Earth's new regime at the dawn of the Paleoproterozoic: Hf isotope evidence for efficient crustal growth and reworking in the São Francisco Craton, Brazil

Henrique Bruno^{1,2}, Monica Heilbron¹, Rob Strachan², Mike Fowler², Claudio de Morisson Valeriano¹, Samuel Bersan^{1,2}, Hugo Moreira², Kathryn Cutts¹, Joseph Dunlop², Rasec Almeida¹, Julio Almeida¹, Craig Storey²

¹*Tektos- Grupo de Pesquisa em Geotectônica, Universidade do Estado do Rio de Janeiro, Faculdade de Geologia. Rua São Francisco Xavier 524, Maracanã, Rio de Janeiro, Brazil.*

²*University of Portsmouth, School of the Environment, Geography and Geosciences, Burnaby Building, Burnaby Road, Portsmouth, PO1 3QL, UK.*

METHODOLOGY

A total of fifteen samples of the Piedade, Mantiqueira and Mineiro terranes were selected for zircon Lu-Hf analysis. The location of the samples is shown on Figure 1 of the manuscript and all the data is presented in Supplementary Material B, with a summary of the results shown in Table 1 of Supplementary Material A. All these samples were previously dated via (LA-ICP-MS) U-Pb in zircon by Bruno et al. (2020) and Bruno et al. (2021).

The Lu-Hf analyses were performed on concordant to sub-concordant zircon grains directly on U-Pb spots (when possible), using 40 µm spots. Analyses were performed at the University of Portsmouth (UK) using an ASI Resolution SE 193 excimer laser connected to a Nu Plasma I MC-ICP-MS. Laser conditions for tuning were 40 µm, 4.5 J/cm² and 10 Hz. Total Hf intensity was typically 15 V for the Keuhl lake zircon and nearly 0.5 V for the glass. For the unknown analysis, laser fluence was 6.0 J/cm², repetition rate was 6 Hz and gas flows were Ar 0.8 L/min, He 320 mL/min. The following masses were measured in the respective Faraday collector cups configuration transmitted to pre-amplifiers with a 1011-ohm resistor: 171 (L3), 173 (L2), 175 (Ax),

¹⁷⁶Hf (H1), ¹⁷⁷Hf (H2), ¹⁷⁸Hf (H3), ¹⁷⁹Hf (H4) and ¹⁸⁰Hf (H5). Calibration of the equipment was realized utilizing raster lines on NIST 610 glass, Mud Tank and on an in-house zircon collected at the same location of the 91500-zircon standard, the Keuhl lake syenite, Canada (Wiedenbeck et al., 1995). Automatic runs consisted of background measured for each analysis for 25 seconds before 50 seconds of ablation time, intercalating unknowns and standards. The isotopes ¹⁷¹Yb, ¹⁷³Yb and ¹⁷⁵Lu were monitored to allow correction of isobaric interferences of Lu and Yb isotopes on mass 176. Data reduction was realized using the Hf Isotopes data reduction scheme (DRS) of Iolite 3.62 software (Paton et al., 2011). The accuracy and precision of Lu-Hf measurements were monitored via periodic measurements of reference values as shown in Supplementary Material B.

We evaluate the slope of the ϵ_{Hf} for each of the presented orogens. Regressions were fitted to the <2500 Ma components of the evolution arrays of the orogenic systems using the software Past v.3.10 (Hammer et al., 2001). To find the relationship between ¹⁷⁶Hf/¹⁷⁷Hf, least trimmed squares regression was used through the robust regression model, which minimizes variation on the Y-axis (Rousseeuw and Driessen, 1999; Zumel et al., 2014). Pearson's r correlation and the probability that ϵ_{Hf} and age are presented in Tables 2 and 3. The positive r-values means that ϵ_{Hf} are positively related to the age, i.e as age increases so does ϵ_{Hf} . Additionally, for ease of use, we estimate the ¹⁷⁶Lu/¹⁷⁷Hf evolution trajectory as a function of ϵ_{Hf} /Ma through the equation:

$$\frac{\text{Lu}}{\text{Hf}} = -1.5116 \cdot \frac{\epsilon_{\text{Hf}}(t)}{\text{Ma}} + 0.0337 \text{ (Spencer et al. 2020).}$$

