^{144}Nd$ ratios of a continental rock can be used to calculate not only its initial Nd-isotope ratio, presuming that its age is known, but also the time at which it, or its crustal precursor, was derived from the upper mantle. This is illustrated in figure 2.

Data from a granitic suite are plotted on an isotope evolution diagram in figure 2. All samples have similar and low Sm/Nd ratios, and so evolved along similar and relatively flat-lying straight lines from the time of formation to the present day. Their initial Nd isotope ratio is much lower than that of the bulk earth or the depleted upper mantle at the time of the formation of the granite, and so the simplest interpretation consistent with their bulk rock composition is that they were derived from a crustal source. Assuming that Sm/Nd in the granite was similar to that in its crustal

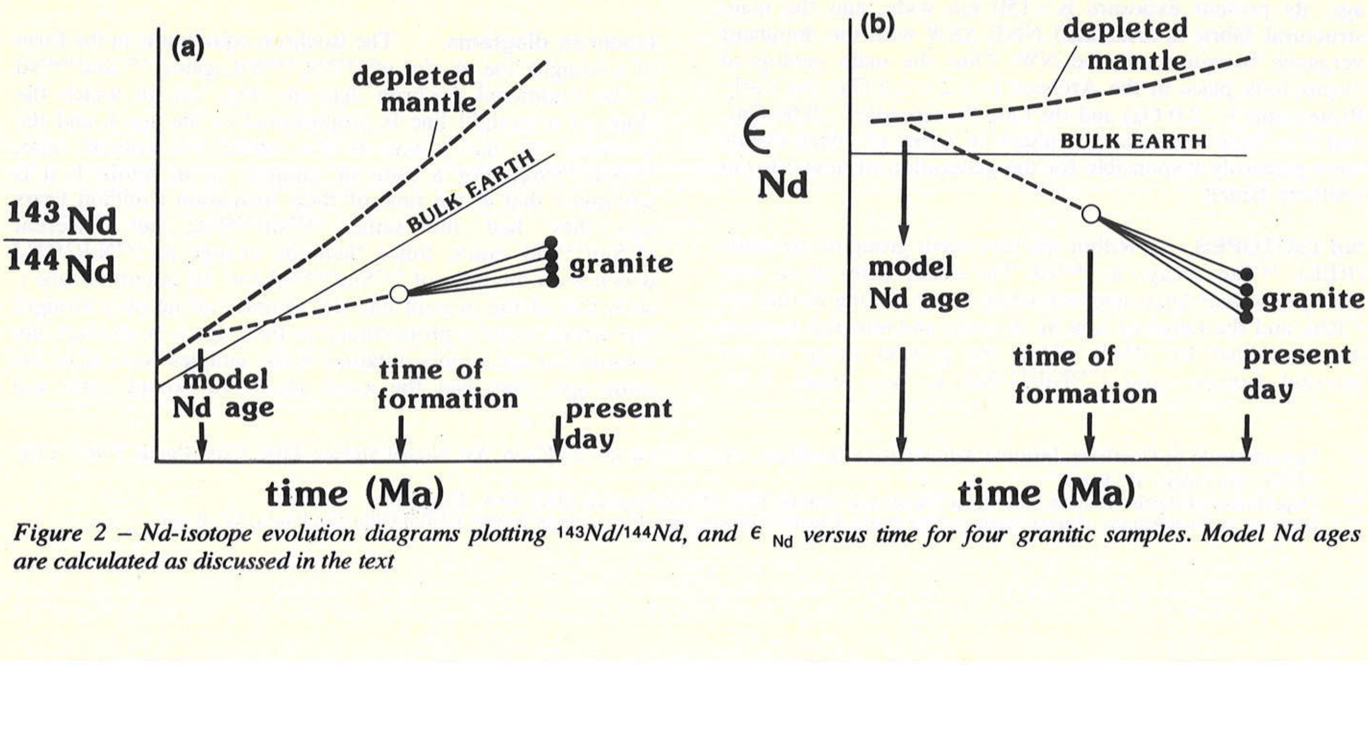

Figure 2 – Nd-isotope evolution diagrams plotting $^{143}Nd/^{144}Nd$, and ϵ_{Nd} versus time for four granitic samples. Model Nd ages are calculated as discussed in the text

