Pre-Brasiliano orogenic evolution in the Seridó Belt, NE Brazil: conflicting geochronological and structural data

REPLY

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The comments by Archanjo & Legrand (1997) provide a welcome opportunity to further discuss and enlarge our views on the orogenic evolution of the Seridó Belt. Our paper (Jardim de Sá et al. 1995) was proposed with two main objectives: (i) to illustrate complex tectonic relations where different sets of structural and geochronological data are at variance and no unique, satisfactory solution has been achieved as yet; (ii) to call attention to the fact that geochronological data should not be handled without due attention to the tectonic framework and field constraints. The paper was stimulated by the impressive amount (and unexpected results, at least to us) of radiometric dates performed in the last years by W.R. Van Schmus and co-workers. It is clear to us that a "final" answer, at least at this stage, will have to consider both data sets.

Central to the present discussion about the Seridó Belt are the structural and stratigraphic relations between the ubiquitous "G2" augen gneisses and their host rocks - the Caicó Complex augen gneisses and migmatites and the Seridó Group supracrustals (sensu Jardim de Sá 1984, 1994 and Jardim de Sá et al. 1995), as well as the main deformation events in the region (D1, D2 and D3).

To illustrate the complexity of the problem and the disconcerting multiplicity of interpretations, sometimes even by the same workers, the following chronological summary should be initially considered concerning field relations:

(i) The concept of the G2 augen gneisses as syntectonic intrusions, coeval to a main tangential deformation (D2) and hosted either by the basement gneisses (the Caicó Complex, where they cross-cut an earlier, S1 metamorphic banding) or the Seridó Group (especially the Jucurutu Formation) supracrustals (all of them sharing the same D2 fabric, clearly overprinted by the younger, strike-slip D3 Brasilianian event), was initially proposed by Jardim de Sá et al. (1981, 1987 - at this time with the participation of J.M. Legrand). The consistency of this view has been confirmed and further developed by our subsequent work (Jardim de Sá 1994, Jardim de Sá et al. 1995) plus a number of detailed field maps by UFRN Geology students, for instance. These papers also defined the "G1" plutons as the dominant orthogneissic component of the Caicó basement (and intrusive into older supracrustal protoliths), as well as the better known, syn to late-D3 Brasilianian granites, called "G3" plutons. Macedo et al. (1984) and Jardim de Sá et al. (1987) reported the first Rb-Sr ca. 2.0 Ga dates on the G2 orthogneisses.

(ii) Caby (1985,1989; see also Caby et al. 1991) was the first to propose a different interpretation for the G2 plutons. Assuming that these intrusions were hosted just by the Jucurutu Formation and basement gneisses, not reaching the stratigraphic level of the uppermost, Seridó Formation micaschists, they were considered as syn-sedimentary, anorogenic plutons. This view was followed by Archanjo & Salim (1986) and Archanjo (1987); a regional unconformity had to be placed at the base of the Seridó Formation (renamed as the Seridó Group) due to the ca. 2.0 Ga dates reported for the G2 plutons, while the syn-orogenic, flysch-type Seridó micaschists were related to the Brasiliano orogeny. Caby et al. (1995, including C.J.Archanjo as co-author) maintained the same view.

(iii) A substantially different interpretation was put forward by Legrand et al. (1991) and Hackspacher et al. (1992). Taking into account: a) the 2.15 Ga U-Pb dates reported by Hackspacher et al. (1990) for the basement orthogneisses at São Vicente, and similar dates subsequently obtained by other authors in the same or related areas (Caico, Açú) in Seridó; b) a misleading correlation between old supracrustal (mega)enclaves in the Caico orthogneisses and the Jucurutu Formation paragneisses, even though lacking the typical marble layers of the latter; c) the U-Pb zircon systematics of a G2 augen gneiss SW of Angicos (whose U-Pb zircon date of 1.93 Ga is regarded as a minimum, meaningless age by Legrand et al. 1991 and Archanjo & Legrand 1997; see below), those authors proposed a stratigraphic sequence in this region comprising an older supracrustal sequence, including the Jucurutu Formation, intruded by the "São Vicente" and "Caico" micaschists, they were considered as syn-sedimentary, anorogenic plutons, while the syn-orogenic, flysch-type Seridó micaschists were related to the Brasiliano orogeny. Caby et al. (1995), including C.J.Archanjo as co-author) maintained the same view.

