Differential Phanerozoic evolution of cratonic and non-cratonic lithosphere from a thermochronological perspective: São Francisco Craton and marginal orogens (Brazil)

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1.Introduction.

The **São Francisco Craton** (SFC) and its marginal **Araçuaí and Brasília orogens** exhibit a significant diversity in their **lithospheric architecture**. These orogens were shaped during the **Neoproterozoic–Cambrian amalgamation of West Gondwana** (Heilbron et al., 2017). The rigid cratonic lithosphere of the SFC and the relatively weak lithosphere of the Araçuaí Orogen were disrupted during the **Cretaceous opening of the South Atlantic Ocean,** whereas the Brasília Orogen remained in the continental hinterland (de Wit et al., 2008). In earlier research, the thermal effects of the **Phanerozoic reactivations** in the shallow crust of the Araçuaí Orogen have been revealed by low-temperature thermochronology, mainly by apatite fission track (AFT) analysis. However, analyses from the **continental interior** are scarce. We aim to constrain the **exhumation phases** of each terrain **far from the coast**, investigating the possible relationships of cooling/heating episodes to geodynamic processes and their surface expressions. From these, we can evaluate if there is a **differential exhumation pattern** between the terrains and if it is related to the **lithospheric characteristics** of each tectonic province.

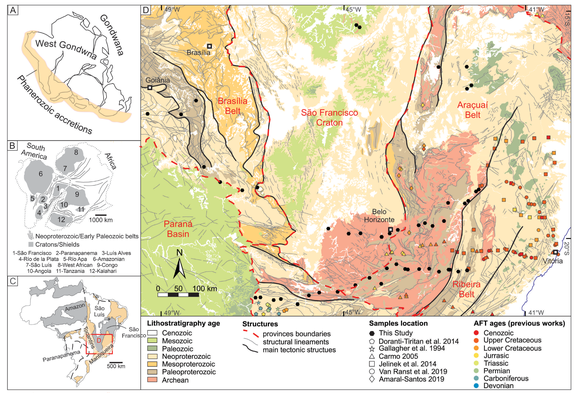

Fig.1 – Geological context of the study area. A) Gondwana Supercontinent and Phanerozoic accretions (after Almeida et al., 1981). B) Schematic representation of West Gondwana basement, with the shields, cratonic continental masses and Neoproterozoic-Late Paleozoic orogenic belts (after Vaughan and Pankhurst, 2008). C) Brazilian tectonic provinces (Alkimim, 2015). D) Chronostratigraphic regional map showing the location of analyzed samples with the major structural lineaments and AFT ages from previous works. * indicates samples from Fonseca et al., (2020).

2.Samples and Method.

Fifty samples of granites and gneisses were collected following three E–W oriented transects: S(outh), C(entral) and N(orth) (Fig.1). These transects were selected to cross the structural fabric established during the Brasiliano orogenic cycle, and cover the three tectonic provinces. Twenty-four samples are from the Araçuaí Orogen, twelve samples from the SFC and seven samples are from the Brasília Orogen.

For this study we applied the Apatite Fission Track (AFT) external detector method (Fleischer et al., 1975) based on the standard procedures used at the fission track laboratory at Ghent University (described by e.g. Van Ranst et al., 2020). Data from samples with a sufficient number of track lengths (> 50) were used as input in the QTQt software (Gallagher, 2012) to perform the Markov Chain Monte Carlo (MCMC) inverse modeling with 10^7 pre- and post-burn in iterations. We opted not to use c-axis projection because the anisotropy of our samples is anomalously low, causing c-axis projection to 'overcorrect' and invert anisotropy (Van Ranst et al., 2020). Only the present-day temperature was constrained as (25 ± 15) °C in order to not bias the models. The prior for the MCMC run was set to the (central age ± central age) for time and, (70 ± 70) °C for temperature.

3.Results.

3.1.Araçuaí Orogen.

The AFT ages range from the late Triassic (210 ± 10 Ma) to the early Paleogene (53 ± 2 Ma). On the age–elevation plot, the sample set from the Araçuaí Orogen describes a normal trend. In six samples (S1, S3, C6, C2, N3 and N5) it was possible to measure more than 50 tracks to produce representative length–frequency histograms. Samples from the northern transect yield the shortest mean track lengths (MTL) (11.5 µm, N3 and N5) and MTL values become longer to the south (13.5).

3.2.São Francisco Craton.

The samples exhibit pre-rift AFT central ages ranging from early Carboniferous (344 ± 16 Ma) to Late Jurassic (160 ± 13 Ma). The majority of the samples close to the boundary with the orogenic belt present Triassic to Jurassic ages. In the cratonic interior, samples yield ages from the Carboniferous to Permian. In six samples (S11, S13, C18, C19, N10 and N11) it was possible to produce representative length–frequency histograms. Samples from the southern transect display the longest MTL (12.7 and 12.6 µm) whereas in the others the MTLs range from 11.2 µm to 11.9 µm.

3.3.Brasília Orogen.

The majority of samples from the Brasília Orogen exhibit AFT ages ranging from the Triassic (206 ± 15 Ma) to the Carboniferous (331 ± 23 Ma). Sample N12 presents a disparate Albian AFT age (106 ± 15 Ma), but only nine grains could be analyzed. In five samples (8, 9, C14, C16, N13) it was possible to produce representative length–frequency histograms. The MTL ranges from 11.4 µm to 13.7 µm.