source the measured Sm/Nd ratio may be used to extrapolate the straight line evolution path on figure 2 back in time until it intersects the lines for the bulk earth of the depleted upper mantle. The times at the intersections are the model Nd ages of the granite relative to the bulk Earth or depleted mantle respectively. The choice of which age to calculate depends on wheter the continental crust is ultimately derived from LREE depleted or chondritic mantle, and in recent years the tendency has been to report model Nd ages relative to the evolution of depleted mantle - T^{Nd}_{Dm}.

Likely sources of error in the interpretation of model Nd ages and their geological limitations, are beyond the scope of this contribution, but they are discussed in the original paper by McCulloch & Wasserburg (1978), and in a review by Hawkesworth & Van Calsteren (1984).

An important aspect of Nd-isotope studies has been to compare the initial $^{143}Nd/^{144}Nd$ ratios of rocks of different ages and hence to chart the evolution of reservoirs such as the continental crust and MOR-type upper mantle. To facilitate such comparisons Nd-isotope data are often reported as ϵ_{Nd} values in which the $^{143}Nd/^{144}Nd$ of the sample at a particular time t is expressed relative to that of the bulk earth (BE) at the same time:

$$\epsilon_{Nd} = \left(\frac{^{143}Nd/^{144}Nd_{sample\ (t)}}{^{143}Nd/^{144}Nd_{BE(t)}} - 1 \right).10^4 \qquad (2)$$

Thus ϵ Nd for the bulk earth is always zero, and ϵ Nd is positive for rocks with higher, and negative for rocks with lower $^{143}Nd/^{144}Nd$ than the bulk earth (Fig. 2b).

RESULTS Composite samples were prepared from selected whole rock powders of representative rock types in the two major geotectonic units of the Rio de la Plata Craton and the Dom Feliciano Belt (Fig. 3). The geochronological