(iv) A fourth view comes from the recent dates (Sm-Nd model dates and U-Pb in zircons, also commented by Jardim de Sá et al. 1995) performed by Van Schmus and co-authors in the region (Van Schmus et al. 1995a,b), being subscribed by Archanjo & Legrand (see also Dantas et al. 1991) in their comments about our paper: the G2 plutons are now considered by them as late intrusions in the basement complex, pre-dating deposition (or tectonic emplacement?) of the Seridó Group supracrustals. Up to the moment, no major age difference has been proved between the Jucurutu, Equador and Seridó formations, as shown by those radiometric dates.

These widely changing interpretations shared by C.J. Archanjo and J.M.Legrand in different papers suggest that their field constraints are not the strongest points of their contributions as their arguments were easily modified according to the forthcoming radiometric dates. Turning to the specific points raised by Archanjo & Legrand (1997), we follow their same order. It is not possible to avoid repetition of the arguments...
presented in our 1995 paper, which are once more reinforced and further detailed; the reader may also benefit from another recent contribution on the same subject (Jardim de Sá 1996).

The first specific point raised by Archanjo & Legrand (their second and third paragraphs) concerns the contact relations between a G2 augen gneiss and Seridó micaschists NE of Cerro Corá (fig. 2 and photo 1 of Jardim de Sã et al. 1995). According to these authors, primary relations such as intrusive contacts would have been completely obliterated due to reworking by a D3 shear zone, and granitic apophyses (which are cast in doubt if they relate either to G2 or G3 suites) and micaschist xenoliths reported by us should be interpreted rather as strike-slip horses. We disagree with their observations. Strain heterogeneities are a rule along and across shear zones and new strain pods from their strong fabrics (pre-shear zone) relations to be recognized. Thus, even if reworked by shearing, an original unconformity would be recognized at some place by a basic metaconglomerate, while intrusive relations will be detected through xenoliths and apophyses (see detailed discussion by Jardim de Sá 1994, p. 392-398 and especially fig. 4.22). As a close and related example, Caby et al. (1995, including C.J. Archanjo as co-author) discussed the evidence for an unconformity at the base of the Seridó Formation and in other areas in NE Brazil, exactly in the same kind of structural setting.

Coming back to the Cerro Corá G2 pluton, Archanjo & Legrand’s alternative explanations cannot be applied to this specific place (photo 1; a few others are described by Jardim de Sá 1994), where continuous exposures along river beds allow the recognition of the isolated nature of typical micaschist xenoliths (some of them cordierite-bearing, for instance), up to 100 m away from the ultramylonitic contact and not bordered by D3 shear zones, as required by their alternative hypothesis (strike-slip horses). The boudinaged G2 apophyses (figs. 4.24 and 4.25), with their strong fabrics (D2-D3, with highly stretched augen) concordant with one of the host micaschists, clearly differ from the G3 dykes illustrated by Archanjo & Bouchez (1991, fig. 4D,E), which either preserve a plutonic texture (fig. 4D) or cross-cut the host-rock (S2+S3) foliation (fig. 4E).

The xenoliths sampled by W.R. Van Schmus and one of us (E.F.J.S.) SE of Acú (third paragraph of Archanjo & Legrand’s discussion) did not include more typical micaschists (because they are too weathered at that outcrop) or others displaying calcisilicate layers typical of the Jucurutu Formation. Besides other explanations involving closed or open Nd isotope system behavior (as discussed in our paper), the Nd model dates reported by Van Schmus et al. (1995b) certainly demand a closer look to this place. Nevertheless, they do not deny our previous conclusions about the intrusive character of the G2 plutons as regards to the Seridó Group, which are supported by additional observations from several other places (Santa de Matos, Bodó, NW of Cruzeita, south of Currais Novos, Ipeiras, south of Serra Negra do Norte and so on) and discussed with experienced field/geological geologists along several field trips in this region.

