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Corresponding Author: Professor Maurizio Mazzucchelli, Full Professor

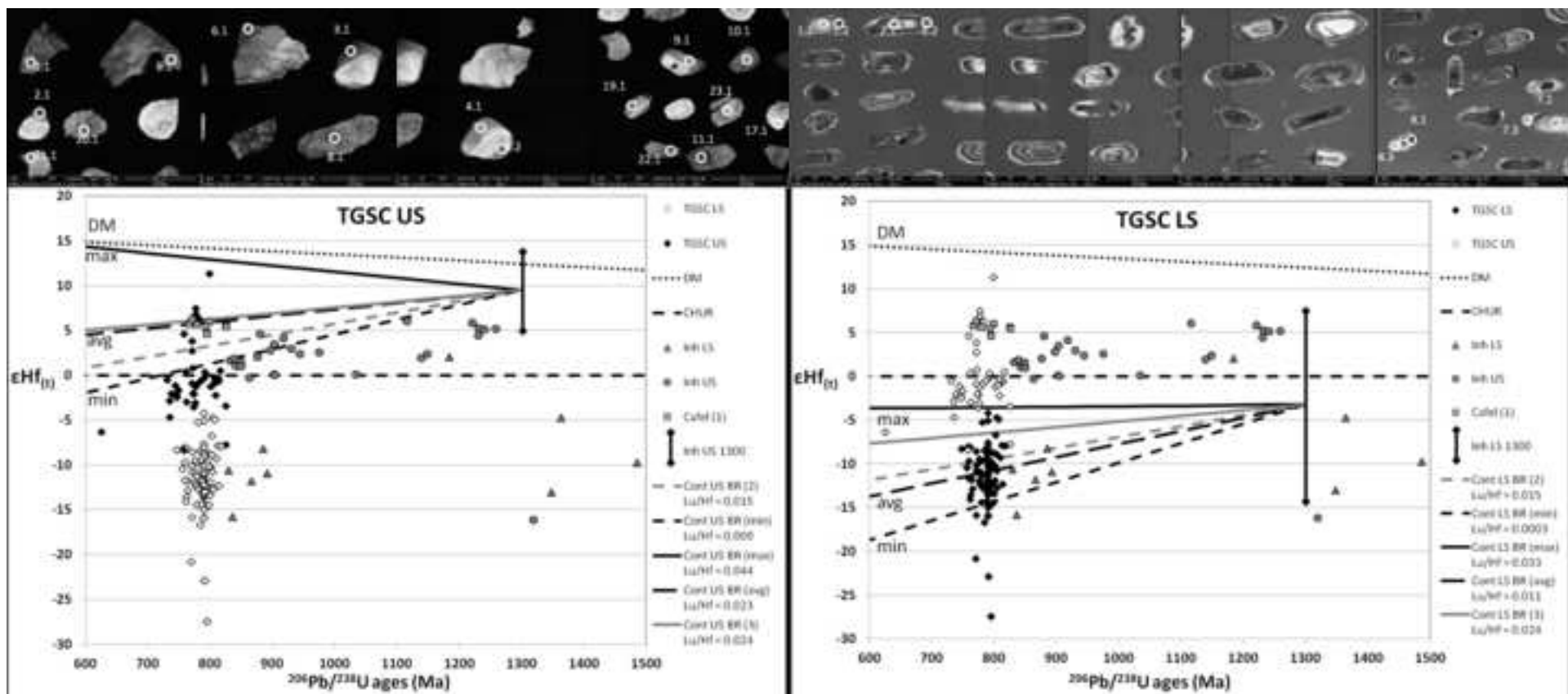
Corresponding Author's Institution: Università di Modena e Reggio Emilia

First Author: Tommaso Giovanardi

Order of Authors: Tommaso Giovanardi; Maurizio Mazzucchelli, Full Professor; Federico Lugli; Vicente Girardi, Full Professor; Ciro Correia, Professor; Colombo Tassinari, Full Professor; Anna Cipriani, Professor

Abstract: The Cana Brava, Niquelândia and Barro Alto complexes (Goiás, central Brazil) are three of the largest mafic-ultramafic layered complexes in the world. Recent geochemical, geochronological and structural evidences have constrained their origin from a single intrusion (i.e. the Tonian Goias Stratiform Complex), however, still debated is the style and source of contamination of the two sequences that characterize the complex. New in situ Lu-Hf zircon data suggest a strong crustal contamination of the Lower Sequence, but coherent with literature bulk-rock Rb-Sr and Sm-Nd systematics in Cana Brava and Niquelandia. The extremely low Hf isotope ratios are consistent with contamination from meta-pelitic and calc-silicate rocks found as xenoliths within the LS. The Upper Sequence zircons are characterized by more primitive Hf isotope ratios than the LS and in the scientific community have been largely considered uncontaminated. Our geochemical evaluation and modelling suggests that the US zircons have been affected by contamination from mantle-derived melts, which was masked in the Rb-Sr and Sm-Nd systematics, but in agreement with amphibolite xenoliths presence in the US stratigraphy. The Hf isotope composition of inherited zircons in both LS and US supports this hypothesis, showing negative $\epsilon_{\text{Hf}}(t)$ values in inherited zircons from the LS and positive, mantle-derived $\epsilon_{\text{Hf}}(t)$ values in inherited zircons from the US.

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Highlights

- Lu-Hf systematics of zircons from the Tonian Goiás Stratiform Complex
- Contaminants have crustal affinity in the LS and MORB-like affinity in the US
- Hf isotopes reveal interaction between melts and rocks with similar affinity

1 **The Tonian Goias Stratiform Complex: Lu-Hf isotopes evidences of crustal MORB**
2 **contamination in mantle-derived melts.**

3

4 Tommaso Giovanardi^{1,2}, Maurizio Mazzucchelli², Federico Lugli², Vicente A.V. Girardi¹, Ciro T.
5 Correia¹, Colombo C.G. Tassinari¹, Anna Cipriani^{2,3}.

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7 1 Instituto de Geociências, Universidade de São Paulo, Rua do Lago 562, Cidade Universitária, B-
8 05508-900, São Paulo, Brazil; e-mail: maurizio.mazzucchelli@unimore.it

9 2 Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Via
10 Campi 103, I-41125 Modena, Italy;

11 3 Lamont Doherty Earth Observatory of Columbia University, Palisades, New York, 10964, USA.

12

13 **Abstract**

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17 Stratiform Complex), however, still debated is the style and source of contamination of the two
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22 Sequence zircons are characterized by more primitive Hf isotope ratios than the LS and in the
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29

30

31 **Keywords**

32 layered complex; contamination; Lu-Hf; zircon; Goias

33

34 **Introduction**

35 The Tonian Goias Stratiform Complex (TGSC hereafter) is a large intrusion discontinuously
36 outcropping along c.a. 350 km in a NNE trend within the Brasilia Belt (northern Goias, central
37 Brasil; Giovanardi et al., 2017a, b). It consists of three major fragments (formerly known as Barro
38 Alto, Niquelândia and Cana Brava, from S to N), only recently identified as one large intrusive
39 event (Giovanardi et al., 2017a, b).

40 A longstanding debate exists over the degree of contamination of the lower and upper sequences
41 (LS and US hereafter) of the TGSC. While the LS is formed by ultramafics and gabbros showing
42 increasing crustal contamination along the stratigraphy (Correia et al., 1997, 2012; Rivalenti et al.,
43 2008; Giovanardi et al., 2017a), the US consists of anorthosites and olivine-gabbros and is
44 considered uncontaminated (Rivalenti et al., 2008; Correia et al., 2012). This difference between the
45 two units has generated two opposite models of formation: the two-intrusions model, where the LS
46 and US are considered separated intrusions of Neoproterozoic and Mesoproterozoic ages,
47 respectively (Pimentel et al., 2004, 2006; Ferreira Filho et al., 2010; Della Giustina et al., 2011) and
48 the one-intrusion model, in which the US crystallized from an anorthositic melt segregated from the
49 precipitation of the LS ultramafics (Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al.,
50 2017b).

51 Literature Sr and Nd isotope ratios show a general increase of crustal contamination along the LS,
52 reaching its maximum in correspondence of the LS top ($^{87}\text{Sr}/^{86}\text{Sr}_{(t)}$ from 0.706605 up to 0.736590;

53 $\epsilon\text{Nd}_{(t)}$ from 1.7 down to -8.5; Correia et al., 1997, 2012; Giovanardi et al., 2017a), where dispersed
54 xenoliths from the country metavolcanic-metasedimentary sequence are common (Girardi and
55 Kurat, 1982; Girardi et al., 1981, 1986; Correia et al., 2012; Giovanardi et al., 2017a). Conversely,
56 along the US stratigraphy the Sr and Nd isotopes show almost constant values with mantle-derived
57 affinities and have led to the idea that these are mantle values and therefore the US is not
58 contaminated ($^{87}\text{Sr}/^{86}\text{Sr}_{(t)}$ from 0.702034 up to 0.704293; $\epsilon\text{Nd}_{(t)}$ from 8.0 down to 4.9; Rivalenti et
59 al., 2008; Correia et al., 2012). However, several metabasaltic and amphibolitic xenoliths are
60 dispersed in the sequence and this led us to believe that also the US must be contaminated.
61 Therefore, new Lu-Hf isotopic analyses of zircons were carried out to constrain the contamination
62 of LS and US in the three fragments of the TGSC. Analyses were also performed on previously
63 SHRIMP U-Pb dated zircons from Giovanardi et al. (2017b) and Correia et al. (2007, 2012).
64 Moreover, new U-Pb and trace elements analyses were carried out to evaluate chemical variations
65 between inherited and magmatic zircons and to expand the U-Pb dataset on poorly-evaluated
66 samples.

67

68 **Geological setting**

69 The Tonian Goiás Stratiform Complex (TGSC) is formed by three separated layered mafic-
70 ultramafic intrusions known as Barro Alto, Niquelândia and Cana Brava complexes outcropping in
71 the Goiás state (central Brazil). The TGSC forms a c.a. 350 km discontinuous belt with NNE
72 direction within the Brasília Belt (Fig. 1) and is part of the Goiás Massif. This is an exotic terrane,
73 or microcontinent, disrupted and accreted to the São Francisco craton during the Neoproterozoic
74 Brasiliano/Panafrican event that led to the formation of the Gondwana supercontinent (Brito Neves
75 and Cordani, 1991; Pimentel and Fuck, 1992; Fuck et al., 1994; Pimentel et al., 2000).

76 The TGSC overthrusts to the E the rocks of the Rio Maranhão Thrust Zone, and to the W it is in
77 magmatic contact with a metavolcanic-metasedimentary sequence. The latter is named as
78 Palmeirópolis, Indaianópolis and Juscelândia when in contact respectively with Cana Brava,

79 Niquelandia and Barro Alto (Figs. 2, 3 and 4). The TGSC has a lopolitic structure, thicker in its
80 center (in correspondence of the Niquelandia and the N-S trending part of Barro Alto), where more
81 differentiated units outcrop at its roof, and thinner/tending to disappear at the edges (Cana Brava and
82 the E-W trending part of Barro Alto). The TGSC stratigraphy is divided in two major sequences:
83 the Lower Sequence (i.e. LS), which is common to all fragments, and the Upper Sequence (i.e. US),
84 which outcrops only in Niquelandia and in the N-S portion of Barro Alto.

85 Starting from the E, the LS of the TGSC is made up by the following units (Figs. 2, 3 and 4):

86 i) Lower Mafic Zone (LMZ), formed by gabbros mainly recrystallized in micro and mylonitic
87 textures and/or epidote-bearing amphibolites. The recrystallization of this unit is interpreted to be
88 the consequence of the tectonic emplacement of the complexes over the Rio Maranhão Thrust Zone,
89 with a pervasive percolation of fluids in the lower units of the TGSC (Girardi et al., 1986; Correia
90 and Girardi, 1998; Correia et al., 1999; Biondi, 2014).