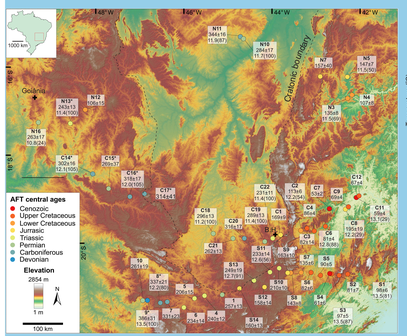

Fig.2 – Digital Elevation Model (DEM) map of the study area with indication of the sample locations, central AFT ages (in Ma), Mean Track Lengths (MTL) (in µm), and number of measured confined track lengths in brackets. For general location see figure 1. * indicates samples from Fonseca et al., (2020). BH = Belo Horizonte.

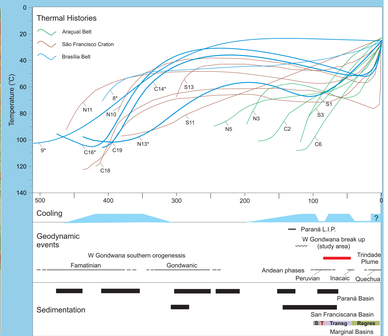

Fig.3 – Summary figure from thermochronology and geological events. Expected t-T paths from models obtained by QTQt (Gallagher, 2012). Periods of cooling interpreted from the thermal history, geodynamic events and sedimentation events during the Phanerozoic (after Milani et al., 2007) are added. S = syn-rift and T= transitional phases in the marginal basins.

3.4.Thermal history.

Samples from the SFC and the Brasília Orogen were exhumed mainly during the Paleozoic with slight exhumation in the Cenozoic. Samples from the Araçuaí Orogen were mainly exhumed during the Meso-Cenozoic.

4.Discussion.

A **Paleozoic** cooling phase is revealed through the thermochronometry and thermal history modelling. The main cooling was constrained between ca. 430 Ma and 350 Ma (Fig. 3) by the inverse modeling (expected model) and corroborated by the relatively high mean track length (MTL) values from sample 9 with a Devonian AFT age. We suggest a close connection between the tectonic subsidence of the adjoing Paraná Basin (Fig;1) and the coeval denudational cooling of basement. This is interpreted as a result of exhumation after possible reactivation and basement erosion, which in turn was triggered by the tectonic extension during the rifting processes.

An **Early Cretaceous to Cenomanian** (ca. 150 to 95 Ma) cooling phase is inferred by the inverse models. Since it corresponds to the syn-rift stage, it must be linked to the stretching and thinning processes in response to the extensional stress field that resulted in the opening of South Atlantic Ocean and subsequent formation of new oceanic basins. A widespread post-rift erosional event, i.e. **Late Cretaceous to Paleocene**, is displayed by some samples. It was probably connected with reactivations prompted by the interplay between flexural bending of the margin and the intraplate compressive stress transmitted from the plate boundaries.

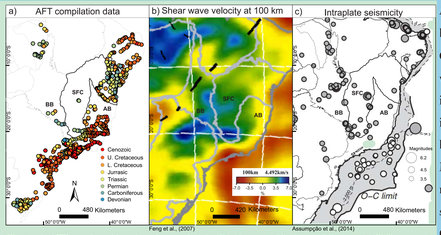

Fig.4 – A) AFT ages from this and previous works (after Engelmann de Oliveira and Jelinek, 2017). B) Shear wave (s) velocity at 100 km depth (Feng et al., 2007). C) Intraplate seismicity onshore and offshore (Assumpção et al., 2014).

Differential uplift and exhumation in our study area are recorded in our AFT data. While the Araçuaí Orogen samples experienced fairly rapid cooling during Meso-Cenozoic times, the SFC and Brasília Orogen samples exhumed long before, during the Paleozoic, and remained in relative stable conditions near present outcrop position from the Mesozoic until the present day. We investigate how lithospheric architecture of the tectonic provinces (e.g. crustal thickness and seismicity Fig.4) is deeply connected with deformational response to tectonic stresses. Rigid and stiff lithosphere of the SFC is more resilient to major tectonic events (Artemieva, 2006). Orogenic lithosphere of the Araçuaí orogen is favorable for reworking due to its fertile content, high concentration in radiogenic elements, and its mantle anisotropy array. The Brasília Orogen seems to be an example of a strong orogenic lithosphere, since it remained stable from the early Mesozoic to the present.

5.Conclusion.

Three main periods of basement exhumation were identified: (i) Paleozoic, recorded both by samples from the SFC and Brasília Orogen; (ii) Early Cretaceous to Cenomanian, recorded by samples from the Araçuaí Orogen; and (iii) Late Cretaceous to Paleocene, inferred in samples from all domains. We compare the differential exhumation pattern of the different geotectonic provinces with their lithospheric strengths. We suggest that the SFC likely concentrated the Meso-Cenozoic reactivations in narrow weak zones while the Araçuaí Orogen displayed a far-reaching Meso-Cenozoic deformation. The Brasília Orogen seems to be an example of a stronger orogenic lithosphere, inhibiting reworking. Understanding the role of the lithosphere rigidity may be decisive to comprehend the processes of differential denudation and the tectonic–morphological evolution over Phanerozoic events.

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