In their fourth paragraph, Archanjo & Legrand (1997) stated that G1 (the Caico-São Vicente orthogneisses, which also include augen types) and G2 plutons have no compositional or structural differences. Once again we disagree. These suites display different REE and other minor trace element patterns as shown by figs. 4.17, 4.18, 4.83 and 4.87 from Jardim de Sá (1994). The G2 sheets cross-cut the S1 banding in the Caico gneisses intruding alongside F2 axial surfaces (Jardim de Sá et al. 1995, photos 2 and 3; Jardim de Sá 1994, photos 4.5 and 4.6) and contain previously deformed xenoliths from those rocks. At the same time, pre-D2 amphibolite dykes also cut across the S1 banding of the Caico augen gneisses and other coeval rock types (ESE of Acú in the road to Angicos, for instance) and are absent from the G2 plutons. Concerning absolute ages, the available geochronological data, even if imprecise (as stated in our paper), do show an age difference between the two associations, either on Rb-Sr whole rock isochron data and U-Pb zircon data grounds at Acú-Angicos and other areas (see Jardim de Sá 1994 pages 370-371 and 494-514, and our discussion in the 1995 paper), or according to the evaporation data presented for the Cerro Corá pluton (our fig. 3 and related discussion). The meaningless lower intercept of the G2 augen gneiss discordia at Angicos does not preclude that the upper intercept figure is a correct (and indeed the best) estimate for its age. Even if new analytical points from abraded zircons come to plot closer to concordia, this does not imply, a priori, that a much older age will be obtained for this rock. Unless future dating proves the G2 suites to be as old as 2.15 Ga, there is no basis to support Archanjo & Legrand (1997) claims in this paragraph.

In their fifth paragraph and following the mentioned text and figures by Passchier et al. (1990), Archanjo & Legrand suggested that the G3 sheets along F2 axial surfaces (see above) could simply be “late Transamazonian”, pre-tectonic (pre-D2) dykes, folded or boudinaged according to their original orientation as regards to the local D2 strain ellipsoids. Once again this is a theoretically viable hypothesis, but it does not match the pertinent field relations. The vast majority of these intrusions are flat-lying (still-like) sheets which strongly argue for an emplacement controlled by correspondingly flat-lying structures, impressed as the rock’s solid state fabric (and in a few points, viscous fabrics - see Jardim de Sá 1994, photo 4.24). Some of these sheets, emplaced along the axial surface of F2 folds, imply space opening when the folds were already developed. Late to post-tectonic intrusions and dykes would have a more random orientation and different shapes. From the three sketches proposed by Passchier et al. (1990, fig.4.34) to explain the kind of geometry here discussed, two of them essentially agree with our syntectonic interpretation for the G2 sheets alongside F3 axial surfaces, while the third one is unlikely in the case.

Even though not being of major concern as regards to the age problem, Archanjo & Legrand (1997) demanded (fifth paragraph) for criteria to ascribe D2 to a contractual regime. This point was already discussed by Jardim de Sá & Barbalho (1991), Fonseca et al. (1991) and, in more detail, by Jardim de Sá (1994, pages 467-480). Notwithstanding, it has not been dealt with in our 1995 paper due to space restrictions. Briefly and not excluding late-D2 extensional structures, our criteria for an overall contractual D2 regime include: a) pre-D3 basement slices overlying the Seridó supracrustals at a number of places (west of Cruzeta, NW and SE of Santa Luzia, SE of Lajes); b) the kyanite-bearing syn-Dj parageneses; c) less confidently, the abundance of F2 recumbent folds in the supracrustals, better explained by a contractual deformation if bedding was originally flat-lying.