SAMPLE DESCRIPTION

Neoproterozoic Piedade Microcontinent

Sample 50 is a hornblende biotite gneiss from the TTG compositional group with crystallization age defined by a U-Pb concordia age of 2691 ± 18 Ma determined by zircon cores with igneous oscillatory zoning and metamorphic age defined by sub-concordant dark rims with ²⁰⁷Pb/²⁰⁶Pb age of 2021 ± 30 Ma (spot#20), 2043 ± 29 Ma (spot#34) and 2015 ± 27 Ma (spot#8) (Bruno et. al., 2021). The crystallization analysis corresponds to ϵ_{Hf} (2691 Ma) values between -1.06 and -6.59 and the analysis performed in metamorphic rims correspond to ϵ_{Hf} values, ²⁰⁷Pb/²⁰⁶Pb age, between -12.23 and -14.84. The Lu-Hf isotopic analysis yield identical ¹⁷⁶Hf/¹⁷⁷Hf(t) when back

calculated at the concordant age, for the crystallization age and $^{207}\text{Pb}/^{206}\text{Pb}$ age for the metamorphism, ranging from 0.28089 ± 0.00003 to 0.28114 ± 0.00003 (Figure 1). TDM varies from Paleo- to Mesoarchean ages ca. 3.31 to 3.01 Ga.

Twenty Lu-Hf analysis were performed in Sample 66A, an intermediate orthogranulite from the sanukitoid compositional group. The U-Pb analysis of the cores with fine igneous oscillatory zoning yielded an upper intercept at 2693 ± 23 Ma considered the crystallization age (Bruno et. al., 2020) and corresponds to ϵHf (2693 Ma) values between -0.65 and -8.70, whereas the Lu-Hf analysis performed on the metamorphic bright rims range in ϵHf (2043 Ma) values between -13.15 and -22.01. TDM of sample 66A zircon grains varies from 3.55 to 3.04 Ga. The samples yield a $^{176}\text{Hf}/^{177}\text{Hf}(t)$ of 0.28082 ± 0.00009 to 0.28110 ± 0.00006 when regressed to the crystallization and metamorphic ages, respectively (Figure 2).

Sample 66B is a tholeiitic metabasic rock crystallized at 2710 ± 32 Ma and metamorphosed under granulite facies metamorphism at 2067 ± 82 Ma (Bruno et. al., 2020). The ϵHf (2710 Ma) of the fine igneous oscillatory zoning zircon grains display values between -3.76 and -7.39 and the bright metamorphic rims yield an ϵHf (2067 Ma) of approximately -14. The initial $^{176}\text{Hf}/^{177}\text{Hf}(t)$ was determined using the crystallization and metamorphic ages of the sample, varying from 0.280833 ± 0.00006 to 0.28105 ± 0.00002 (Figure 3).

Mineiro Magmatic Arc

Sample 42, a metagranodiorite sanukitoid, with average $^{207}\text{Pb}/^{206}\text{Pb}$ ages mean, with at least 95% of concordance, gives a crystallization age of 2114 ± 10 Ma (Bruno et. al. 2021). Thirteen Lu-Hf analysis show Paleoproterozoic TDM values of 2.36 to 2.27 Ga and yielded ϵHf (2114 Ma) between +3.65 and +1.99 and yield identical $^{176}\text{Hf}/^{177}\text{Hf}(t)$ values defining an average of 0.281514 ± 0.00003 when back calculated at the concordant age (Figure 4).

Six Lu-Hf analysis were performed on concordant to sub concordant zircon grains of sample 51B, an amphibolitic gneiss of the sanukitoid compositional group with crystallization age of 2117 ± 24 Ma (Bruno et. al., 2021). ϵHf (2117 Ma) values range between +5.84 and +2.59 and yield $^{176}\text{Hf}/^{177}\text{Hf}(t)$ ranging between 0.28150 ± 0.00003 and 0.28157 ± 0.00001 (Figure 5).

Fourteen Lu-Hf analysis were made in fine igneous oscillatory zoning zircon grains from sample 52B, a hornblende biotite orthogneiss from the sanukitoid compositional group with crystallization age defined by an upper intercept of 2152 ± 11 Ma (Bruno et. al., 2021). When back calculated at the concordant age, the sample gives ϵ_{Hf} (2152 Ma) values between +1.09 and -5.52 and yield $^{176}\text{Hf}/^{177}\text{Hf}(\text{t})$ ranging between 0.28128 ± 0.0002 and 0.28143 ± 0.0005 (Figure 6).

