Comment on “A preserved early Ediacaran magmatic arc at the northernmost part of the transversal zone - central domain of the Borborema Province, Northeast of South America”, by B. B. de Brito Neves et al. (2016)

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ABSTRACT: The recent proposition for a long-lived (635–580 Ma) magmatic arc in the central portion of the Borborema Province is critically evaluated. Evidence favoring subduction include: low-T, high-P metamorphism; local occurrence of retroclastics; and the probable participation of juvenile material in the genesis of 630–620 Ma-old plutons. However, several factors argue against the existence of a large ocean separating the Northern and Central subprovinces. First, early Tonian detrital zircons (1.0–0.9 Ga) in the Northern Subprovince indicate derivation from the Central Subprovince, and thus a connection between them until the time of deposition (ca. 660 Ma). Second, the age of peak metamorphism in the Northern Subprovince implies concomitant deformation in the upper and lower plates at 630–610 Ma. Third, 630–620 Ma-old granites have characteristics (e.g., high \(\delta^{18}O\) values, low magnetic susceptibility) unlike plutons emplaced in continental active margins. Fourth, 590–580 Ma-old granites are clearly syn-transcurrent, i.e., post-collisional. Finally, the Patos shear zone, proposed to be a boundary transform between the two plates, is younger than 570 Ma, and thus cannot represent a suture zone. Therefore, if a magmatic arc existed, it had short duration and was developed at the end of the Cryogenian.

KEYWORDS: subduction; collision; detrital zircons; granitic magmatism; orogenic metamorphism.

INTRODUCTION

The accretionary model for the Neoproterozoic evolution of the Borborema Province vindicates that it would be the product of collage of several distinct terranes (Santos and Medeiros 1999, Brito Neves et al. 2000, Padilha et al. 2017). In this model, subduction zones would be present not only around the periphery of the Borborema Province but also in its interior. Whereas a subduction to collision setting is well-established in the Central Ceará Domain, as indicated, for instance, by juvenile magmatic rocks with arc characteristics in the Tamboril-Santa Quitéria Complex and by the occurrence of high- to ultra-high P metabasic rocks (e.g., Araújo et al. 2014, Santos et al. 2015), the former existence of several subduction zones in the interior of the Borborema Province is disputed (Neves 2003, 2015). It is in the context of the accretionary model that Brito Neves et al. (2016) recently proposed a magmatic arc, lasting from 635 to 580 Ma, in the Piancó-Alto Brígida belt (western portion of the Central Subprovince of the Borborema Province). Additionally, they and Brito Neves and Campos Neto (2016) proposed that the Patos shear zone is a continental plate boundary transform separating lithologies of the lower (the Northern Subprovince) and upper (the Central Subprovince) plates, and attributed low-grade metasedimentary rocks between the inferred arc and the Patos shear zone to deformation of sediments deposited in a forearc basin. Here, I critically review the available information derived from geological, geochemical, isotopic and geochronological data pertaining to the geological evolution of the Piancó-Alto Brígida belt, and discuss:
the tectonic significance of the Patos shear zone.

**GEOLOGICAL SETTING**

The Piancó-Alto Brígida belt (equivalent to the Cachoeirinha-Salgueiro belt; Sial 1986, Sial and Ferreira 2016) consists of low-grade metapelites and metagraywacks of the Cachoeirinha Group and higher grade micaschists of the Salgueiro Group (Kozuch 2003, Medeiros 2004). U-Pb dating of metavolcanic rocks and of detrital zircons in metasedimentary rocks of the Cachoeirinha Group indicate that deposition occurred in the Late Neooproterozoic (< 650 Ma), possibly with the top of the sequence being synorogenic (Kozuch 2003, Medeiros 2004, Van Schmus et al. 2011). The Piancó-Alto Brígida belt is intruded by a large number of plutons and batholiths, the most abundant represented by two groups of granitoids (Sial 1986, Sial and Ferreira 1990, Mariano and Sial 1990, Mariano et al. 1996, Ferreira et al. 1998, Sial and Ferreira 2016):

- **lenses of metamafic and metaultramafic rocks that occur within the Cachoeirinha-Salgueiro belt; Sial 1986, Sial and Ferreira 2016):**
- **epidote-bearing, equigranular, calc-alkaline tonalites to granodiorites, regionally known as Conceição type:**
- **high-K calc-alkaline porphyritic granites to quartz monzonites associated with enclaves and dike swarms of K-rich biotite diorites to quartz diorites, regionally known as Itaporanga type.**

The first group comprises c. 50 plutons and the second one is represented by three large batholiths. There are very few geochronological data available for these rocks. Brito Neves et al. (2003) reports a U-Pb TIMS age of 635 ± 9 Ma for the Conceição pluton (type locality of group 1), but with a large mean standard weighted deviation (MSWD) (22). Given the low grade of the country rocks, it is possible that the $^{40}$Ar/$^{39}$Ar age of 618 ± 2.7 Ma obtained in amphibole (Sial and Ferreira 1990) more closely approaches the age of crystallization. For the Itaporanga batholith, a better constrained U-Pb age of 584 ± 2 Ma is available (MSWD = 2.5) (Brito Neves et al. 2003). In spite of the limited number of data, it is clear that intrusion of group 1 granitoids is older, probably occurring in the interval 635–615 Ma, whereas intrusion of group 2 granitoids took place at ca. 590–580 Ma.