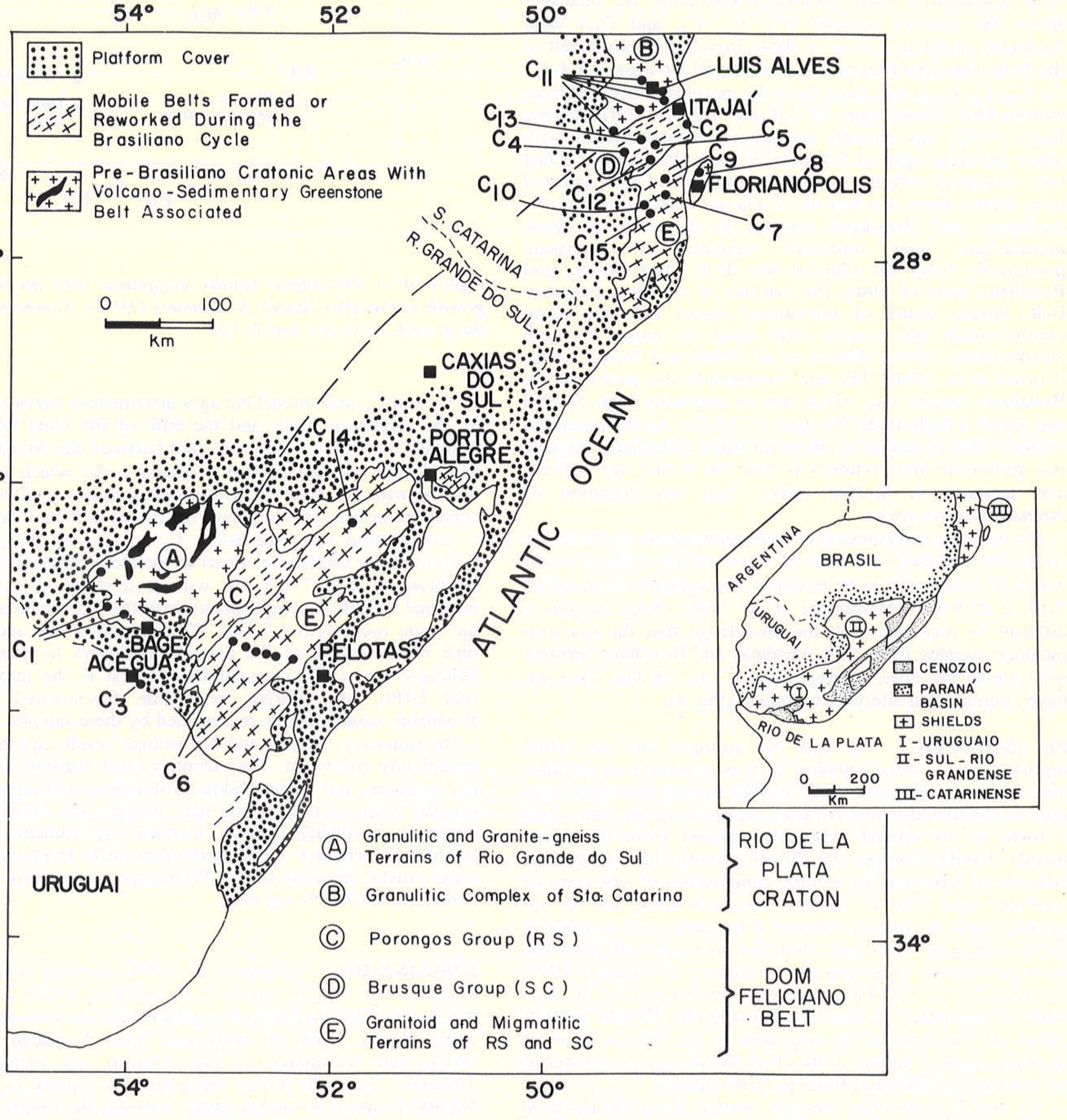

Figure 3 – Geological sketch map outlining the major tectonic units and the sample localities for the composite samples analysed

data are varied, but the granites and gneisses from the Dom Feliciano Belt have yielded Rb/Sr whole rock and/or U/Pb zircon ages of 650-520 Ma, characteristic of the Brasiliano-Pan African tectono-thermal event (Basei 1985, Soliani 1986). The Rio de la Plata Craton is mapped as Archaean, affected by the Transamazonian event at ~ 2.0 Ga, and in Rio Grande do Sul also by the Brasiliano. ϵ_{Nd} values have been calculated at 2.6 Ga for the Rio de la Plata composites and at 0.6 Ga for those from Dom Feliciano Belt, and they range from +3.0 to –5.2 and –5.6 to –15.0, respectively (Tab. 1). Positive ϵ_{Nd} values indicate a period of new crustal growth, whereas negative values, as observed in the Dom Feliciano rocks, suggest a high degree of crustal remorking.

Model Nd ages (T^{Nd}_{Dm}) offer an alternative way of expressing the data. Those for the Rio de La Plata samples are 2.6-3.3 Ga confirming the Archaean heritage for the granulitic terrains, but those from within the Dom Feliciano Belt vary from 1.3 to 2.2 Ga. Significantly these appear to vary consistently with geological sub-units. As indicated above the cratonic samples (C_1, C_2, C_4, and C_{11}) yield Archaean model ages; most of those from the granitoid belt of the Dom Feliciano Belt proper have model Nd ages = 1.4-1.7 Ga (C_6-C_9, C_{15}); and those from the marginal schist belt have intermediate model ages of 2.0 and 2.2 Ga. Furthermore, Basei (1985) has recently recognized detrital zircons with upper intercept ages of 1.9 and 2.9 Ga in the Brusque schist belt, consistent with the intermediate model Nd ages reported here. Either there is a belt of 2.0 Ga old crust separating the Archaean and Brasiliano terrains in the area, or these intermediate ages represent mixtures of Archaean, presumably from the adjacent Rio de la Plata Craton, and Brasiliano material along the margins of the Dom Feliciano Belt. Similar zones of transitional model Nd ages along craton/mobile belt margin have been recognized in both Northeastern Africa (Harris *et al.* 1984) and South Africa (Cornell *et al.* 1986). The one exception to this pattern is the Brasiliano sample C_{10} which has an unusually high Sm/Nd and yields a high model Nd ages of 2.6 Ga. As the measured $^{143}Nd/^{144}Nd$ is similar to those in other Brasiliano samples our preferred interpretation is that the model age reflects and increase in Sm/Nd rather than remobilization of Archaean source rocks.