91 ii) Ultramafic Zone (UZ), formed by serpentinites interlayered with amphibolites and subordinated
92 gabbros and pyroxenites. Serpentinites and amphibolites originated from the percolation of fluid
93 within peridotites (serpentinites) and pyroxenites, and gabbros (amphibolites). Primary cumulus
94 textures are commonly preserved in these rocks. Approaching the top of the unit, the
95 recrystallization decreases and pyroxenites become predominant. The top of the unit consists of
96 pyroxenites (mainly websterites and subordinate orthopyroxenites) interlayered with gabbros. The
97 transition to the upper unit is characterized by an increase of gabbros and decrease of pyroxenite
98 layers.

99 iii) Mafic Zone (MZ), formed by gabbros, gabbro-norites and norites. Hydrous minerals (i.e.
100 amphibole and biotite) abundance increases discontinuously along the stratigraphy, reaching its
101 maximum at the top of the unit (named by Girardi et al., 1986, as the 'Hydrous Zone' in
102 Niquelândia). Discontinuous outcrops of diorites, sometimes containing garnet, occur in the
103 sequence. Rocks of this unit are commonly recrystallized and show a foliation parallel to the TGSC
104 direction. Recent studies have demonstrated that this super-imposed foliation formed during the

105 cooling of the TGSC, from hyper- to sub-solidus, under deformative conditions. In this unit,
106 xenoliths from the upper metavolcanic-metasedimentary sequence occur. The first xenolith
107 occurrence consists of decametres-long quartzite layers parallel to the foliation of the TGSC,
108 recognized in both Niquelândia and Cana Brava. Along the stratigraphic succession, xenoliths
109 diminish their dimensions and change in composition. They are amphibolites, garnet-bearing
110 amphibolites, gneisses, metapelite and calc-silicate rocks. Xenoliths maximum abundance is at the
111 top of the MZ (Correia et al., 2012; Giovanardi et al., 2017a).

112 The US is organized in the following units:

113 iv) Upper Gabbro-Anorthosite Zone (UGAZ), formed by olivine gabbros grading into anorthosites
114 and troctolites with local occurrence of layers and lenses of subophitic coarse grained isotropic
115 gabbros.

116 v) Upper Amphibolite (UA), formed by amphibole-bearing gabbros interlayered with amphibolites,
117 epidote-bearing gneisses and/or other lithologies of the metavolcanic-metasedimentary country
118 sequences.

119 The contact with the stratigraphic upper metavolcanic-metasedimentary sequences (i.e.
120 Palmeirópolis, Indaianópolis and Juscelândia) is magmatic in all the complexes and in both LS and
121 US (Girardi and Kurat, 1982; Girardi et al., 1986; Correia and Girardi, 1998; Ferreira Filho et al.,
122 2010).

123 The Palmeirópolis, Indaianópolis and Juscelândia sequences are considered fragments of the same
124 crustal sequence (Ferreira Filho et al. 2010 and references therein), showing similar stratigraphy
125 and lithologies. Among the three, the Palmeirópolis Sequence, in contact with Cana Brava, is the
126 largest (c.a. 80 km long and up to 35 km wide).

127 This crustal unit is formed by successions of metasedimentary rocks (i.e. metacherts, metapelites
128 and calc-silicate rocks) with interbedded metavolcanics (i.e. amphibolites, gneisses and intrusive
129 and sub-volcanic granites; Brod and Jost 1991; Araújo et al. 1995; Araújo 1996; Moraes and Fuck
130 1994, 1999; Moraes et al. 2003, 2006; Ferreira Filho et al. 2010). The metavolcanics have a

131 compositional variability, from E-MORB to N-MORB geochemical affinity, interpreted to suggest
132 a transitional setting from a continental rift to an aborted ocean basin (Araújo, 1996; Moraes et al.
133 2003, 2006). Geochronological data on the metavolcanic rocks point to a Mesoproterozoic age
134 between 1.26-1.30 Ga for the magmatic event (Pimentel et al., 2000; Moraes et al., 2006; Ferreira
135 Filho et al., 2010). Rocks of the crustal sequence show a metamorphic recrystallization from
136 greenschist-facies in the W to amphibolite-facies, locally up to granulite-facies, near the contacts
137 with the TGSC (Moraes and Fuck, 1994; Araújo 1996; Moraes et al. 2003, 2006; Ferreira Filho et
138 al. 2010).

139

140 **Samples**

141 4 samples from Cana Brava, 3 from Barro Alto and 3 from Niquelândia were selected for analyses
142 in zircons of the Lu-Hf and U-Pb isotope systematics. Some of these samples were already
143 investigated for U-Pb analysis (Correia et al., 2007, 2012; Giovanardi et al., 2015, 2017b). When
144 possible, Lu-Hf analyses were carried out onto the same crystals and domains analyzed for U-Pb.
145 The sample list, with position and references, is reported in Table 1.

146 Samples from Cana Brava (named CB) are three gabbros (samples CB1100, CB1175 and CB1382)
147 and one diorite (sample CB1030) from the LS (Fig. 2). U-Pb SHRIMP ages from the three samples
148 were discussed in Giovanardi et al. (2017b). Samples CB1175 and CB1382 are hydrous
149 granoblastic gabbros with foliation parallel to the complex direction derived by the alignment of
150 pyroxenes and plagioclases. Amphibole is the most abundant hydrous phase and is often associated
151 with biotite. K-feldspar and quartz are minor phases and apatite, spinel and zircon are accessories.
152 Sample CB1100 is a non-foliated gabbro. Differently from the others, it is almost anhydrous,
153 containing only minor amounts of amphibole, but it is enriched in spinel. Diorite sample CB1030 is
154 enriched in orthopyroxene, K-feldspar and quartz with respect to the gabbros. Biotite is the major
155 hydrous phase while amphibole occurs as accessory together with apatite, titanite and zircon.

156 Zircons from Cana Brava samples commonly show sub-euhedral habits and cathodoluminescence
157 (CL hereafter) internal structures with black cores and a brighter magmatic oscillatory zoning
158 (Giovanardi et al., 2017b). Sometimes bright rim domains with superimposed accretion reabsorb the
159 oscillatory zoning. Anhedral zircons are rare and commonly show irregular chaotic zoning and
160 superimposed domains (Giovanardi et al., 2017b).

161 Samples from Niquelandia (named NQ) are one gabbro from the LS (sample NQ1549) and two
162 anorthosites from the US (samples NQ1551 and NQ1552). The latter have been previously
163 sparingly dated by U-Pb SHRIMP (Correia et al., 2012 sample NQ1551, and Correia et al. 2007
164 sample NQ1552). Sample NQ1549 is a foliated hydrous gabbro from the top of the LS, outcropping
165 near a gneiss septa, and with a granoblastic texture (Fig. 3). Amphibole is the major hydrous phase
166 while biotite is accessory together with spinel and zircon. $\epsilon\text{Nd}(t)$ value at -6.3 shows crustal
167 contamination (Correia et al., 2012). Samples NQ1551 and NQ1552 are anorthosites with
168 granoblastic texture. They are formed by c.a. 95 % by Vol. of plagioclase with minor amount of
169 amphibole, epidote, scapolite and zircon.

170 Zircons from sample NQ1549 are similar to those from the Cana Brava gabbros. Description is
171 provided in the 'Results' chapter together with zircons from sample NQ1552. Zircons from sample
172 NQ1551 were divided in three groups (Correia et al., 2012): i) rounded anhedral zircons and
173 xenocrystal cores, ii) euhedral to sub-euhedral crystals with rhythmic zoning or domains and iii)
174 fragments.

175 Samples from Barro Alto (named BA) are one gabbro (sample BA06T) from the LS and two
176 anorthosites (samples BA01T and BA1541) from the US (Fig. 4). U-Pb SHRIMP data from
177 samples BA06T and BA01T are reported in Giovanardi et al. (2017b) while seven analyses are
178 reported for sample BA1541 by Correia et al. (2007). Sample BA06T is a coarse-grained stratified
179 hydrous gabbro. Stratification is parallel to the complex direction and is formed by the alternance of
180 pyroxenes and amphibole layers with plagioclase layers (Giovanardi et al., 2017b). Spinel is
181 abundant in the femic layers while zircon occurs as accessory. Samples BA01T and BA1541 have

182 granoblastic textures and plagioclase is more than 90% by Vol (Correia et al., 2007). Minor
183 amounts of clinopyroxene and amphibole occur as interstitial phases along deformative structures
184 (Giovanardi et al., 2017b). Apatite, rutile, epidote and zircon occur as accessory phases.
185 Zircons from sample BA06T are euhedral to sub-euhedral, with commonly dark cores and
186 magmatic oscillatory zoning/domains in CL. Rim zoning is commonly brighter than cores. Zircons
187 from sample BA01T are commonly anhedral, with few crystals sub-euhedral. CL internal structures
188 are commonly erased, appearing as homogeneous grey areas, while in few grains a dark core is
189 surrounded by chaotic overgrowth structures.

190

191 **Analytical methods**

192 Zircons were separated after crushing, milling, magnetic and heavy liquid separation, and hand
193 picking and embedded in resin. After Au-coating, the polished mounts were comprehensively
194 examined with a FEI-QUANTA 250 scanning electron microscope equipped with secondary-
195 electron and cathodoluminescence (CL) detectors at IGc-CPGeo-USP; the most common conditions
196 used in CL analysis were 60 μ A of emission current, 15.0 kV of accelerating voltage, 7 μ m of beam
197 diameter, 200 μ s of acquisition time, and a resolution of 2048x1887 pixels and 345 dpi. Some
198 samples were also analyzed by the U-Pb isotopic technique using a SHRIMP-IIe machine also at
199 IGc-CPGeo, Universidade de São Paulo, following the analytical procedures presented in Williams
200 (1998). Correction for common Pb was made based on the ^{204}Pb measured, and the typical error
201 component for the $^{206}\text{Pb}/^{238}\text{U}$ ratio is less than 2%; U abundance and U-Pb ratios were calibrated
202 against the TEMORA-II standard. The dataset consists of 56 U-Pb SHRIMP-II analyses and is
203 reported in Supplementary Material A. 24 analyses were performed on zircons from the US
204 anorthosite of Barro Alto (sample BA1541) and 32 analyses were carried on zircons from
205 Niquelândia, 16 for sample NQ1549 (a gabbro from the top of the LS) and 16 for sample NQ1552
206 (an anorthosite from US). For all samples, $^{207}\text{Pb}/^{235}\text{U}$ and $^{206}\text{Pb}/^{238}\text{U}$ concordia age (with 95% of
207 confidence level and 2σ error) are calculated using Isoplot© 4.1 software (Ludwig, 2009).

208 In situ Lu–Hf isotope analyses were performed at the Centro Interdipartimentale Grandi Strumenti
209 (CIGS) of the University of Modena and Reggio Emilia (Italy) using a double focusing MC–ICP–
210 MS with a forward Nier–Johnson geometry (Thermo Fisher Scientific, Neptune™), coupled to a
211 213 nm Nd:YAG laser ablation system (New Wave Research™).

212 During the analytical session, two zircon reference materials (TEMORA-2 and CZ3) were
213 employed to check the accuracy and the precision of the measurements. Eight of nine Faraday
214 detectors were used to collect the following masses: 171Yb, 173Yb, 175Lu, 176Hf+Lu+Yb, 177Hf,
215 178Hf, 179Hf, 180Hf.

216 Laser data were acquired in static mode with a block of 250 cycles (including laser warm-up, ~50–
217 80 cycles of analysis and wash-out), an integration time of 0.5 s, a laser spot of 55 μm and a fluence
218 of ~10 J/cm². A low laser frequency (~10 Hz) was used to achieve a better signal stability (Vroon et
219 al. 2008) with a He flux of ~0.5 L/min. Before each analysis, the surface of the zircon was pre-
220 ablated with a spot size of 60 μm.