Mantiqueira Magmatic Arc

Sample 08, a hornblende biotite gneiss of the sanukitoid compositional group displays prismatic, euhedral to subhedral zircon grains with fine igneous oscillatory zoning in the cores surrounded by homogeneous bright rims with crystallization age defined by an upper intercept of 2168 ± 21 Ma and metamorphic overprint defined by a lower intercept of 584 ± 14 Ma (Bruno et. al., 2020). Ten Lu-Hf analysis of the zircon grains related to the crystallization yielded ϵ_{Hf} (2168 Ma) ranging between -3.45 and -8.68. The $^{176}\text{Hf}/^{177}\text{Hf}(\text{t})$ values of all the zircon grains back calculated at the crystallization and metamorphic age range between 0.28117 ± 0.00003 and 0.28126 ± 0.00002 (Figure 7).

Thirty-two U-Pb analyses of sample 67, a biotite gneiss of the TTG compositional group, yielded a discordia with an upper intercept of 2117 ± 28 Ma, interpreted as the igneous crystallization age and a lower intercept of 553 ± 75 Ma that dates the Ediacaran metamorphic overprint (Bruno et. al., 2020). Four analysis on concordant to sub concordant zircon grains related to the crystallization of the TTG yielded ϵ_{Hf} (2117 Ma) ranging between +1.68 and +0.57 and $^{176}\text{Hf}/^{177}\text{Hf}(\text{t})$ values ranging between 0.28145 ± 0.00003 and 0.28149 ± 0.00003 (Figure 8).

Sample 64B, a hornblende biotite gneiss displays a discordia of twenty-nine analyses with an upper intercept age of 2107 ± 17 Ma, thought to represent the igneous crystallization age and a lower intercept age of 567 ± 41 Ma, interpreted as the Ediacaran metamorphism (Bruno et. al., 2020). Six analysis on concordant and sub-concordant zircon grains related to the crystallization yielded values of ϵ_{Hf} (2107 Ma) ranging between -3.40 and -5.01. $^{176}\text{Hf}/^{177}\text{Hf}(\text{t})$ values of all analyzed spots ranges between 0.28130 ± 0.00003 and 0.28141 ± 0.00002 (Figure 9).

Rhyacian–Orosirian Piedade Terrane

Twelve Lu-Hf analysis yielded ϵHf (2058 Ma) values between -7.21 and -8.44 on sample 58A, an alkaline hornblende biotite gneiss, with crystallization age of 2058 ± 6 Ma calculated by a $^{207}\text{Pb}/^{206}\text{Pb}$ average mean of thirty-three U-Pb analysis in concordant to sub-concordant zircon grains (Bruno et. al., 2021). The Lu-Hf isotopic analysis yield $^{176}\text{Hf}/^{177}\text{Hf}$ (2058 Ma) of 0.28125 ± 0.00003 when back calculated at the concordant age (Figure 10).

Thirteen Lu-Hf analysis were performed on concordant to sub-concordant zircon grains of Sample 58B, a biotite-muscovite peraluminous adakite (hybrid granitoid). The U-Pb analysis of the fine igneous oscillatory zoning of the cores, yielded a discordia with upper intercept at 2054 ± 24 Ma, interpreted as the crystallization age (Bruno et. al., 2021). The ϵHf (2054 Ma) varies between -7.62 and -8.60 and an average of the initial $^{176}\text{Hf}/^{177}\text{Hf}$ (2054 Ma) yield 0.28125 ± 0.00003 (Figure 11).

Eight Lu-Hf analysis were performed on concordant to sub-concordant fine igneous oscillatory zoning zircon grains interpreted as related to the crystallization age at 2011 ± 30 Ma, of Sample 65, a felsic orthogneiss of the biotite- two-mica compositional group (Bruno et. al., 2021). The ϵHf (2011 Ma) values vary between -13.76 and -18.1. Two Lu-Hf analysis were performed in inherited zircon grains, $\epsilon\text{Hf}(t)$ of -5.74 of spot#15 with $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2529 ± 37 Ma and $\epsilon\text{Hf}(t)$ of -1.43 spot#18 with $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2674 ± 38 Ma. The initial $^{176}\text{Hf}/^{177}\text{Hf}(t)$ was determined using the crystallization ages for the concordant to sub-concordant igneous grains and $^{207}\text{Pb}/^{206}\text{Pb}$ age for the inherited cores, varying from 0.280912 ± 0.00003 to 0.28127 ± 0.00002 . (Figure 12).