Pb isotopes determinations were undertaken on 11 of the composite samples and nine of them define a linear trend which, if interpreted as an isochron, corresponds to an age of 2.18 ± 0.18 Ga (Mantovani *et al.* 1986). Such an age is difficult to reconcile with the knowledge that the isochron includes samples from both Arcahean and Brasiliano terrains with model Nd ages ranging from 1.3 to 2.6 Ga. Thus we have attempted an alternative analysis (Fig. 4).

Pb ISOTOPES Pb and Nd isotopes are not often reported on the same samples, so it is necessary to consider how both may be interpreted. Sm-Nd isotope data have been used to calculated model Nd ages, representing the time when a rock, or its crustal precursor, formed from the upper mantle. For Pb isotopes the Pb ore growth curve (Fig. 4) is believed to represent the isotope composition of new crust of different ages. The Pb isotope evolution along the Pb ore growth curve is complex because it requires a net increase in U/Pb with time. How and when that increase took place has been the subject of several papers (Stacey & Kramers 1975, Zartman & Doe 1981) and need not concern us here. Rather, what is important is that conceptually the Pb-ore growth curve may be regarded as analogous to the Nd-evolution of depleted mantle, because both chart the isotope compositions of new crust at different times in Earth history.

C_4 and C_{11}, the two samples omitted from the isochron calculation by Mantovani *et al.* (1986), plot above the Pb-ore growth curve (Fig. 4). Their high $^{207}Pb/^{204}Pb$ at comparatively low $^{206}Pb/^{204}$ ratios relatively high U/Pb early in earth history consistent with their Archaean ages. Fortuitously, since they were collected some 500 km apart (Fig. 3), C_1 and C_2 fall on a 2.6 Ga Pb-Pb line. Overall, however, the four composite samples from Archaean areas have Pb isotope ratios consistent with derivation from the Pb ore growth curve reservoir 3.2-2.6 Ga ago, and their model Nd ages are also 3.3 - 2.6 Ga.

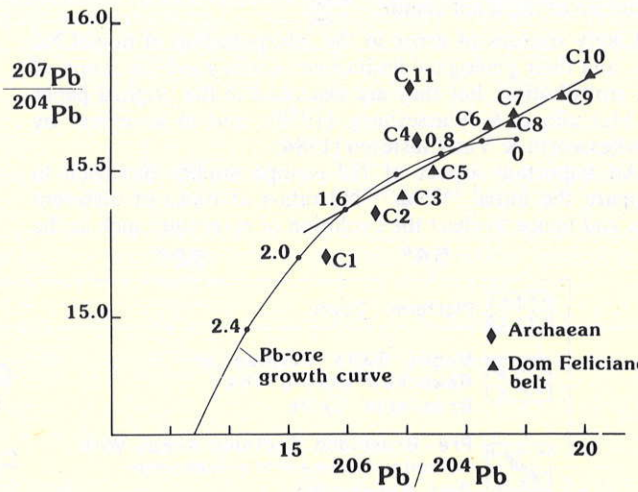

Figure 4 – Pb-isotope results compared with the Pb-ore growth curve after Stacey & Kramers (1975). Numbers along the growth curve are time in Ga

C_3 and C_5 have model Nd ages intermediate between those of the Archaean rocks and the bulk of the Dom Feliciano samples. On figure 4 they also plot between the Archaean C_1 and C_2 and the other Dom Feliciano rocks which suggests that, as with Nd, their Pb isotope compositions could reflect a contribution from the neighbouring Rio de la Plata Craton.