221 Data reduction was performed with the Hf-INATOR excel spreadsheet (Giovanardi & Lugli, 2017).
222 TEMORA-2 yielded a ¹⁷⁶Hf/¹⁷⁷Hf ratio of 0.282689 ± 0.000080 (2σ; n = 37), identical within the
223 error to the reference value of 0.282693 (Matteini et al., 2010); similarly, CZ3 yielded a ¹⁷⁶Hf/¹⁷⁷Hf
224 ratio of 0.281722 ± 0.000027 (2σ; n = 20; reference value: 0.281729; Wu et al., 2006). The entire
225 dataset resulting from the analyses of our zircon samples consists in 145 analyses reported in
226 Supplementary Material B and average of magmatic and inherited zircons for each sample are
227 reported in Table 2. When possible, Lu–Hf analyses were carried out within the same domain of U–
228 Pb analyses. Lu–Hf data have been recalculated to 790 Ma, considering this age as the best
229 representative for the complexes intrusion. Data were recalculated using the (¹⁷⁶Hf/¹⁷⁷Hf)_{CHUR} and
230 (¹⁷⁶Lu/¹⁷⁷Hf)_{CHUR} present-day values as 0.282772 and 0.0332 from Blichert-Toft and Albarede
231 (1997).

232 U–Pb in situ analyses were also replicated at the CIGS of the University of Modena and Reggio
233 Emilia on several zircons already investigated through SHRIMP analyses. Analyses were carried

234 out coupling the laser ablation system to a quadrupole ICP-MS X Series II (Thermo Fisher
235 Scientific) and employing a laser spot size of 40 μm , a repetition rate of 10 Hz and a fluence of 10
236 J/cm^2 . The ICP-MS was tuned using NIST612 glass reference material to optimize the signal
237 intensity and stability, checking ^{139}La , ^{238}U and the $^{238}\text{U}/^{232}\text{Th}$ ratio. The oxide production within
238 the plasma was monitored employing the $^{232}\text{Th}^{16}\text{O}/^{232}\text{Th}$ ratio, constantly kept below 0.01%.
239 Acquired masses were 202Hg, 204Pb(+204Hg), 206Pb, 207Pb, 208Pb, 232Th, 235U and 238U.
240 $^{206}\text{Pb}/^{207}\text{Pb}$, $^{207}\text{Pb}/^{235}\text{U}$ and $^{206}\text{Pb}/^{238}\text{U}$ ratios were calculated during the analyses. TEMORA-2 and
241 CZ3 were used as known and unknown (respectively) zircon reference materials and bracketed
242 during the analysis. Sample U-Pb ratios were thus corrected for laser induced elemental
243 fractionation using TEMORA-2 as reference. Analyses are reported in Supplementary Material A.
244 Trace element analysis was performed at the CIGS using the same instrumental condition presented
245 for U-Pb determination (e.g. Lugli et al., 2017a; Sforza and Lugli, 2017). The system is equipped
246 with a collision-reaction cell to drastically attenuate polyatomic interferences. Si, Ti, REE and Hf
247 were thus acquired within two analytical sessions. Elemental quantification was performed using
248 NIST 610, 612 and 614 as reference materials and Si as internal standard, previously measured by
249 ion microprobe. Resulting RSD for all the trace element data is always better than 10%. Data are
250 reported in Supplementary Material C.

251 Sr isotopes analyses were determined for 2 samples (Table 3). Plagioclases were handpicked under
252 a microscope and leached, dissolved and separated using standard techniques. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios
253 were measured as 200 ppb solutions by MC-ICP-MS on a Thermo Scientific Neptune housed at the
254 CIGS UNIMORE. Samples and standards were analysed in a static multi-collection mode in a
255 single block of 100 cycles with an integration time of 8 seconds per cycle. The instrumental mass
256 fractionation was corrected for by using a stable isotopic $^{86}\text{Sr}/^{88}\text{Sr}$ ratio of 0.1194 and an
257 exponential law. Repeated analyses of the NBS-987 reference material yielded a mean $^{87}\text{Sr}/^{86}\text{Sr}$
258 ratio of 0.710270 ± 0.000010 (2σ ; $n = 4$). The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were corrected for instrumental bias to
259 an accepted value for the NBS-987 of 0.710260.

260 In situ Sr isotope analyses were performed at the CIGS using the 213 nm laser ablation system and
261 the Neptune MC-ICP-MS (Lugli et al., 2017b). Laser ablation parameters were the same of Hf
262 isotope analyses. We collected the same masses of the dissolution analyses plus mass 85.5 and 86.5
263 to check for the doubly charged Yb interference. Background Kr was corrected measuring 60 s of
264 gas blank with laser switched off. The presence of Ca dimers and argides was also monitored on
265 mass 82 after the Kr subtraction. Isobaric Rb was corrected as for the dissolution analysis. The
266 instrument was tuned for the maximum sensitivity on mass 88, but also checking the accuracy of
267 the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of an in-house reference material (modern marine shell), which yielded a Sr
268 isotopic ratio of 0.709166 ± 0.000039 (2σ ; $n = 4$), in agreement with modern seawater (0.70917).
269 International reference material Jct-1 was also analyzed yielding a $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of $0.709151 \pm$
270 0.000013 (2σ ; $n = 4$). Analyses are reported in Table 3.

271

272 **Results**

273 **Plagioclase Sr isotopes**

274 Plagioclase from gabbro BA06T (LS) and anorthosites BA01T (US) and BA02T (US) have an
275 average Sr concentration of 164 ± 8 ppm, 151 ± 8 ppm and 148 ± 9 ppm, respectively, calculated on
276 30 LA-ICP-MS analyses each. Rb average concentration is 0.5 ± 0.4 ppm in sample BA06T, $0.2 \pm$
277 0.1 ppm in sample BA01T and 0.3 ± 0.4 ppm in BA02T, with Rb/Sr ratios of 0.0030, 0.0011 and
278 0.0020, respectively.

279 LS gabbro BA06T show a solution $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.729226 ± 0.000012 and an in situ $^{87}\text{Sr}/^{86}\text{Sr}$
280 ratio of 0.729948 ± 0.000125 (2σ ; average of 3 analyses). The solution $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of US
281 anorthosite BA02T is 0.702368 ± 0.000012 , the in situ $^{87}\text{Sr}/^{86}\text{Sr}$ is 0.702444 ± 0.000329 (2σ ;
282 average of 3 analyses). US anorthosite BA01T was not analysed in solution, but the in situ $^{87}\text{Sr}/^{86}\text{Sr}$
283 ratio is 0.702452 ± 0.000040 (2σ ; average of 2 analyses), consistent with anorthosite BA02T.
284 Recalculated $^{87}\text{Sr}/^{86}\text{Sr}$ ratios at 790 Ma provide $^{87}\text{Sr}/^{86}\text{Sr}_{(790)}$ ratios of 0.729192 and 0.729914 (in

285 solution and in situ, respectively) for gabbro BA06T, of 0.702355 and 0.702432 (in solution and in
286 situ, respectively) for anorthosite BA02T and of 0.702430 (in situ) for anorthosite BA01T.
287 The Sr isotope ratios of LS gabbro BA06T are consistent with literature bulk-rock data from the
288 upper MZ (i.e. the Hydrous Zone) of Cana Brava and Niquelandia, with $^{87}\text{Sr}/^{86}\text{Sr}_{(790)}$ ratios between
289 0.721461 and 0.736590 (Correia et al., 2012; Giovanardi et al., 2017a; Fig. 5). Similarly, Sr
290 isotopes from US anorthosites BA01T and BA02T are consistent with bulk rock literature data from
291 the Niquelandia US, with $^{87}\text{Sr}/^{86}\text{Sr}_{(790)}$ ratios between 0.702243 and 0.702839 (Correia et al., 2012;
292 Fig. 5).

293

294 **U-Pb zircon geochronology**

295 *Barro Alto US anorthosite (sample BA1541)*

296 Sample BA15-41 is an anorthosite from the Barro Alto US located near the contact with the
297 Juscelandia Sequence. Zircons from sample BA1541 could be divided in two groups. The first
298 includes anhedral to sub-euhedral extremely fractured zircons which in CL show almost
299 homogeneous medium emission suggesting a complete recrystallization (Fig. 6). The second group
300 is formed by anhedral crystals which in CL show extremely bright core domains and a discordant
301 darker rim growth with poor or no zonation (Fig. 6).

302 Twentyfour U-Pb analyses were performed on 23 zircons from sample BA1541. Zircons from
303 sample BA1541 yielded twenty one concordant ages ranging between 863 ± 15 Ma and 731 ± 26
304 Ma ($^{206}\text{Pb}/^{238}\text{U}$ single spot age, 1σ error), with a weighted average of 774 ± 12 Ma (95% confidence
305 error level, MSWD = 2.2; Fig. 6) and a concordia age of 780 ± 10 Ma (95% confidence error level,
306 decay-const. errs included, MSWD = 0.48, probability of concordance = 0.49; Fig. 6). Two
307 discordant ages were discarded, but fall within the range. One older concordant $^{206}\text{Pb}/^{238}\text{U}$ single
308 spot age of 1034 ± 19 Ma was also obtained.

309

310 *Niquelândia LS gabbro (sample NQ1549)*

311 Zircons from sample NQ1549 are euhedral to sub-euhedral and commonly show an oscillatory
312 magmatic zonation in CL (Fig. 7). This zonation is sometimes truncated by a discordant, thin bright
313 rim (Fig. 7). Few zircons show an inherited core commonly bright and unzoned in CL (Fig. 7).
314 Sixteen analyses were performed on 7 zircons. Eleven analyses yielded concordant ages ranging
315 between 793 ± 11 Ma and 759 ± 10 Ma ($^{206}\text{Pb}/^{238}\text{U}$ single spot age, 1σ error), with a weighted
316 average of 771 ± 8 Ma (95% confidence error level, MSWD = 1.5; Fig. 7) and a concordia age of
317 772 ± 6 Ma (95% confidence error level, decay-const. errs included, MSWD = 2.8, probability of
318 concordance = 0.09; Fig. 7). A younger discordant analysis gave a $^{206}\text{Pb}/^{238}\text{U}$ single spot age at 756
319 ± 16 Ma. Four concordant analyses from inherited cores provide for older $^{206}\text{Pb}/^{238}\text{U}$ single spot
320 ages between 1364 ± 24 Ma and 1063 ± 21 Ma.

321

322 *Niquelândia US anorthosite (sample NQ1552)*

323 Zircons are anhedral to sub-euhedral and are commonly fractured. Similar to sample BA1541, two
324 different groups are defined with CL images: the first is characterized by unzoned, extremely bright
325 crystals and the second by poor or unzoned crystals with medium emissions and a discontinuous
326 bright rim (Fig. 8).

327 Fifteen Analyses yielded concordant ages ranging between 975 ± 17 Ma and 762 ± 12 Ma
328 ($^{206}\text{Pb}/^{238}\text{U}$ single spot age, 1σ error) with a weighted average of 850 ± 33 Ma (95% confidence
329 error level, MSWD = 18). One discordant age falls in the interval.

330

331 **Lu-Hf zircon data**

332 One-hundred and fortyfive in situ Lu-Hf analyses were performed on zircon grains as follow:
333 fiftytwo analyses on zircons from Cana Brava (CB1030 = 16; CB1175 = 15; CB1382 = 6; CB1100
334 =15), fortythree analyses on zircons from Niquelândia (NQ1549= 20; NQ1552 = 18; NQ1551 = 5)
335 and fifty analyses on zircons from Barro Alto (BA06T = 20; BA01T = 12; BA1541 = 18). When
336 possible, Lu-Hf analyses were carried out in the same domain of U-Pb SHRIMP analyses.

337 Otherwise, the Lu-Hf data have been recalculated to 790 Ma, considering this age as the best
338 representative for the complexes intrusion (Giovanardi et al., 2017b).