Trying to correlate flat-lying structures in the country rocks and magmatic fabrics in some Brasiliano plutons to a tangential, extensional deformation of that age (fifth and sixth paragraphs of Archanjo & Legrand), we believe that some misinterpretations were made by those authors concerning the structural setting of the plutons (see detailed discussion in Jardim de Sá 1994, pages 452-454). An important negative residual gravity anomaly around the São Rafael pluton (UFRRN Geophysics data bank) indicates that this is a rooted body; so, the outwards-dipping and central flat-lying foliations measured by Archanjo et al. (1992) are best seen as the upper level of a drop-formed pluton head of a sill-like body. Furthermore, its N to NNE-trending magmatic foliation is consistent with the strike-slip L3 ones of the country rocks, and differ from the high strain, gently SSE-plunging L2 lineations associated with the D2 tangential regime (fig. 4.44B of
In the other mentioned example, the emplacement of the late to post-tectonic Umarizal pluton was related to the supposedly extensional Frutuoso Gomes zone of Brasiliano age shear zone (Archanjo & Galindo 1995). However, the NW-trending magnetic lineation of the granite is at a high angle to the assumed ENE shear direction of this structure. In this case, the interpretation of Archanjo & Galindo (1995) is at variance as regards to the main criteria used by Archanjo et al. (1992) and other authors to confirm the syntectonic emplacement of the Brasiliano granites in Seridó and elsewhere - that is, the coincidence between the viscous, magmatic lineations and the country rocks L (or SL) fabric. The Frutuoso Gomes shear zone was previously mapped by Jardim de Sá (1994) as a NW-trending strike-slip, left-lateral D3 structure on satellite imagery grounds, and its kinematics (or at least a later movement, which could have influenced the pluton emplacement) has been confirmed by asymmetric carbonate boudins and en échelon gashes in Jucurutu marble layers cropping out along this structure (west of Almino Afonso, for instance). The NW-trending lineation of the granite thus fits with this left-hand strike-slip movement. At the same time, the misleading ENE “extensional” movement of this D3 shear zone was deduced by those authors from older, D2 shear criteria along the main S2+L2 fabrics of Gz-type augen gneisses.

Following along with these arguments, well constrained Brasiliano, D3 extensional deformation has been reported from the eastern domain of the Seridó Belt (Jardim de Sá et al. 1993, Souza & Jardim de Sá 1993, Jardim de Sá 1994 pages 113-120), based on the correlation of the country rocks structures with the fabrics in Brasiliano granites, in this case supported by the coincidence of S+L fabrics, both in orientation and kinematics, between these different rock types. In these areas, the extensional deformation in the basement gneisses and Seridó micaschist allochthons is overprinted upon an earlier, high strain fabric (including inversions of way-up structures in the micaschists) which can be thus interpreted as of D2 age.

Finally, we agree that the deep flat-lying reflectors in the basement of the Potiguar basin probably correspond to (but not necessarily are; unfortunately, seismic reflectors and other kinds of geophysical anomalies usually do not carry appropriate and obvious time-markers) extensional or strike-slip detachments of Brasiliano/D3 age (following Matos 1992 and Archanjo & Legrand’s suggestion in their sixth paragraph); however this flattening out the existence association flat-lying D2 fabric (including shear zones as well) in the Precambrian basement, as shown by the field relations mentioned above.

In their sixth paragraph, Archanjo & Legrand reinforced the suggestion that the G2 and the Caicó gneisses acted as basement to the Seridó Formation flysch unit (but, what about the forgotten, Jucurutu and Equador formations?). The absence of G2-related volcanic products (invoked by us as an evidence against their interpretation as anorogenic, syn-sedimentary intrusions) was explained by deep erosion of the basement before deposition of the Seridó Formation. However: a) why do the G2 sheets so frequently follow the (unconformable or tectonic?) contact between the Seridó Group (especially the Jucurutu Formation) and the Caicó Complex (see maps in Jardim de Sá 1994), a contact that supposedly did not exist at the time of their emplacement? b) being volumetrically so important (see also Jardim de Sá et al. 1995, fig. 1) and displaying characteristic texture/composition that enable appropriate recognition, where are the clasts of the plutonic facies of an hypothetical G2 metasedimentary association?; c) although complete erosion of hypothetical, “G2”-type volcanics is not impossible, why would such kind of volcanic equivalents remain so well preserved in the Amazonas or São Francisco cratons (or at the nearby Orós Belt - Sá et al. 1991, or in western Hoggar - Caby & Andreopolous-Renaud 1983), given that the same (or an even longer) time span for erosion is also implicit in these cases?