Considering only the rocks C_6 to C_{10} of the granitic portion in the southeastern part of the Dom Feliciano Belt, an isochron of 1.6 ± 0.3 Ga with a μ value of 10.8 was obtained, which is in agreement with the Nd-model ages for the same rocks (1.3-1.7 Ga). We interpreted this age as the time of formation of the crustal precursors to these Dom Feliciano rocks. Of considerable interest is the implication that U/Pb, like Sm/Nd, was little fractionated by the Brasiliano magmatism as represented by these samples.

In summary, the Pb and Nd isotope results appear to be remarkably consistent. They identify crust-forming events in the Archaean and in the Middle Proterozoic, and suggest that samples along craton/mobile belt margins are derived from different (hydrib?) source terrains. It remains to be established whether U/Pb undergoes little fractionation in some crustal environs so that Pb isotope studies may provide consistent model Pb-age data.

DISCUSSION Harris *et al.* (1978) recently collated the available Nd isotope results from southern Africa and these are summarized on figure 5 together with the new data from south Brazil. Both sub-continents have Archaean cratonic blocks and Brasiliano, or Pan African, age mobile belts. However, in south Africa there are also clearly recognised Middle-Proterozoic mobile belts, whereas the significance of 2.0 - 1.5 Ga events in south Brazil is not yet clear. Despite that discrepancy the similarity of the variation of ϵ_{Nd} in

Table 1 – Analytical results

Sample	Type[1]	Lithologic Units	Sm/Nd	$^{143}Nd/^{144}Nd$	ϵ_{Nd} [2]	T_{Nd} (DM)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
C1	C	Santa Maria Chico gneiss and granulites	0.179	0.511262±26	2.59	2.61	15.665	15.197	35.385
C2	C	Camboriú migmatites	0.177	0.511256±10	2.99	2.58	16.471	15.349	37.768
C3	SCH	Aceguá granitoid	0.188	0.511523±18	−15.06	2.22	16.976	15.417	38.08
C4	C	Presidente Nereu orthogneisses	0.196	0.511037±12	− 5.19	3.28	17.186	15.606	37.911
C5	SCH	Valsungana granitoid	0.158	0.511487±14	−14.74	2.02	17.450	15.496	38.617
C6	γ B	Dom Feliciano granitoid	0.146	0.511874±12	− 6.59	1.42	18.394	15.644	38.558
C7	γ B	Granitos Foliados granitic and migmatitic complex	0.204	0.512008±26	− 6.66	1.74	18.814	15.685	38.063
C8	γ B	Armação granitoid	0.193	0.512009±28	− 6.13	1.62	18.822	15.688	39.18
C9	γ B	Santa Luzia granitoid	0.206	0.512052±14	− 5.91	1.69	19.644	15.742	38.818
C10	γ B	Barra do Rio dos Bugres granitoid	0.257	0.512067±10	− 8.01	2.59	20.114	15.82	39.142
C11	C	Luís Alves-granulitic gneisses	0.181	0.51119 ±10	+ 0.98	2.73	17.126	15.773	38.404
C12	SCH	Brusque biotite schists	0.217	0.511975±10	− 7.94	1.98	–	–	–
C13	SCH	Brusque phyllites	0.195	0.511758±14	−11.13	2.04	–	–	–
C14	γ B	Dom Feliciano granitoid	0.214	0.511964±10	− 7.99	1.95	–	–	–
C15	γ B	Queçaba phyllites	0.179	0.511915± 6	− 7.31	1.63	–	–	–

[1]C = cratonic; SCH = schist belt; B = granitic belt ɜlt
[2]Calculated at 0.6 Ga, except for C_1, C_2, C_4, and C_{11} which are calculated at 2.6 Ga

SAMPLE DESCRIPTIONS

C 1 - Santa Maria Chico Granulitic Complex: quartz feldspathic gneisses granulite with interbedded basic gneisses, anorthosites and ultramafics