339 LS Cana Brava zircons range between $\epsilon\text{Hf}(t)$ -25.1 and -24.8, with an average $\epsilon\text{Hf}(t)$ of -11.68 (Fig.
340 9). In details, analyses on zircons from LS gabbro CB1175 show $^{176}\text{Hf}/^{177}\text{Hf}$ ratios between
341 0.281653 and 0.282153. $\epsilon\text{Hf}(t)$ varies from -12.7 to -4.8 with one single spot showing a lower value
342 at -22.9. Zircons from LS gabbro CB1382 have $^{176}\text{Hf}/^{177}\text{Hf}$ ratios between 0.281911 and 0.282038
343 and $\epsilon\text{Hf}(t)$ values between -14.4 and -9.4. $^{176}\text{Hf}/^{177}\text{Hf}$ ratios in zircons from LS gabbro CB1100 is
344 between 0.281589 and 0.281976. $\epsilon\text{Hf}(t)$ varies between -16.0 to -10.6 with one spot at -25.1. LS
345 diorite CB1030 show $^{176}\text{Hf}/^{177}\text{Hf}$ between 0.28827 and 0.282058 with $\epsilon\text{Hf}(t)$ values between -16.7
346 and -8.5.

347 $^{176}\text{Hf}/^{177}\text{Hf}$ ratios from the LS Barro Alto gabbro (sample BA06T) range between 0.281824 and
348 0.282077. $\epsilon\text{Hf}(t)$ values are between -15.8 and -8.3 (Fig. 9). The US Barro Alto anorthosite BA01T
349 show $^{176}\text{Hf}/^{177}\text{Hf}$ ratios between 0.281523 and 0.282596 with very scattered $\epsilon\text{Hf}(t)$ values ranging
350 from -16.1 to 11.3 (Fig. 9). Conversely, $\epsilon\text{Hf}(t)$ values from US anorthosite sample BA1541 vary
351 between -3.6 and 2.4 (Fig. 9) with $^{176}\text{Hf}/^{177}\text{Hf}$ ratios between 0.282154 and 0.282313.

352 Zircons from LS Niquelândia gabbro NQ1549 show $^{176}\text{Hf}/^{177}\text{Hf}$ ratios between 0.281602 and
353 0.282194 with scattered $\epsilon\text{Hf}(t)$ values varying from -27.6 and 5.9 (Fig. 9). Mesoproterozoic cores
354 show positive values ($\epsilon\text{Hf}(t) = 2.0$ and 5.9) and, commonly, less negative values compared to rims.
355 The US anorthosite NQ1552 zircons have $^{176}\text{Hf}/^{177}\text{Hf}$ ratios between 0.282212 and 0.282363 and
356 $\epsilon\text{Hf}(t)$ values between -3.0 and 4.6 (Fig. 9). The few data from the other US anorthosite, sample
357 NQ1551, are commonly higher ($^{176}\text{Hf}/^{177}\text{Hf}$ between 0.282439 and 0.282501; $\epsilon\text{Hf}(t)$ between 5.3
358 and 7.7; Fig. 9) with one value lower than sample NQ1552 ($^{176}\text{Hf}/^{177}\text{Hf} = 0.282070$; $\epsilon\text{Hf}(t) = -7.7$;
359 Fig. 9).

360 Overall, the LS gabbros from the three complexes show the same $\epsilon\text{Hf}(t)$ range, with values falling
361 below the CHUR array and thus sub-chondritic in composition (Fig. 9). Similarly, zircons from the
362 US samples have mostly overlapping $\epsilon\text{Hf}(t)$ values (Fig. 9). With the exception of zircons from

363 anorthosite NQ1551, samples from US form a decreasing $\epsilon\text{Hf}(t)$ linear trend from older zircons to
364 younger ones (Fig. 9): the $\epsilon\text{Hf}(t)$ values range from positive (older zircons) to slightly negative
365 (younger zircons). With few exceptions, the $\epsilon\text{Hf}(t)$ values of US zircons are less negative than those
366 of the LS samples (Fig. 9).

367

368 **Zircon trace elements**

369 According to the REE abundances, zircons are classified in magmatic (Hoskin et al., 2005) and
370 continental (according to the U/Yb vs Hf discriminant diagram from Grimes et al., 2007). From here,
371 we will use the term 'magmatic' to define those zircons that show ages consistent with the TGSC
372 Neoproterozoic intrusion (i.e. younger than 825 Ma) and with CL structures consistent with their
373 magmatic origin.

374 Magmatic zircons from the TGSC show, in the LS, large variation of LREE (in the order of 3 orders
375 of magnitude for La, Fig. 10) with respect to HREE (less than 1 order for Lu). US zircons are
376 characterized by LREE abundances commonly lower than LS zircons, with the exception of Ce
377 (Fig. 10). An increase in the La content is accompanied by an increase in REE abundances in both
378 LS and US zircons. Zircons in the two sequences show, with the exception of US anorthosite
379 NQ1551, similar REE patterns with comparable pronounced Eu negative anomalies ($(\text{Eu}/\text{Eu}^*)_{\text{N}}$
380 between 0.1 and 0.4). Zircons from US anorthosite NQ1551 have lower ΣREE and less negative Eu
381 anomalies (Fig. 10; $(\text{Eu}/\text{Eu}^*)_{\text{N}}$ between 0.8 and 1.0). Two similar patterns were found in inherited
382 zircons in the US, both in Niquelandia and Barro Alto (Fig. 10), showing $(\text{Eu}/\text{Eu}^*)_{\text{N}}$ between 0.9
383 and 1.3.

384 One magmatic zircon from Barro Alto US and two inherited zircons from US in both Barro Alto
385 and Niquelandia show flat LREE trends with poor/none Ce anomalies (Fig. 10). Similar REE
386 patterns have been recognized in granitoids zircons (Belusova et al., 2002) and hydrothermal
387 zircons (Hoskin and Schaltegger, 2003; Yang et al., 2014).

388 Inherited zircons from US commonly show lower REE abundances than inherited zircons from LS
389 (e.g., Lu between 10 and 55 ppm and between 20 and 143 ppm, respectively). LS inherited zircons
390 have higher LREE contents (e.g., La_N between 0.40-3.33 and 0.04-0.34 respectively) and more
391 pronounced Eu negative anomalies ($(Eu/Eu^*)_N$ between 0.07 and 0.49 and between 0.34 and 1.3
392 respectively).

393

394 **Discussion**

395 *The magmatic affinity of the TGSC*

396 The new Sr isotopes data on plagioclases from the Barro Alto complex show that its US and LS
397 have the same geochemical affinity of Niquelandia and Cana Brava (Fig. 5). These data (together
398 with Nd isotopes from Niquelandia and Cana Brava) suggest that the LS was progressively
399 contaminated during its crystallization by incorporated xenoliths of the upper metavolcanic-
400 metasedimentary sequence. Conversely, the US appears to be uncontaminated, notwithstanding
401 xenoliths occurrences reported in both Niquelandia and Barro Alto (Girardi et al., 1981, 1986;
402 Rivalenti et al., 2008; Correia et al., 2012; Giovanardi et al., 2017a, b), showing Sr isotopic values
403 comparable with mantle-derived melts.

404 Although this isotopic discrepancy suggests that US and LS could be interpreted as two separate
405 intrusions (i.e. the two-intrusions model; Ferreira Filho et al., 2010; Della Giustina et al., 2011 and
406 references therein), U-Pb zircon chronology provides the same intrusion age for the two sequences
407 (Correia et al., 2007, 2012; Giovanardi et al., 2017b). The new U-Pb data in this work reinforce this
408 interpretation, pointing to a Neoproterozoic intrusion age for the TGSC at ~790 Ma, in agreement
409 with the one-intrusion model (Correia et al., 2007, 2012; Giovanardi et al., 2017b).

410 Lu-Hf zircon data from the TGSC produce two almost separated $\epsilon Hf(t)$ fields with US values from
411 slightly negative to positive and much lower LS values ($\epsilon Hf(t)$ from -8.1 up to 11.3 from US
412 magmatic zircons and from -27.5 up to -4.2 from LS magmatic zircons).

413 The higher $\epsilon_{\text{Hf}}(t)$ values of the US zircons suggest a more primitive mantle-derived source for the
414 parent melts of the US zircons with respect to the LS zircons. The negative sub-chondritic values of
415 the LS zircons clearly indicate a strong crustal (mainly detritic) component in the parent melt,
416 which is compatible with the crustal contamination observed with Sr and Nd isotopes.

417 Among the US magmatic zircons, those from anorthosite NQ1551 show the highest $\epsilon_{\text{Hf}}(t)$ (between
418 5.3 and 7.7, with the exception of one zircon from anorthosite BA1541 with a value of 11.3) and
419 lowest REE abundances (Fig.s 9 and 10). Differently from other US zircons, they show a poor/none
420 Eu negative anomaly ($(\text{Eu}/\text{Eu}^*)_{\text{N}}$ between 0.8 and 1.0). The absence of Eu anomaly could be related
421 to i) the different f_{O_2} condition of the parent melt (Trail et al., 2012) or ii) the zircon crystallization
422 before plagioclase precipitation. The lower REE contents with respect to other zircons suggest the
423 second hypothesis. These features suggest that zircons from anorthosite NQ1551 could be
424 considered as the most primitive among the studied ones, thus reflecting the original isotopic
425 composition of the TGSC parent melt.

426 Hf isotopic data from other US zircons exhibit $\epsilon_{\text{Hf}}(t)$ values commonly slightly negative (Fig. 9),
427 which suggest that they crystallized from a contaminated melt similar to LS zircons.

428 The commonly low REE zircons of the US with respect to LS zircons suggest that the US
429 anorthosites formed during the initial stages of the TGSC intrusion considering also that these rocks
430 are formed by >90% of plagioclase and the absence of others HREE-compatible minerals.

431 The new trace element and isotopic data thus support the hypothesis that the US crystallized from
432 an anorthositic melt formed during the segregation of the ultramafic cumulates (i.e. the UZ) during
433 the first stages of the TGSC intrusion (Rivalenti et al., 2008; Correia et al., 2012).

434 Given that Hf isotopes are not easily mobilized in zircons (Kinny and Maas, 2003), the consistent
435 behaviour of Sr and Nd isotopes in bulk rock and Hf ratios in zircons suggest that Sr and Nd
436 systematics in the TGSC are dependant from magmatic contamination/primary nature of the parent
437 melt and were poorly/none affected by later events. According to these isotope data and to other
438 field, petrological and geochronological evidences (Correia et al., 2012; Giovanardi et al., 2017a,

439 b), the two-intrusions model with TGSC recrystallization by granulitic- and amphibolite-facies
440 metamorphic events (also with fluids occurrences, Pimentel et al., 2004, 2006; Ferreira Filho et al.,
441 2010; Della Giustina et al., 2011) must be discarded.

442

443 *Inherited zircons and re-opening processes as revealed from Lu-Hf isotopes*

444 Inherited zircons from LS and US show different elemental and isotopic signatures (Fig.s 9 and 10).
445 Inherited zircons from the LS have higher REE abundances and Eu negative anomaly associated to
446 lower $\epsilon\text{Hf}(t)$ values than US inherited zircons ($\epsilon\text{Hf}(t)$ average of -6.8 and 2.6 respectively) thus
447 suggesting a contamination by a crustal component. These data agree with xenolith occurrences
448 reported in literature, with a stratigraphic variation of xenoliths within the TGSC, from the base of
449 the MZ up to the complex roof. In the MZ, xenoliths are quartzites (near the base of the MZ), meta-
450 pelite, calc-silicatic rocks and subordinate amphibolites (Girardi et al., 1981, 1986; Correia et al.,
451 1997, 2012; Giovanardi et al., 2017a). Xenoliths in the US are amphibolites with subordinate minor
452 amounts of calc-silicatic rocks near the LS-US transition (Girardi et al., 1981, 1986; Correia et al.,
453 1997, 2012; Giovanardi et al., 2017a). Amphibolites have been related to MORB magmatism
454 between 1.26 and 1.30 Ga in connection with the development and abortion of a continental rift
455 (Pimentel et al., 2000; Moraes et al., 2006).