**EVIDENCE FOR SUBDUCTION**

Previous models had already suggested the genesis of group 1 granitoids in relation to subduction (Medeiros 2004; Caby et al. 2009; Sial and Ferreira 2016). The main difference with the model of Brito Neves et al. (2016) is that these latter authors propose a long-lived magmatic arc still active during intrusion of group 2 granitoids, thus implying over 50 Ma of arc magmatism. This proposition requires the existence of a large oceanic domain between the Northern and Central subprovinces. Lines of evidence supporting the former existence of a subduction zone in the Piancó-Alto Brígida belt include:

- **lenses of metamafic and metaultramafic rocks that occur near Bodocó town, in the western portion of the domain, that record peak metamorphic conditions of the order of 13 kbar and 525ºC, symptomatic of subduction metamorphism (Beurlen et al. 1992):**
- **thermobarometric estimates for metapelites indicating pressure (P)-temperature (T) conditions for the regional metamorphism of 6–7 kbar and 420 ± 20ºC, implying a high P/T geothermal gradient, also consistent with subduction (Caby et al. 2009):**
- **whole-rock chemical analyzes of Group 1 granitoids falling on the field of arc granites in tectonic discrimination diagrams (Ferreira et al. 2004; Fig. 1A):**
- **(d) Late Mesoproterozoic (1.2–1.3 Ga) Nd-model ages and slightly negative $e_{Nd}$ (600 Ma) values (~1.2–2.0) (Brito Neves et al. 2003; Sial and Ferreira 2016) of the Conceição-type plutons, suggesting interaction of juvenile calc-alkaline magmas with older crustal material, a common situation in continental magmatic arcs.**

Therefore, metamorphism of the sedimentary package and conversion of mafic rocks to eclogite were attributed to the transport of these lithologies to depths up to 45 km in a subduction channel, shortly followed by intrusion of calc-alkaline magmas (Caby et al. 2009). Sial and Ferreira (2016) estimated the interval 650–620 Ma for the closure of a narrow oceanic basin by activities along a subduction zone dipping southeastward.

**EVIDENCE AGAINST A LONG-LIVED MAGMATIC ARC**

Although the Conceição-type plutons have some characteristics suggestive of magma generation associated with subduction, several geological aspects are unlike those of calc-alkaline batholiths found on active continental margins:

- **I-type granitoids in this setting are part of the calc-alkaline suite, which includes important volumes of mafic and intermediate rocks (gabbros and diorites), which contrasts with their restricted occurrence in the Conceição-type**
plutons. This is reflected in the small compositional range
of silica contents (62–72 wt.%; Ferreira et al. 2004) as
compared with that typical of calc-alkaline magmas
(50–80 wt.% SiO₂; e.g., Stern 2002);
■ Calc-alkaline plutons belong to the magnetite-type series
(Ishihara 1977) whereas the Conceição-type plutons have
low magnetic susceptibilities (Sial and Ferreira 2016);
■ The whole-rock high δ18O values (10–13‰) of the
Conceição-type granites (Sial 1993, Sial and Ferreira
2016) are distinct from those of arc granites, which
typically have less than 8‰ (O’Neil et al. 1977);
■ Amphibolite xenoliths, interpreted as fragments of meta-
basaltic source rocks, also exhibit high values of δ18O
(Sial and Ferreira 2016), which contrasts with the mantle
d values of c. 5‰ typical of unaltered oceanic crust
(e.g., Valley et al. 2005);
■ If partial melting of amphibolite in the oceanic part of
the slab had occurred during subduction, adakitic melts
would be produced (e.g., Defant and Kepezhinskas 2001),
which have geochemical characteristics (e.g., high Sr/Y)
rather distinct from those of the Conceição-type granites.