C 2 - Dom Feliciano Belt: basement core. Folded banded migmatites. The melanosome is medium grey and granoblastic with a granodioritic composition; the leucosome is quartzo-feldspathic, whitish with a trondhjemitic-tonalitie composition; trondhjemitic, often with amphibolites boudins

C 3 - "Ilha Cristalina" de Aceguá Granite, inequigranular granitoid, coarse, pinkish, non-foliated, porphyroblastic rock of syenogranitic to alkali-feldspatic-granitic composition

C 4 - Dom Feliciano Belt: basement core. Orthogneisses of dioritic-granodiorite composition. Massive with granoblastic textures: foliated, partly cataclastic

C 5 - Valsungana Intrusive Suite: Valsungana granitoid. Granodiorites with megacrysts of centimeter size of microline with plagioclase, biotite, and muscovite forming the groundmass; incipient foliation. Calc-alkaline granitoids

C 6 - Granite Migmatitic Complex: Composite of granitoids lying between Pinheiro Machado and Pelotas. Predominantly inequigranular grey foliated granitoids of granodioritic to monzogranite composition

C 7 - Migmatitic Granite Complex: Foliated granites. Granitoid rocks with migmatitic structures and with well defined schistosity. Light to medium grey in colour, coarse grained, and inequigranular with a predominantly quartz-monzonitic composition

C 8 - Pedras Grandes Suite: Armação Granite. This granitic batholit intrudes the foliated granites. The samples are mainly of granitic composition, porphyritic and homogenêous textures occur. Coarse grained and grey. The composition is quartz-monzonitic to granite

C 9 - São Pedro de Alcântara Suite: Santa Luzia Granitoid. The batholith intrudes the foliated granite. Its composition is predominantly granitic to quartz monzonitic, massive texture, light grey, inequigranular, and porphyritic, often with microgranular dioritic inclusions

C10 - Pedras Grandes Suite: Barra do Rio dos Bugres Granite. Representative of the small peripheral stock of Tabuleiro batholith. Non-foliated pinkish to reddish alaskite granitoid

C11 - Granulitic Complex of Santa Catarina: Hypersthene bearing quartzo-feldspathic gneisses, light grey, foliated, granoblastic. Both massive and banded gneisses, locally migmatitic

C12 - Brusque Group: Quartz biotite schists, banded with layers of micaceous quartzite. Regional metamorphism of greenchists facies

C13 - Brusque Group. Quartz sericite schists, light grey with greenish tinge. Finely foliated on a millimetre scale, banded, alternated layers of micaceous quartzites

C14 - Pedras Grandes Suite: Complex of intrusive granitoid into the foliated granites of the migmatitic complex. Pink, non-foliated, coarse texture, inequigranular of monzonitic to syenogranitic composition

C15 - Queçaba Formation: "Rouf pendent" of metamorphic rocks of greenschists facies overile the Pedras Grandes granitoid suite. Predominantly grey phyllites slightly bluish. Banded on a milimetre scale with micaceous quartzite layers

rocks of different ages from southern Africa and south Brazil is very striking (Fig. 5). Archaean rocks are characterized by positive ϵ_{Nd} values indicating that it was a period of significant crustal growth, perhaps in a continuum of events from 3.5 - 2.6 Ga. In contrast, the Brasiliano and Pan African data, the latter being from the Damara orogen of Namibia, suggest that very little new crust was generated in these events and they predominantly reworked pre-existing crust which may have ranged in age from 1.2 - 2.2 Ga.