456 Inherited zircons from US show $\epsilon\text{Hf}(t)$ values recalculated to the age of the MORB magmatic event
457 in the metavolcanic-metasedimentary sequence (i.e. 1.3 Ga) comparable with mantle-derived melts
458 between 5.5 and 13.9 with an average of 9.5 (with the exception of a single zircon at -16.5). As
459 expected, recalculated $\epsilon\text{Hf}(t)$ values at the 1.3 Ga magmatic event of LS inherited zircons point to
460 crustal values with an average of -3.2 showing a wide range between -14.1 and 7.6. This range
461 reflects the lithological variability of the LS xenoliths, while the low xenolith diversity in the US
462 results in a narrow Hf isotope range.

463 The linear trend formed by the US inherited zircons $\epsilon\text{Hf}(t)$ values with $^{206}\text{Pb}/^{238}\text{U}$ ages (Fig. 9)
464 suggests that these zircons suffered a re-opening of the system, which caused Pb loss and age

465 rejuvenation (Vervoot and Kempt, 2016). The LS inherited zircons $\epsilon\text{Hf}(t)$ values plotted with U/Pb
466 ages do not show a well-defined trend as for the US inherited zircons. Their lack of data along the
467 time interval between the 1.3 Ga magmatism and the 790 Ma TGSC intrusion could be the result of
468 a more efficient Pb loss process than for the US inherited zircons. This hypothesis is supported by
469 the absence, between the 1.3 Ga magmatism and the TGSC intrusion age, of other recognized
470 magmatic events in the upper metavolcanic-metasedimentary sequence. Moreover, REE trends of
471 inherited zircons in both US and LS are similar to the magmatic ones (Fig. 10), suggesting the re-
472 equilibration of these elements with the TGSC parent melt. In this scenario, the re-opening of the
473 zircon system occurred during the zircon residence in the magmatic chamber.
474 Conversely, the flat-LREE patterns of few zircons from US, comparable with hydrothermal zircons,
475 suggest re-equilibration processes occurring locally after the TGSC crystallization. The
476 hydrothermal nature of this re-equilibration process, the low number of such zircons and their
477 occurrence only in the US suggest that this process is related to local tectonism (visible in the many
478 faults and shear zones in the area), possibly related to the bending/exhumation of the complex,
479 estimated at c.a. 650 Ma by U-Pb zircon discordant ages and rutile analyses (Ferreira Filho et al.,
480 1994, 1998; Giovanardi et al., 2017b).

481

482 *Contamination of the TGSC: Lu-Hf isotopes constraints*

483 Rb-Sr and Sm-Nd isotopes suggested that while the LS was strongly contaminated by xenoliths
484 from the metavolcanic-metasedimentary sequence, the US seemed unaffected by contamination
485 (Fig. 5; Rivalenti et al., 2008; Correia et al., 2012). Accordingly, zircon Hf isotopes of the LS and
486 US plot into two almost distinct fields (Fig. 9).
487 LS Hf zircon isotope ratios are consistent with crustal contamination as shown by other systematics
488 (Fig. 9). Likewise, the LS inherited zircons show negative $\epsilon\text{Hf}(t)$ values, which are consistent with
489 the crustal origin of the contaminants. The Hf isotopic variability of the US zircons provides for
490 positive to negative $\epsilon\text{Hf}(t)$ values and suggests that part of the US suffered contamination similar to

491 LS: the two fields slightly overlap and provide a unique trend of contamination from the US to the
492 LS (Fig. 9). The commonly slightly negative $\epsilon\text{Hf}(t)$ values of magmatic US zircons (with the
493 exception of sample NQ1551 and few others) do not resemble mantle-derived melts, which usually
494 have positive $\epsilon\text{Hf}(t)$ (Kemp et al., 2006; Hawkesworth and Kemp, 2006). Inherited US zircons also
495 show an evolutionary trend related to the U-Pb system re-opening, which suggest negative $\epsilon\text{Hf}(t)$
496 values at the time of their incorporation within the US.

497 Because Hf isotopes are immobile in zircons (Kinny and Maas, 2003), variations in their Hf
498 isotopic composition are constrained by variations in the composition of the melt. The different
499 lithologies of the xenoliths recognized in US and LS suggest that the contamination of the two
500 sequences is related to the contaminant composition: continental/detrital crustal contaminant for the
501 LS, where xenoliths are meta-sedimentary rocks, and MORB-like contaminant for the US, where
502 xenoliths are amphibolites related to mantle-derived melts.

503 As discussed above, zircons from anorthosite NQ1551 show the most primitive geochemical and Hf
504 isotopic features and could be considered as a proxy of the uncontaminated Hf isotopic values of the
505 TGSC parent melt.

506 Considering the $^{176}\text{Hf}/^{177}\text{Hf}(t)$ of inherited zircons as a proxy of the initial Hf isotopic value of the
507 rock at its time of formation we calculated the average $^{176}\text{Hf}/^{177}\text{Hf}_{(1300)}$ of inherited zircons as the
508 bulk rock contaminant, which averages at 0.281866 for LS and at 0.282224 for the US (Fig. 11).
509 For the US average calculation, a single zircon with $^{176}\text{Hf}/^{177}\text{Hf}_{(1300)}$ of 0.281490 and $\epsilon\text{Hf}_{(1300)}$ of -
510 16.5 ($^{206}\text{Pb}/^{238}\text{U}$ age at 1319 Ma) was discarded as clearly inherited from a detrital/sedimentary
511 rock. Metasedimentary xenoliths can also be found in the US, however, they are largely
512 subordinated to amphibolites.

513 Contaminants in the LS are mainly metasediments whose ages are still uncertain. To better
514 compare the data and evolution trends between LS and US contaminants, we recalculated the
515 $^{176}\text{Lu}/^{177}\text{Hf}(t)$ of the contaminants at the age of the MORB volcanic activity in the country sequence
516 (i.e., the age of formation of amphibolites) at 1.3 Ga (Moraes et al., 2003, 2006). The $^{176}\text{Lu}/^{177}\text{Hf}$

517 ratio of the bulk rock of the contaminants was estimated using the Bulk Continental Crust of 0.015
518 (Griffin et al., 2002) and the average of MORB at 0.024 (Stracke et al., 2003) for both sequences
519 (Fig. 11). For the LS, evolution trends for the contaminant bulk rock were also calculated using
520 $^{176}\text{Lu}/^{177}\text{Hf}$ ratios obtained from bulk rock analyses of the LS metasedimentary xenoliths
521 ($^{176}\text{Lu}/^{177}\text{Hf}$ min = 0.0003, max = 0.033 and avg = 0.011; recalculated data using the 0.1419
522 constant of conversion from Blichert-Toft et al., 1998; bulk rock analyses from Correia et al., 2012).
523 For the US, $^{176}\text{Lu}/^{177}\text{Hf}$ ratios were obtained from bulk rock analyses of the amphibolites of the
524 metavolcanic-metasedimentary sequence ($^{176}\text{Lu}/^{177}\text{Hf}$ min = 0.009, max = 0.044 and avg = 0.023;
525 bulk rock analyses from Moraes et al., 2003). The similarities between the $^{176}\text{Lu}/^{177}\text{Hf}$ average
526 ratios calculated for the US and LS contaminants with the average MORB and Bulk Continental
527 Crust are consistent with contamination processes in both sequences, but with different lithologies.
528 Average bulk rock contaminants calculated for LS show $\epsilon\text{Hf}_{(790)}$ between -14.5 and -3.6 with an
529 average of -10.9 at the time of the TGSC intrusion, including almost all the $\epsilon\text{Hf}_{(790)}$ of magmatic
530 zircons (Fig. 11). The more crustal values from few LS magmatic zircons can be modelled by using
531 the lowest $^{176}\text{Hf}/^{177}\text{Hf}_{(1300)}$ of 0.281560 from LS inherited zircons which provides $\epsilon\text{Hf}_{(790)}$ of the
532 contaminants between -25.3 and -14.4 with an average of -21.7. The absence of inherited domains
533 in these zircons, as shown by CL investigation, suggests their crystallization from an extremely
534 contaminated melt if not directly from a melt derived from the contaminant itself.
535 Average bulk rock contaminants calculated for US at the time of the TGSC intrusion show $\epsilon\text{Hf}_{(790)}$
536 between 1.1 and 13.0 with an average of 5.9. These values are higher than most of the TGSC
537 magmatic zircons (Fig. 11). Recalculating the contaminants bulk rock using the lowest MORB-like
538 $^{176}\text{Hf}/^{177}\text{Hf}_{(1300)}$ of 0.282112 (i.e. the lower recalculated inherited zircon for the US was at
539 0.281490) provides $\epsilon\text{Hf}_{(790)}$ values between -2.9 and 9.0 with an average of 1.9, which comprise
540 almost all the US magmatic zircons. Six US magmatic zircons with $\epsilon\text{Hf}_{(t)}$ between -3.0 and -8.4
541 require a more detrital/sedimentary component, which is however compatible with the rare
542 occurrence of these xenoliths and related inherited zircons.

543 The Hf isotopic data from zircons thus provide a valuable tool to recognize contamination processes
544 between melt and rock with similar original isotopic compositions, which could not be identified
545 with other bulk-rock isotopic systematics (i.e. Rb-Sr and Sm-Nd). Similarly, the occurrences in
546 magmatic systems of magmatic and inherited zircons could be used to qualitatively recognize
547 contamination processes and approximate the contaminant Hf isotopic composition when
548 xenoliths/contaminat bulk rock is missing.

549

550 **Conclusions**

551 The emplacement and contamination of the TSGC complex within crustal units has been clearly
552 recorded by Lu-Hf systematics in zircons from both the LS and the US sequences of its three
553 fragments (Niquelandia, Cana Brava and Barro Alto).

554 The intrusion of the LS within the metasedimentary sequence has resulted in a clear crustal
555 signature (negative $\epsilon_{\text{Hf}}(t)$ zircon values), coherent with bulk-rock Rb-Sr and Sm-Nd isotopes.

556 The emplacement of the US at shallower crustal levels, dominated by MORB-mantle like signature
557 amphibolites, resulted in zircon $\epsilon_{\text{Hf}}(t)$ values from slightly positive to negative. The similar original
558 geochemical affinities of the TGSC parent melt and amphibolites masked the contamination
559 processes in the US in the Rb-Sr and Sm-Nd bulk-rock systematics leading over the years to an
560 erroneous geotectonic interpretation of the US. Zircon Hf isotopes record the interaction between
561 the TGSC parent melt and the evolved MORB-like signature of the contaminant from the adjacent
562 metavolcanic sequence.

563 The LS and US were, thus, similarly contaminated during the TGSC intrusion, resulting in different
564 geochemical affinities due to the different composition of the contaminants.

565 The occurrences of un/poorly contaminated zircons in the US suggest that anorthosites crystallized
566 from an anorthositic crystal mush, which was formed during the segregation of the ultramafics in
567 the initial stage of the TGSC intrusion.

568

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574

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725

726 **Figure captions**

727 Fig. 1: regional geotectonic setting of the Brasilia Belt modified after Oliveira Cordeiro and
728 Oliveira (2017).

729

730 Fig. 2: geological map of the Cana Brava Complex, modified after Correia et al. (1997) and
731 Giovanardi et al. (2017b).

732

733 Fig. 3: geological map of the Niquelândia Complex, modified after Correia et al. (2012) and
734 Giovanardi et al. (2017b).

735

736 Fig. 4: geological map of the Barro Alto Complex, modified after Ferreira Filho et al. (2010) and
737 Giovanardi et al. (2017b).

738

739 Fig. 5: $^{87}\text{Sr}/^{86}\text{Sr}$ and ϵNd recalculated at 790 Ma along the stratigraphy of the TGSC. Literature data
740 from Niquelandia and Cana Brava are from Correia et al. (1997, 2012) and Giovanardi et al.
741 (2017a).