Sample 68A, a biotite gneiss of the biotite- two-mica compositional group, displays inherited cores yielded $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 2497 ± 36 Ma (spot #35), 2239 ± 37 Ma (spot #33), 2229 ± 37 Ma (spot #29) and 2130 ± 38 Ma (spot #26) (Bruno et. al., 2021). The $\epsilon\text{Hf}(t)$ calculated for the inherited zircon grains varies from -11.52 and -14.8 and the $^{176}\text{Hf}/^{177}\text{Hf}(t)$ of 0.28083 ± 0.00003 and 0.28109 ± 0.00005 . Thirteen analysis yield a discordia line with upper intercept at 2051 ± 30 Ma, considered the best estimate for the crystallization age of the sample (Bruno et. al., 2020b), and four Lu-Hf analysis on concordant and sub-concordant zircon grains display ϵHf (2051 Ma) between -11.57 and -16.27, with $^{176}\text{Hf}/^{177}\text{Hf}(t)$ values between 0.28101 ± 0.00004 and 0.28114 ± 0.00007 (Figure 13).

Two Lu-Hf analysis performed on concordant igneous oscillatory zoning zircon grains of sample 70A, a 2053 ± 18 Ma tholeiitic metabasic rock (Bruno et. al., 2021), yielded $\epsilon\text{Hf}(2053 \text{ Ma})$ of +1.01 and +2.63 and $^{176}\text{Hf}/^{177}\text{Hf}(t)$ values of 0.28150. Archean and Paleoproterozoic inherited concordant to sub concordant zircon grains, with $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from ca. 2.77 to 2.11 Ga, display $\epsilon\text{Hf}(t)$ varying between -2.60 and -16.29 and $^{176}\text{Hf}/^{177}\text{Hf}(t)$ between 0.28089 ± 0.00003 and 0.28095 ± 0.00006 (Figure 14).

Sample 70B, a biotite orthogneiss of the biotite- two-mica compositional group, with igneous oscillatory zoning zircon grains yielding a concordia age of 2059 ± 35 Ma (Bruno et. al., 2020) have $\epsilon\text{Hf}(2059)$ of -18.65. Archean and Paleoproterozoic inherited concordant to sub concordant zircon grains, with $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from ca. 2.86 to 2.11 Ga, display $\epsilon\text{Hf}(t)$ varying between -2.60 and -18.87. The initial $^{176}\text{Hf}/^{177}\text{Hf}(t)$ was determined using the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of each individual analysis and range between 0.28086 ± 0.00004 for the $^{207}\text{Pb}/^{206}\text{Pb}$ oldest zircon grain (spot#17) and 0.28093 ± 0.00004 for the youngest $^{207}\text{Pb}/^{206}\text{Pb}$ zircon grain (Figure 15).

TABLE CAPTIONS

Table S1: Summary of the Lu-Hf results.

Table S2: Values of the least trimmed squares robust regression as calculated by Past3 (Hammer et al., 2013) for the Minas Segment of the MBO.

Table S3: Values of the ordinary least squares with 95% bootstrapped confidence as calculated by Past3 (Hammer et al., 2013) for the Minas Segment of the MBO.

Figure S1: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 50. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S2: Concordia (Bruno et al., 2020), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 66A. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S3: Concordia (Bruno et al., 2020), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 66B. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S4: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 42. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S5: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 51B. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S6: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 52B. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S7: Concordia (Bruno et al., 2020), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 8. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S8: Concordia (Bruno et al., 2020), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 67. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S9: Concordia (Bruno et al., 202), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 64B. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S10: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 58A. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S11: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 58B. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S12: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 65. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S13: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 68A. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S14: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 70A. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

Figure S15: Concordia (Bruno et al., 2021), ϵHf vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages, $^{176}\text{Hf}/^{177}\text{Hf}(t)$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ ages diagrams and cathodoluminescence (CL) and backscattered electrons (BSE) images of representative grains of Sample 70B. Circles indicate spot locations for U-Pb and Lu-Hf results. Zircon codes refer to analytical ID in in Supplementary Material B.