The Brasiliano/Pan African events arguably occurred at a transitional stage in earth history when regional tectonic processes may have differed from those operating today. In NE Africa, for example, the Pan African was a period of comparatively rapid crustal growth in an accreting island arc terrain (Duyverman *et al.* 1982; Harris *et al.* 1984, and references therein), and yet in south Brasil and Namibia the Pan African belts are complex areas of crustal reworking in tectonic environments which remain poorly understood. The range of ϵ_{Nd} in the Pan African and Brasiliano rocks (Fig. 5) is an indication of that complexity, but there are interesting differences between Namibia and south Brazil. In the former the low ϵ_{Nd} values reflect an old, 2.0 Ga basement that was reworked by sedimentary and magmatic processes. The Damara sediments preserve a striking decrease in ϵ_{Nd} with increasing stratigraphic height such that the observed range in ϵ_{Nd} is in essence a vertical variation through this segment of Pan African crust (Hawkesworth & Marlow 1983, McDermott *et al.* 1986). In south Brazil, however, the changes in ϵ_{Nd} in Brasiliano rocks appear to chart the proximity of adjacent Archaean cratonic blocks and, as such, vary laterally rather than vertically. At present, such data are consistent with discrete crust forming events in the Archaean, at ~ 2.0 Ga, and in the Middle Proterozoic, or with the ~ 2.0 Ga model ages being due to mixing between Archaean and Brasiliano material along the margins of the Dom Feliciano Belt.

On a regional scale, Harris *et al.* (1986) discussed possible evolution paths for the crust of southern Africa, and compared them with the curve for average crust based on Australian shale composites by Allegre & Rousseau (1984) (see Fig. 5). The south African, and by inference from the available data in figure 5, the south Brazilian crust differs from that sampled by the Australian shales in that more of the crust formed in the period 3.5 - 2.0 Ga and less (?< 10%) between 1 Ga and the present day, than suggested by the Australian data. This is illustrated by curve H on figure 5 which represents the present best estimate for the average composition of the south African and south Brazil crust at different times in the geological record. Significantly in both Namibia and south Brazil considerable volumes of new crust appear to have been generated in the middle-Porterozoic, whereas the widespread Pan African and Brasiliano tectono-thermal event was characterized by considerable crustal reworking and remarkably little new crust.

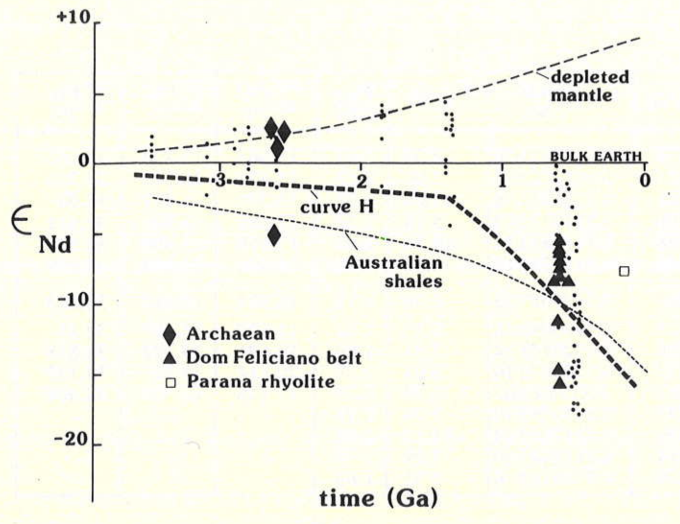

Figure 5 – *Nd versus time for data from Southern Africa (small dots and after Harris* et al. *1986) and the new results for composite samples from Brazil. The curve for Australian shales is from Allegre & Rousseau (1984) and curve H is from Harris* et al. *(in press)*

Finally we note that the only Nd analysis of a probable crustal melt from the Paraná volcanics yields $\epsilon_{Nd} = -7.8$ (Fig. 5, Hawesworth *et al.* 1986). During the considerable magmatic event represented by the Paraná, crustal melting appears to have occurred in the Brasiliano rather than in the Archaean basement.

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REFERENCES

ALLEGRE, C.J. & ROUSSEAU, D. – 1984 – The growth of the continent through geological time studied by Nd isotope analysis of shales. *Earth Planet. Sci. Letts.*, **67**:19-34.

ALMEIDA, F.F.M.; AMARAL, G.; CORDANI, U.G.; KAWASHITA, K. – 1973 – *The Precambrian evolution of South American Cratonic margin south of the Amazon River.* In: THE OCEAN BASIN AND MARGINS. New York, Plenum Publ. 1, 411-446.

BASEI, M.A.S. – 1985 – *O Cinturão Dom Feliciano em Santa Catarina.* São Paulo, (Ph. D. Thesis, Instituto de Geociências da USP).