If the origin of the Conceição-type plutons in a mag-
matic arc is questionable, still more is the case of the
Itaporanga-type granites. There is no evidence for sub-
duction zone processes at the time of their emplacement
at 590–580 Ma and they are clearly syn-transcurrent
(Archanjo et al. 1999). Although strike-slip shear zones
occur at convergent margins, they are much more com-
monly developed following crustal thickening in a colli-
sional setting. Therefore, associated plutons are commonly
dubbed post-collisional. These plutons have dominantly
high-K calc-alkaline signature (e.g., Liégeois et al. 1998),
which is the case of group 2 granitoids (McMurry et al.
1987, Mariano et al. 1996). Unsurprisingly, most anal-
yses of the Itaporanga-type plutons plot in the post-coll-
isional field in tectonic discrimination diagrams (Fig. 1B).
Furthermore, they have negative εNd values and
Paleoproterozoic Nd model ages (Mariano et al. 2001,
Brito Neves et al. 2003, Sial and Ferreira 2016), indicat-
ing derivation from ancient continental lithosphere, with
little or no involvement of juvenile material in their gen-
esis, rather unlike arc-related granitoids.

Brito Neves et al. (2016) enumerate a series of composi-
tional, structural and geochronological differences between
the Northern Subprovince and the Central Subprovince
(their Tab. 3). However, they do not elaborate the argu-
ment for subduction of the first (the lower plate) under the
latter (the upper plate). There are two critical constraints
that must be considered in this respect that were not dealt
with in the Brito Neves et al. (2016) paper. The first is
provided by the ages of detrital zircons in the supracrustal
sequences of the lower plate. Several samples of metasedi-
mentary rocks in the Ceará Complex of the Central Ceará
Domain (Araújo et al. 2012, Kalsbeek et al. 2013, Garcia
et al. 2014, Ancelmi et al. 2015, Arthaud et al. 2015) and
in the Seridó Group of the Rio Grande do Norte Domain
(Van Schmus et al. 2003, Kalsbeek et al. 2013, Hollanda
et al. 2015) contain a significant number of zircons in
the age range 1000–920 Ma (Fig. 2). Rocks of these ages
are unknown in the North Subprovince, where the oldest
Neooproterozoic record of magmatic activity is represented
by an orthogneiss from the Lagoa Caçara unit that yielded
an age of 833 ± 6 Ma (Aratújo et al. 2014). Hence, the
most likely derivation of these detrital early Tonian zir-
cons is from sources related to the Cariris Velhos event in

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**Figure 1.** Tectonic discrimination diagrams (Pearce et al. 1984) for granitoids in the Piancó-Alto Brígida belt. (A) Epidote-bearing calc-alkaline plutons. (B) High-K calc-alkaline plutons. Modified from Ferreira et al. (2004), with addition of the post-collisional field (post-COLG) of Pearce (1996).
the Central and Southern subprovinces (Santos et al. 2010, Guimarães et al. 2016), implying a connection between the Northern and Central subprovinces at the time of deposition. The maximum time of deposition constrained by the ages of the youngest detrital zircon populations are ca. 660 Ma and 630 Ma, respectively, in the Ceará Complex and Seridó Group (Fig. 2).

The second constraint is the age of regional deformation and metamorphism in the Northern Subprovince. Whereas these processes appear to have been initiated only after ca. 600 Ma in the Rio Grande do Norte Domain (Souza et al. 2006, Archanjo et al. 2013), the ages of metamorphic zircons in the Ceará Complex imply that they already had started 640–630 Ma ago (Araújo et al. 2012, Garcia et al. 2014). A pool of 20 analyses of metamorphic zircons from the Ceará Complex gives an age peak of 622 Ma (Fig. 2), which overlaps with the age of the Conceição pluton. As deformation of the lower plate cannot occur in the pre-collisional phase, concomitant deformation in the upper and lower plates implies that collisional processes were already occurring at ca. 630 Ma. Therefore, it appears that at most a few tens of millions of years are available for formation and consumption of oceanic lithosphere between the Piancó-Alto Brígida and Central Ceará domains, and that an oceanic stage was probably never reached in the Rio Grande do Norte Domain.

Brito Neves and Campos Neves (2016) and Brito Neves et al. (2016) interpret the Patos shear zone as a boundary transform, implying that its development started very early during the geological evolution of the region. This shear zone is one of the most expressive in the Borborema Province (Corsini et al. 1991, Vauchez et al. 1995), which makes it a potential candidate for a suture zone. However, recent studies show that the Patos shear zone is a late intracontinental shear zone, with no evidence that it reworked a previous transform contact (Archanjo et al. 2008; Viegas et al. 2013, 2014). Recrystallized rims in zircon crystals recovered from leucosomes of melt-bearing mylonites and crystallization ages of syn-kinematic plutons indicate the age interval 566–558 Ma for the high-grade metamorphism (Viegas et al. 2013, 2014). This age range is ca. 20 Ma younger than the age of other high-temperature shear zones in the Borborema Province (Neves et al. 2004, 2006, Archanjo et al. 2008), showing that the Patos shear zone was the...
last of the major strike-slip shear zones developed during the Brasiliano Orogeny.