REFERENCES CITED

- Albert, C., Farina, F., Lana, C., Stevens, G., Storey, C., Gerdes, A., Dopico, C. 2016. Archean crustal evolution in the Southern São Francisco craton, Brazil: Constraints from U-Pb, Lu-Hf and O isotope analyses. *Lithos* 266-267, 64-86.
- Bahlburg H., Vervoort J.D., DuFrane S.A., Carlotto V., Reimann C., Cárdenas J. 2011. The U-Pb and Hf isotope evidence of detrital zircons of the Ordovician Ollantaytambo Formation, southern Peru, and the Ordovician provenance and paleogeography of southern Peru and northern Bolivia. *Journal of South American Earth Sciences* 32, 196-209.
- Bouvier, A., Vervoort, J. D., Patchett, J. 2008. The Lu–Hf and Sm–Nd isotopic composition of CHUR: Constraints from unequilibrated chondrites and implications for the bulk composition of terrestrial planets. *Earth and Planetary Science Letters* 273 (1-2), 48-57.
- Bruno H., Elizeu V., Heilbron M., Valeriano C.M., Strachan R., Fowler M., Bersan S., Moreira H., Dussin I., Silva L.G.E.S., Tupinambá M., Almeida J., Neto C., Storey C. 2020. Neoarchean and Rhyacian TTG-Sanukitoid suites in the southern São Francisco Paleocontinent, Brazil: Evidence for diachronous change towards modern tectonics. *Geoscience Frontiers* 11 (5), 1763-1787.
- Bruno, H., Heilbron, M., Valeriano, C.M., Strachan, R., Fowler, M., Bersan, S., Moreira, H., Motta, R., Almeida, J., Carvalho, M., Storey, C. 2021. The Rhyacian Minas-Bahia Orogen, southern São Francisco Paleocontinent, Brazil: evidence for a complex accretionary history preceding the amalgamation of Columbia. *Gondwana Research* 92, 149-171.
- Guitreau M. 2012. Les Isotopes de l'Hafnium Dans les TTG et Leurs Zircons: Témoins de la croissance des premiers continents. 2012. (Unpublished PhD Thesis). École Normale Supérieure de Lyon, France.
- Hammer, O., Harper, D.A.T., Ryan, P.D. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica* 4(1): 9pp. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

- Paton, C., Hellstrom, J., Paul, B., Woodhead, J., Hergt, J., 2011. Iolite: freeware for the visualisation and processing of mass spectrometric data. *J. Anal. At. Spectrom.* 26, 2508.
- Rousseeuw, P.J. and Van Driessen, K. (1999) A Fast Algorithm for the Minimum Covariance Determinant Estimator. *Technometrics*, 41, 212-223.
- Spencer, C.J., Kirkland, C.L., Prave, A.R., Strachan, R.A., Pease, V. 2019. Crustal reworking and orogenic styles inferred from zircon Hf isotopes: Proterozoic examples from the North Atlantic region. *Geoscience Frontiers* 10 (2), 414 -424.
- Spencer, C.J., Kirkland, C.L., Roberts, N.M.W., Evans, N.J., Liebmann, J. 2020. Strategies towards robust interpretations of in situ zircon Lu–Hf isotope analyses. *Geoscience Frontiers* 11 (3), 843 – 853.
- Teixeira, W., Oliveira, E.P., Marques, L.S. 2017. Nature and Evolution of the Archean Crust of the São Francisco Craton. In: Heilbron M., Alkmim F., Cordani U.G. (Guest Ed.), *The São Francisco Craton and its margins, Eastern Brazil. Regional Geology Review Series. Springer-Verlag*, Chapter 3, 29-56.
- Wiedenbeck M., Allé P., Corfu F., Griffin W.L., Meier M., Oberli F., Von Quadt A., Roddick J.C., Spiegel W. 1995. Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analysis. *Geostand. Newsl.* (1995), pp. 1-23
- Zumel, N. AND MOUNT, J. *Practical data science with R*. Shelter Island, NY: Manning Publications Co., 2014.