CORNELL, D.H.; HAWKESWORTH, C.J.; VAN CALSTEREN, P.W.C.; SCOTT, D.W. – 1986 – Sm-Nd study of Precambrian crustal development in the Prieska-Copperton Region, Cape Province. *Trans. Geol. Soc. S. Africa*, **89**:17-28.

DUYVERMAN, H.J.; HARRIS, N.B.W.; HAWKESWORTH, C.J. – 1982 – Crustal accretion in the Pan African: Nd- and Sr-isotope evidence from the Arabian Shield. *Earth Planet. Sci. Lett.*, **59**:315-326.

FRAGOSO CÉSAR, A.R.S. – 1980 – O Cráton do Rio de la Plata e o Cinturão Dom Feliciano no Escudo Uruguaiano-Sul-Riograndense. In: CONGR. BRAS. GEOL., 31, Baln. de Camboriú, 1980. *Anais*... Baln. de Camboriú, SBG, v. 1, p. 1-12.

HARRIS, N.B.W.; HAWKESWORTH, C.J.; RIES, A.C. – 1984 – Crustal evidence in NE and E Africa from model neodymium ages. *Nature*, **309**:773-776.

HARRIS, N.B.W.; HAWKESWORTH, C.J.; VAN CALSTEREN, P.; McDERMOTT, F. – in press – Evolution of continental crust in southern Africa. *Earth Planet. Sci. Lett.*

HAWKESWORTH, C.J. & MARLOW, A.G. – 1983 – Isotope evolution of the Damara Orogenic Belt. *Geol. Soc. S. Afr.*, **11**:397-407. (Special Publication).

HAWKESWORTH, C.J. & VAN CALSTEREN, P. – 1984 – Radiogenic Isotopes – some geological applications. In: P. HENDERSON, ed. *Rare earth element geochemistry, developments in Geochemistry.* Elsevier Science Publischers, Amsterdam, v. 2, p. 375-421.

MANTOVANI, M.S.M.; HAWKESWORTH, C.J.; TAYLOR, P.N.; PALACZ, Z. – 1986 – Lithospheric remobilization in continental flood basalts, evidence from the Paraná (Brazil). In: INTERNATIONAL VOLCANOLOGICAL CONGRESS. New Zealand, 1986 *Abstracts*... New Zealand, IAVCEI.

McCULLOCH, M.T. & WASSERBURG, G.J. – 1978 – Sm-Nd and Rb-Sr chronology of continental crust formation. *Science*, **200**:1002-1011.

McDERMOTT, F.; GLEDHILL, A.R.; HARRIS, N.B.W.; HAWKESWORTH, C.J. – 1986 – Crustal remobilisation in the Damara High Belt, Namibia. *Terra Cognita*, **6**:236.

SOLIANO, Jr., E. – 1986 – *Os dados geocronológicos do Escudo Sul-Rio-Grandense e suas implicações de ordem geotectônica.* São Paulo. (Ph.D. Thesis, Instituto de Geociências da USP).

STACEY, J.S. & KRAMERS, J.D. – 1975 – Appoximation of terrestrial lead isotope evolution by a two stage model. *Earth Planet. Sci. Lett.*, **26**:207-221.

ZARTMAN, R.E. & DOE, B.R. – 1981 – Plumbotectonics - The model. *Tectonophysics*, **75**:135-162.

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A universidade tem se limitado a cumprir o papel de guarda-livros do conhecimento sedimentado, e, apenas ocasionalmente, a dar um ou outro avanço neste conhecimento, mas sempre de forma bem comportada, seguindo os padrões normais do arcabouço das idéias que prevalecem ...Entretanto, nunca foi tão importante sair da camisa de força das idéias tradicionais... Os cientistas começam a descobrir as crises de seus processos epistemológicos e a falta de compromisso de suas ciências com a realidade e com a transformação da mesma .

C. Buarque, 1986, Das Idéias de revolução à revolução das idéias, *Pau Brasil*, 14: p.69