Brito Neves and Campos Neto (2016) attributed the rather low-grade rocks of the Rio Salgado belt (their Fig. 2), which is located between the inferred arc and the Patos shear zone, to deformation of sediments deposited in a forearc basin. However, these rocks contain a large fraction of detrital zircons with ages similar to the age of the Conceição pluton (Fig. 9 of Brito Neves and Campos Neto 2016). Therefore, deposition probably occurred in an intermontane basin coeval with deposition of the upper unit of the Cachoeirinha Group, which is not intruded by the Conceição-type plutons (Medeiros 2004) and exhibits petrographic, deformational and metamorphic characteristics similar to the Rio Salgado belt rocks. Furthermore, recent structural and geochronological results show that by 605–590 Ma extensional processes predominated in the Piancó-Alto Brígida Domain (Archanjo 2015), probably reflecting increased thickness and crustal elevation that allowed the vertical stress to overcome the horizontal tectonic stress, inducing orogenic collapse. This event was followed in a short time span, or partially overlapped with, nucleation and growth of transcurrent shear zones, a common situation in collisional and intracontinental orogens (Raimondo et al. 2010, 2014, Faure et al. 2012).

**FINAL REMARKS**

A connection between the subprovinces that comprise the Borborema Province before the Brasiliano Orogeny was first proposed by Neves (2003). The main arguments are reviewed by Neves (2015) and are supported by other studies. In the words of Arthaud et al. (2015):

Zircon populations recorded in the Ceará Group characterize also the Seridó Group in Rio Grande do Norte (Van Schmus et al, 2003) and the East Pernambuco in the Transversal Zone domain (Neves et al., 2006). It appears that these three metasedimentary sequences, presently separated by large ductile strike-slip shear zones, experienced the same evolution and probably belonged to the same continental mass since the Paleoproterozoic.

This interpretation was questioned by Brito Neves et al. (2016), which stated that:

According to these researchers, the Borborema Province has behaved as an intracratonic setting since the late Paleoproterozoic. This means that all fold belts and granitic plutonism were the product of lithosphere extension without any formation of oceanic crust, followed by compression due to far-field stresses.

The statements in the last sentence are incorrect. First, Neves and co-workers never attributed the genesis of granitic plutons younger than 630 Ma to extension. Instead, they were always considered to be syn-orogenic (e.g., Neves et al. 2000, 2006, 2012). Second, the proposition of dominantly intracontinental deformation during the Brasiliano Orogeny does not preclude the local occurrence of subduction, as clearly stated by Neves (2003):

As a result, far-field tensional stresses transmitted to the interior of Atlantica may have promoted extension and development of continental rift basins (Figure 8a). Some of these basins evolved to a proto-oceanic stage, with subsequent subduction and oceanic closure leading to the local occurrence of eclogites in the central domain of the Borborema province [Beurlen et al., 1992].

And

Subduction of oceanic lithosphere explains the low-temperature and medium- to high-pressure metamorphism in the Cachoeirinha belt, which stands in contrast with the general high-temperature metamorphism of other sectors of the Borborema province.

The results reviewed above support the occurrence of a short-lived Wilson Cycle in the Central Subprovince and are fully consistent with previous works. What they contradict are the conclusions by Brito Neves et al. (2016) that the Central and Northern subprovinces belonged to separate plates, that a magmatic arc with a lifespan of 55 Ma existed in the Central Subprovince, and that the Patos shear zone is a boundary transform. The available data favor extension of a single continental block shortly before the Brasiliano Orogeny. At most, a few tens of millions of years would separate the formation of oceanic lithosphere and its complete consumption in a hypothetical subduction zone. The time interval for the sequence of events rift → drift → convergence → initial collision is of the order of 20 Ma, approximately between 650 and 630 Ma. In this short time span, it is unlikely that the newly formed oceanic lithosphere had reached dimensions large enough to be subducted to depths below 80-100 km, which are required to promote the onset of
arc magmatism (e.g., Ernst 1999, Stern 2002, Tatsumi 2005). Therefore, if a magmatic arc existed, it is late Cryogenian, not early Ediacaran. However, it is more likely that calc-alkaline plutons in the Piancó-Alto Brígida Domain record syn-collisional magmatism, the dimension of the newly formed oceanic lithosphere being too small to reach the required depth during subduction to promote partial melting of the mantle wedge or of the oceanic portion of the slab.

In synthesis, there is supporting evidence for subduction in the Piancó-Alto Brígida belt, but existence of a magmatic arc is open to discussion, and if one arc existed, it was of short duration.

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