742

743 Fig. 6: CL images of zircon grains from UGAZ Barro Alto anorthosite sample BA1541 reported
744 with the number of the SHRIMP single spot analysis; calculated concordia and average $^{206}\text{Pb}/^{238}\text{U}$
745 age (errors are calculated as 2σ).

746

747 Fig. 7: CL images of zircon grains from MZ Niquelandia gabbro sample NQ15-49 reported with the
748 number of the SHRIMP single spot analysis; calculated concordia and average $^{206}\text{Pb}/^{238}\text{U}$ age
749 (errors are calculated as 2σ).

750

751 Fig. 8: CL images of zircon grains from UGAZ Niquelandia anorthosite sample NQ15-52 reported
752 with the number of the SHRIMP single spot analysis; calculated concordia and average $^{206}\text{Pb}/^{238}\text{U}$
753 age (errors are calculated as 2σ).

754

755 Fig. 9: recalculated $\epsilon\text{Hf}(t)$ for zircon grains with measured U-Pb ages. (1) literature data from Della
756 Giustina et al. (2011). The depleted mantle (DM) evolution line is calculated using the values of
757 present-day $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of 0.28325 from Nowell et al. (1998) and $^{176}\text{Lu}/^{177}\text{Hf}$ ratio of 0.0384
758 from Griffin et al. (2000). CHUR values are from Blichert-Toft and Albarede (1997).

759

760 Fig. 10: zircons REE patterns normalized to the Chondrite I composition (CI; Anders and Edibara
761 1992). In each panel, the minimum and maximum $^{206}\text{Pb}/^{238}\text{U}$ ages in Ma obtained with LA-ICP-MS
762 are reported.

763

764 Fig. 11: recalculated $\epsilon\text{Hf}(t)$ for zircon grains with measured U-Pb ages. (1) literature data from
765 Della Giustina et al. (2011). The depleted mantle (DM) evolution line is calculated using the values
766 of present-day $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of 0.28325 from Nowell et al. (1998) and $^{176}\text{Lu}/^{177}\text{Hf}$ ratio of 0.0384
767 from Griffin et al. (2000). CHUR values are from Blichert-Toft and Albarede (1997). US and LS
768 inherited fields are the recalculated ϵHf of inherited zircons at 1.3Ga. US and LS inherited avg are

769 the evolutions through time of ϵHf from average inherited zircons. US and LS crust are the
770 estimated evolutions through time of ϵHf from inherited bulk rock calculated from average
771 $^{176}\text{Hf}/^{177}\text{Hf}$ initial ratio from inherited zircons and $^{176}\text{Lu}/^{177}\text{Hf}$ ratio of 0.015 for the continental crust
772 bulk rock from Griffin et al. (2002), the average of MORB at 0.024 (Stracke et al., 2003) and
773 minimum, maximum and average ratios of bulk-rock analysis of xenoliths from LS (Correia et al.,
774 2012) and amphibolites (Moraes et al., 2003).

775

776 **Table captions**

777 Table 1: sample coordinates and references for previously published U-Pb data.

778

779 Table 2: average of Lu-Hf isotopic data from magmatic and inherited zircons. ϵHf , $\epsilon\text{Hf}_{(t)}$, T_{DM} and
780 T_{DM}^{C} are calculated using the Hf-INATOR spreadsheet (Giovanardi and Lugli, 2017). T_{DM} and
781 T_{DM}^{C} are in Ma. M are magmatic zircons whose ages are consistent with the TGSC intrusion age; I
782 are inherited zircons.

783

784 Table 3: solution and in situ Sr isotope ratios from plagioclases from Barro Alto.

785

Figure 1
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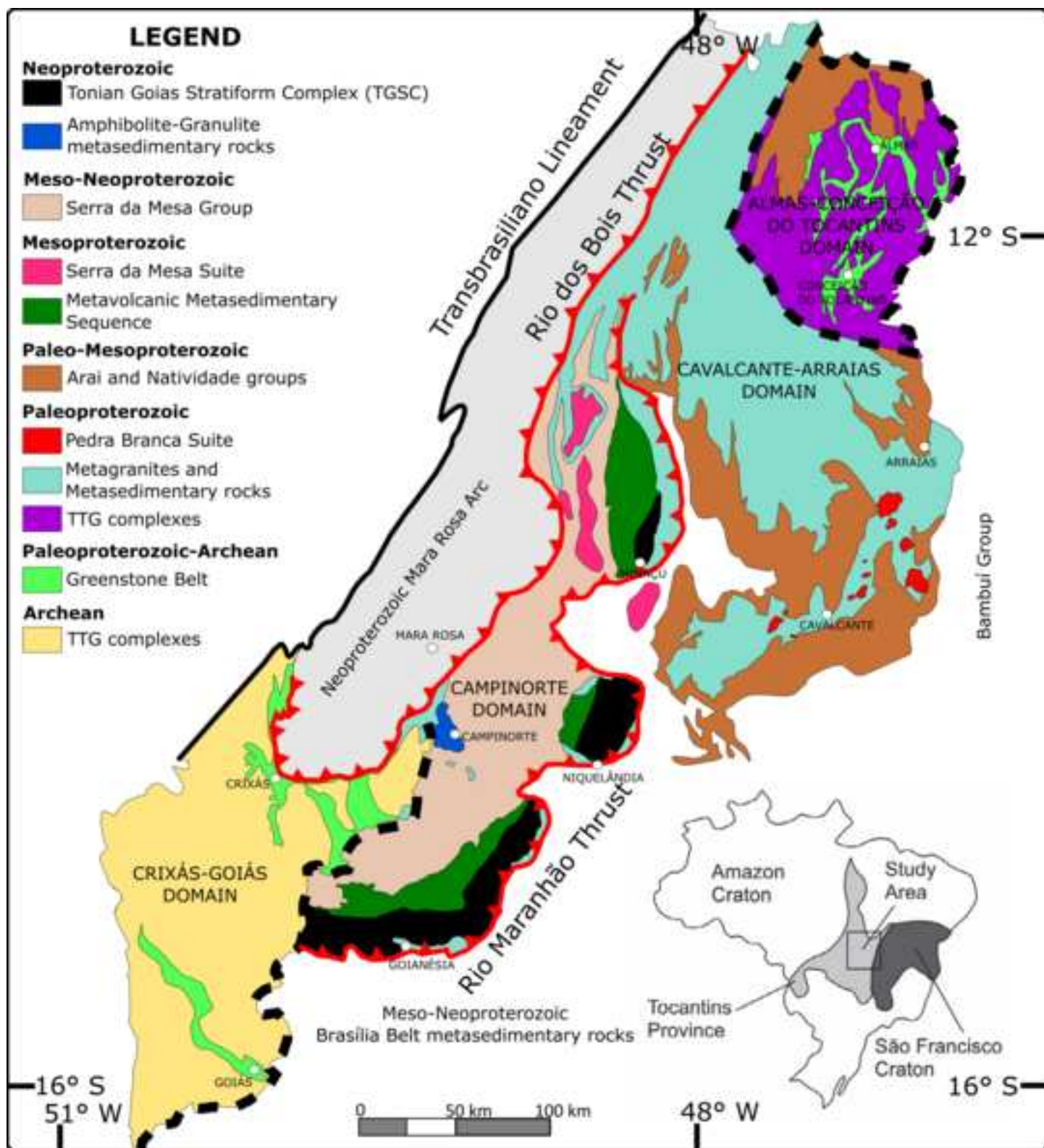


Figure 2
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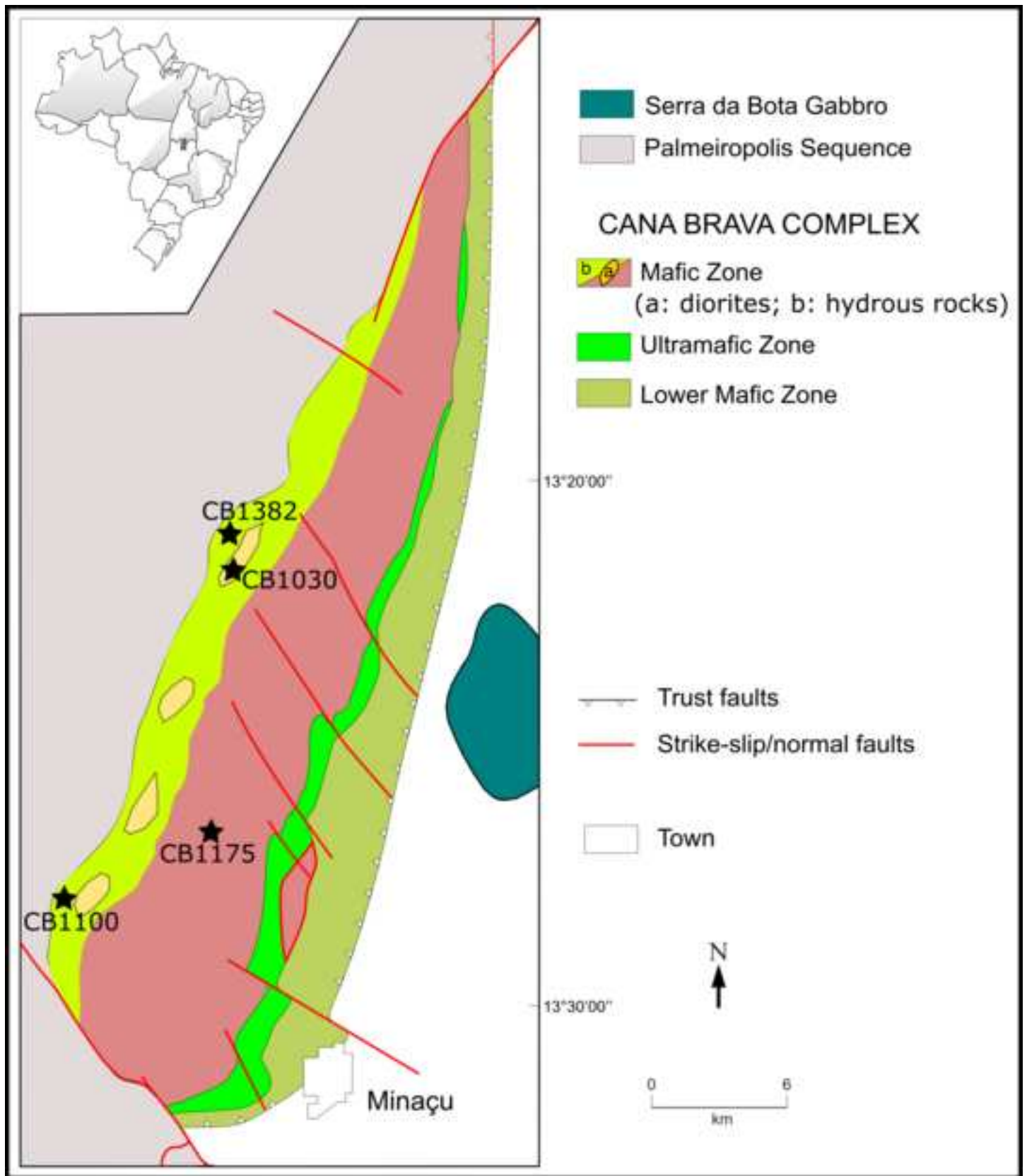