Concerning the regional metamorphic evolution (seventh paragraph of Archanjo & Legrand’s comments), we maintain that it is not easy (but not impossible, of course) to account for the different parageneses in a single P-T path. The early kyanite-staurolite and sillimanite-bearing parageneses require uplift of the terrain before the prograde low-P/high-T evolution. This could happen either in the course of the same or involving different orogenic cycles. The latter view is on line with the radiometric/structural evidence discussed in our paper and was thus retained. The existence of post-D2 low grade-low strain pressure solution structures, overprinted by the main D3 fabric (Jardim de Sá 1994, pages 103-106), points to the same direction, like also do the previous findings by França & Legrand (1989) based on the metamorphic assemblages in the western part of the main Seridó micaschist belt.

On the other hand, the statement that similar minerals (but not exactly the same, including different microtextural aspects that enable the recognition of successive parageneses; see França & Legrand 1989 and Legrand et al. 1995) occur along D2 and D3 is far from strange, being the natural result of superimposing different events (no matter if related to a unique or to different orogenic cycles) keeping the same (or approximately the same) bulk rock chemistry. Apart from a few relic features shown by microprobe work (Lima et al. 1992), chemical reequilibration at the mineral scale is also the rule if one considers the PTX conditions (especially high temperatures and fluid flux) of the D3 event. The superimposition of different metamorphic parageneses at a number of places (higher T D3 overprinted upon lower T D2, like in Currais Novos, west of Acari and in several other places; low T D2 and D3 like in Cruzeta and west of Angicos; high T D2 and D3 like in São Vicente, Caicó and São João do Sabugi, etc.; references in Jardim de Sá 1994, pages 141-151) is consistent with an independent relation between the two tectonometamorphic events (D2 and D3) and their respective heat sources and thermal structure, no matter if involving the same or successive orogenic cycles.

In their final (eighth) paragraph, Archanjo & Legrand (1997) comment that the ca. 740 Ma old zircons reported by Van Schmus et al. (1995b) could not be of metamorphic origin as the regional temperatures were not high enough at that time, but just after 600 Ma. In our paper, we did not state that the older figure corresponds to a metamorphic event, even though it could be so if one considers: a) the tangential D2 structures to be of early Brasiliano age; b) that metamict zircon zones or whole crystals can recrystallize even at greenschist facies conditions, as shown by Gebauer & Grunenfelder 1976,1979); in this case, the zircon ages could well record the initial stage of a prograding (D3) metamorphic evolution, and not its peak conditions. Since the zircon grains dated by Van Schmus et al. (1995b) have not been studied under the SEM, another possibility remains, that ca. 600 Ma old metamorphic zircons do include a minor component of radiogenic Pb related to relict, older nuclei. The apparent lack of a suitable source terrain with that age (740-600 Ma), either in NE Brazil or in Nigeria, is a major difficult in interpreting these zircons as detrital grains.

We conclude by stating that the points raised by Archanjo & Legrand (1997) are poorly constrained and/or lack coherence, their arguments being too hypothetical and prone to generalizations; as such, they do not deny or rule out interpretations in our 1995 paper and elsewhere. Our real concern is the large set of dates put forward by Van Schmus and co-work-
ers and now we wait for additional results (especially U-Pb dates on felsic metavolcanics and G2 plutons) in samples collected together with those authors. Anyway, lacking detailed studies at microscopic and submicroscopic scales (and REE and trace element geochemical data in the case of Sm-Nd model dates), and in the light of the modern, SHRIMP results that have been published in the literature, we cannot consider to have reached a “final” answer to the geochronological questions.

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