Figure 3
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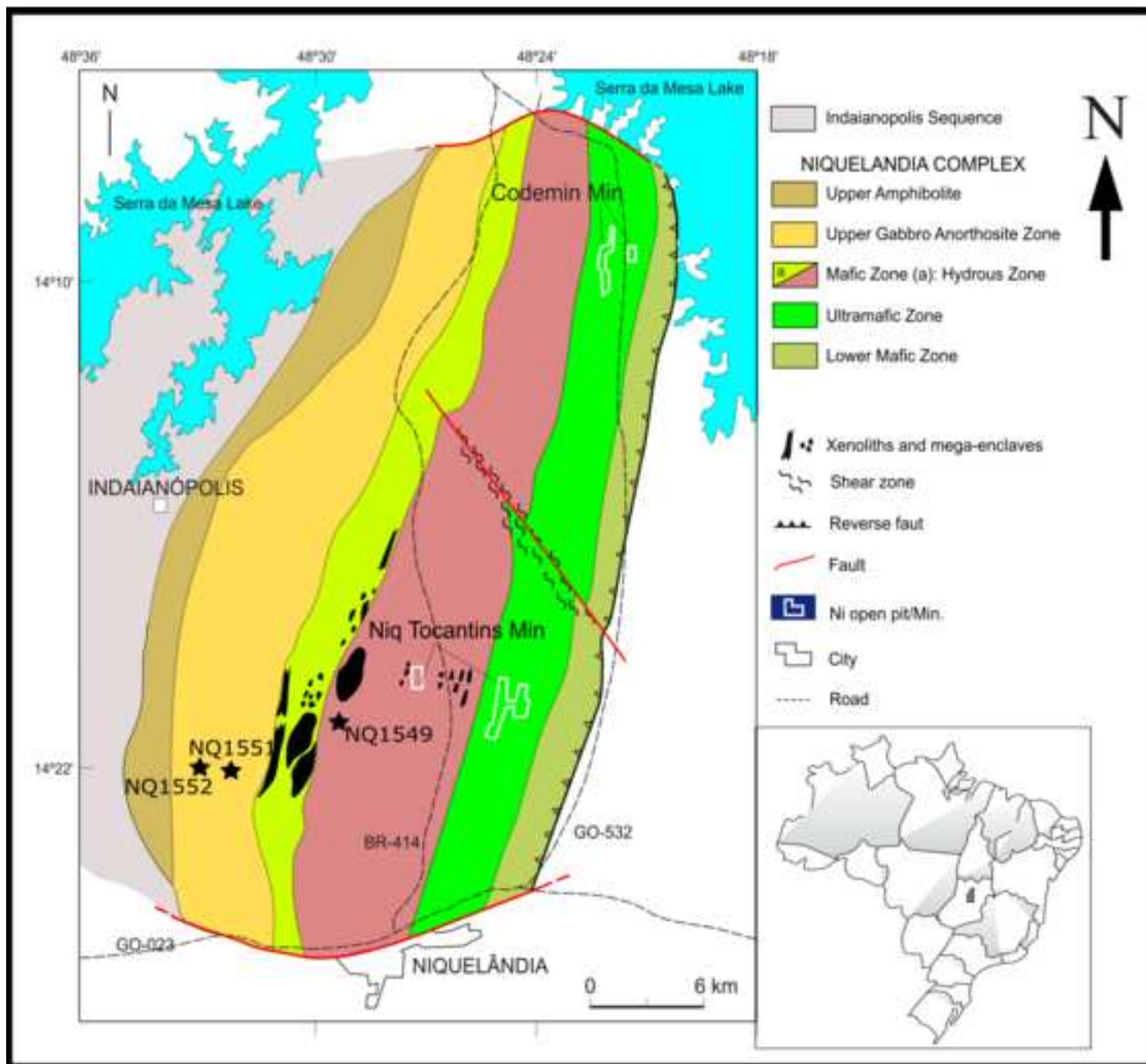


Figure 4

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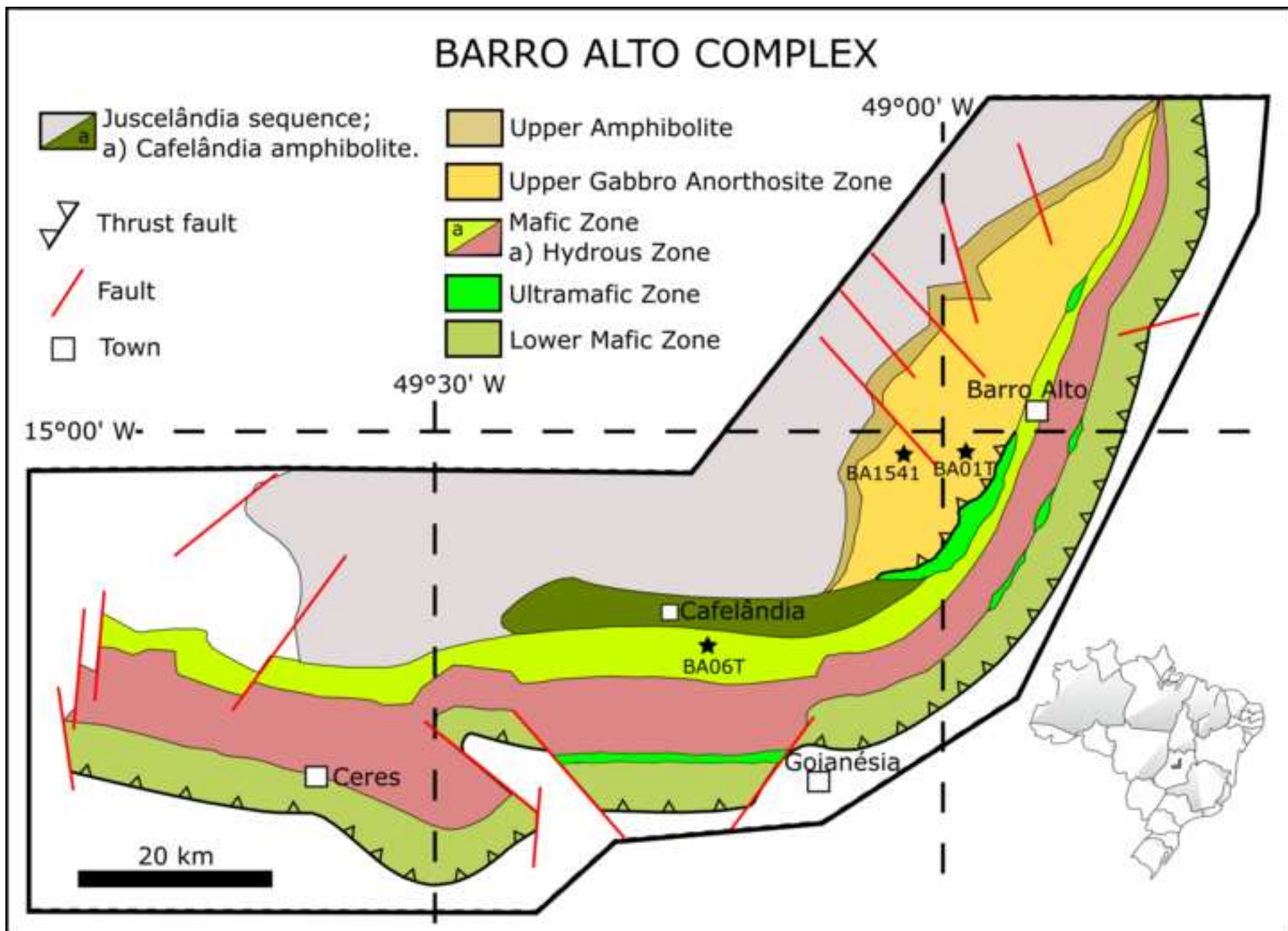


Figure 5
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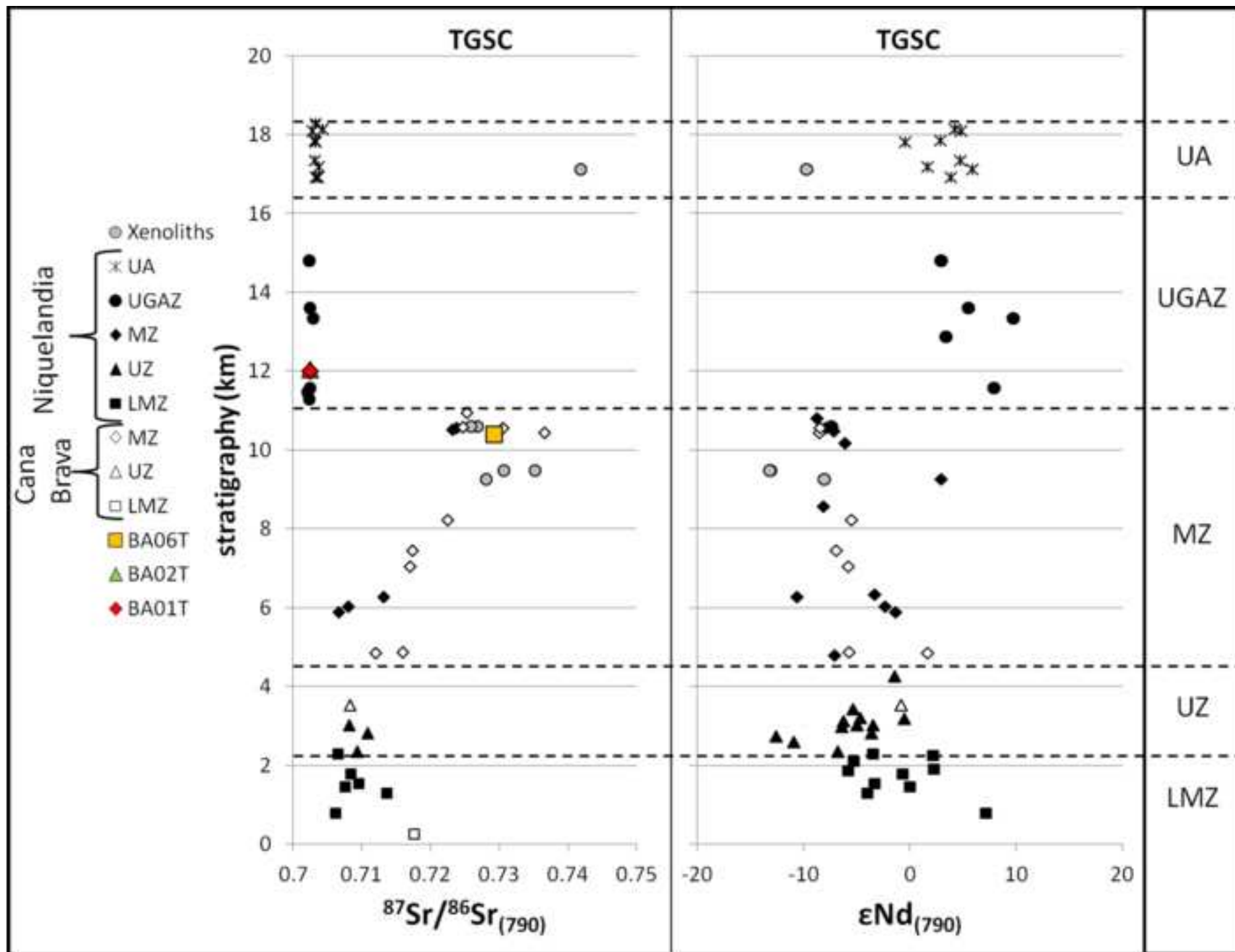


Figure 6
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Sample BA1541

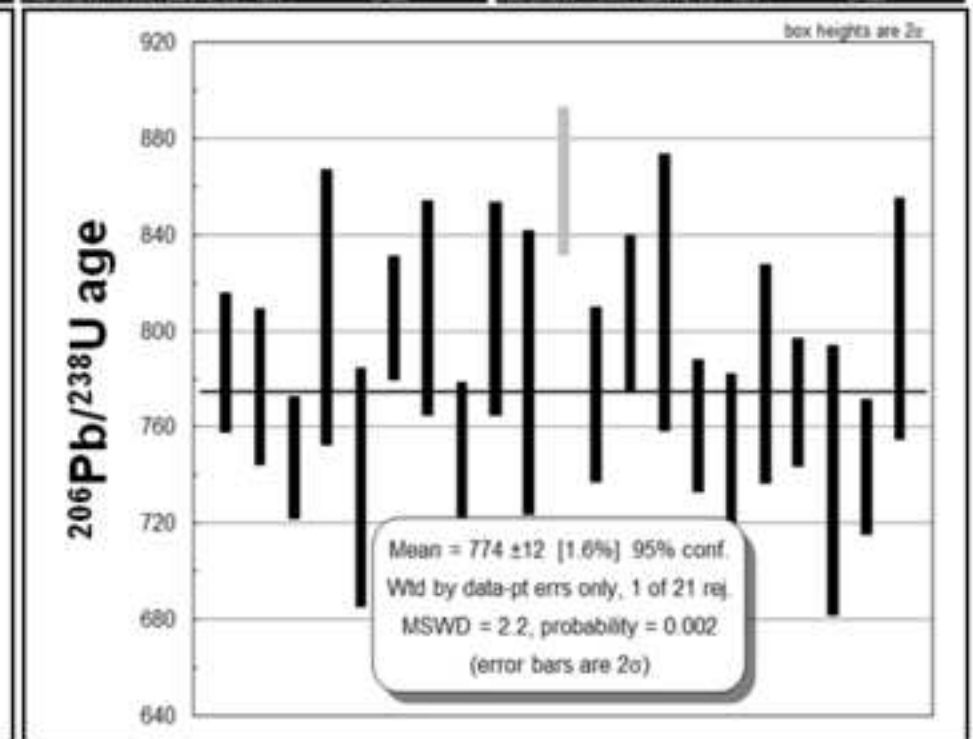
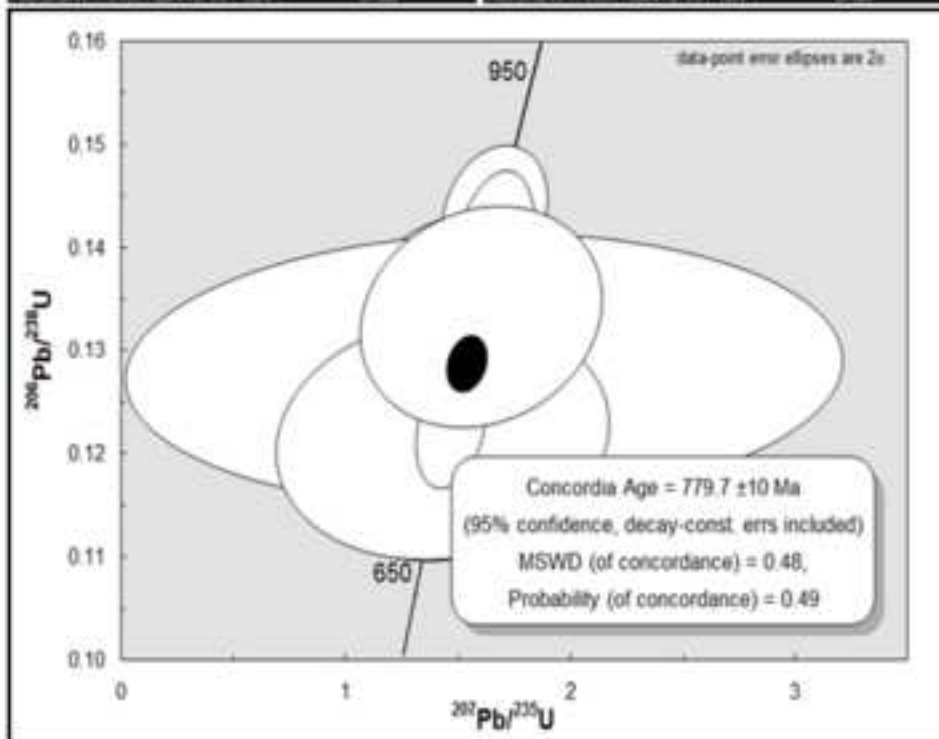
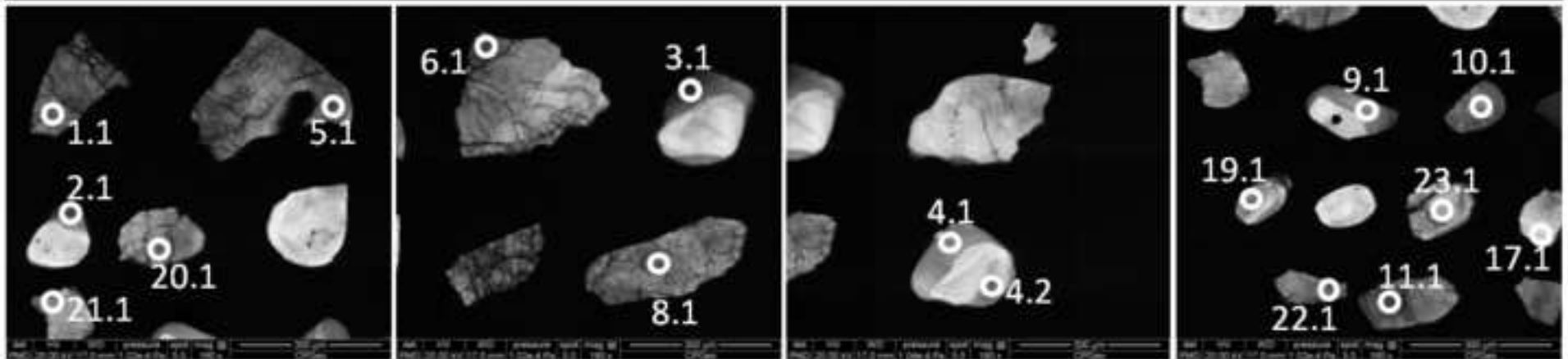


Figure 7
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Sample NQ1549

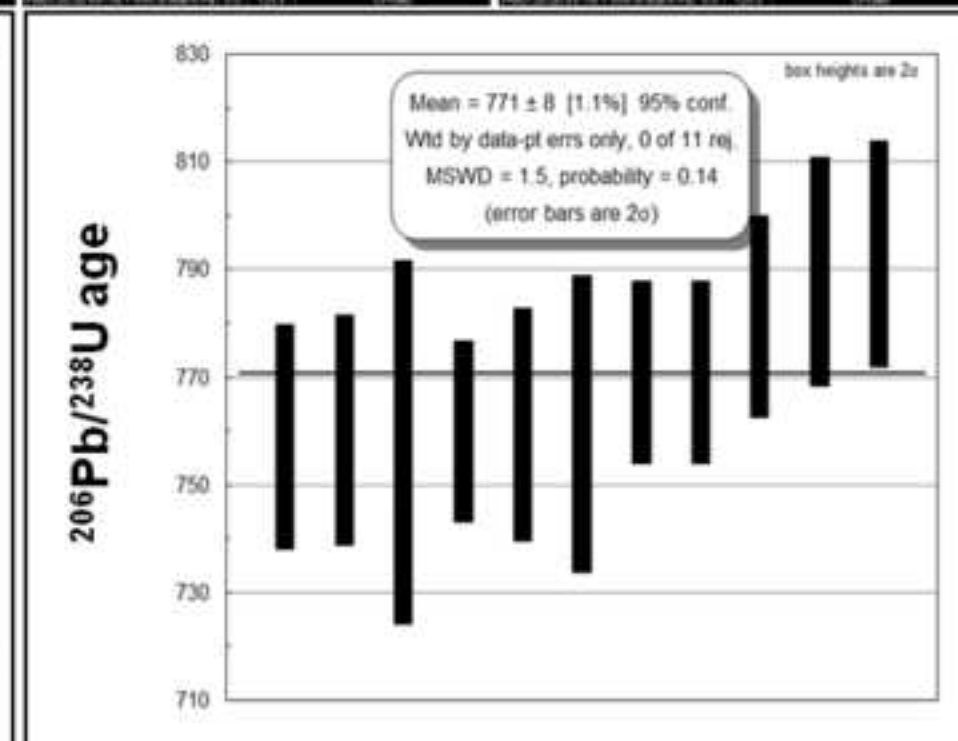
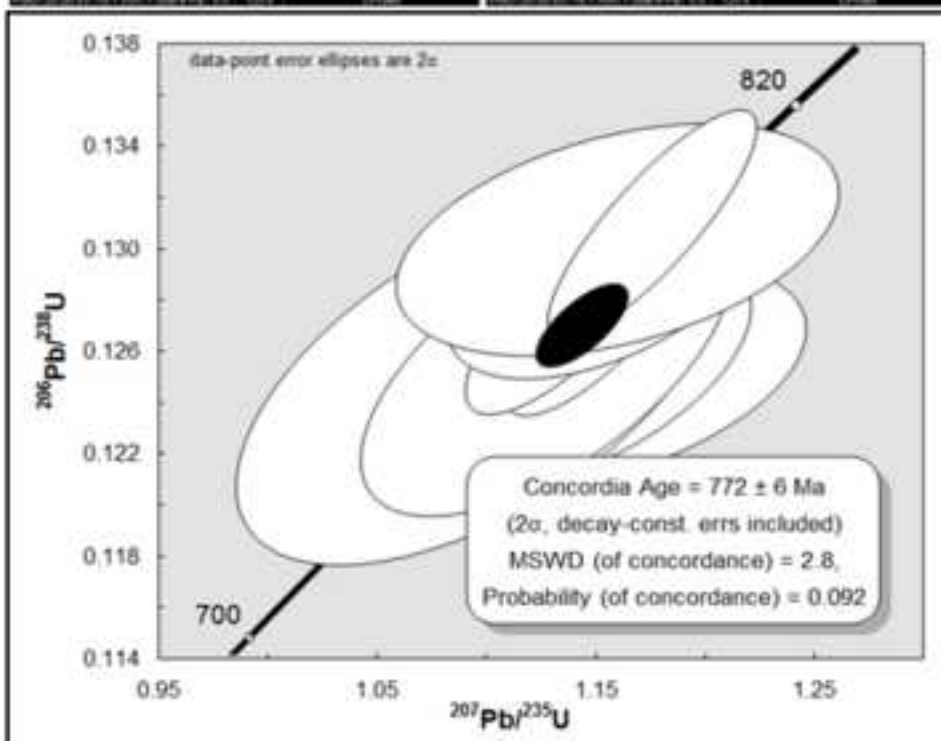
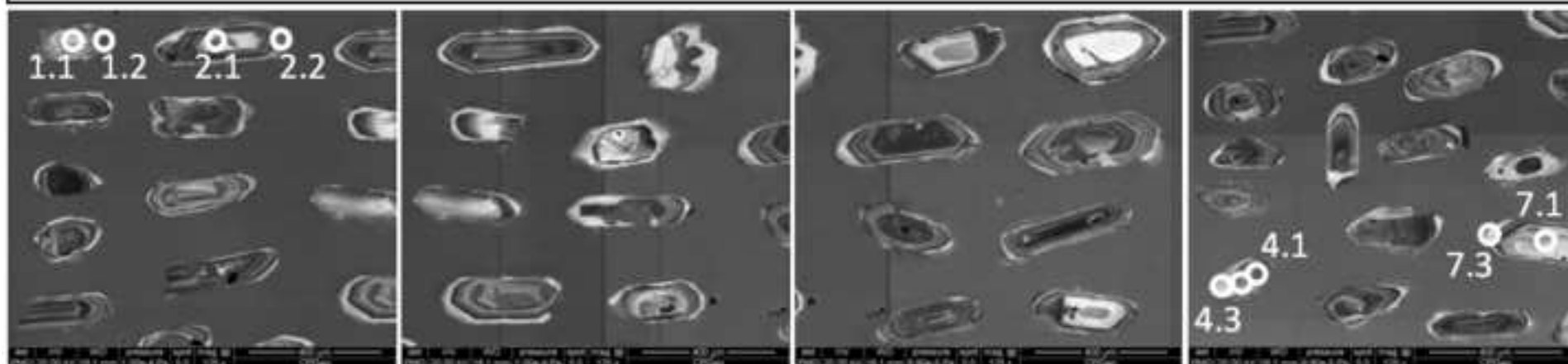


Figure 8
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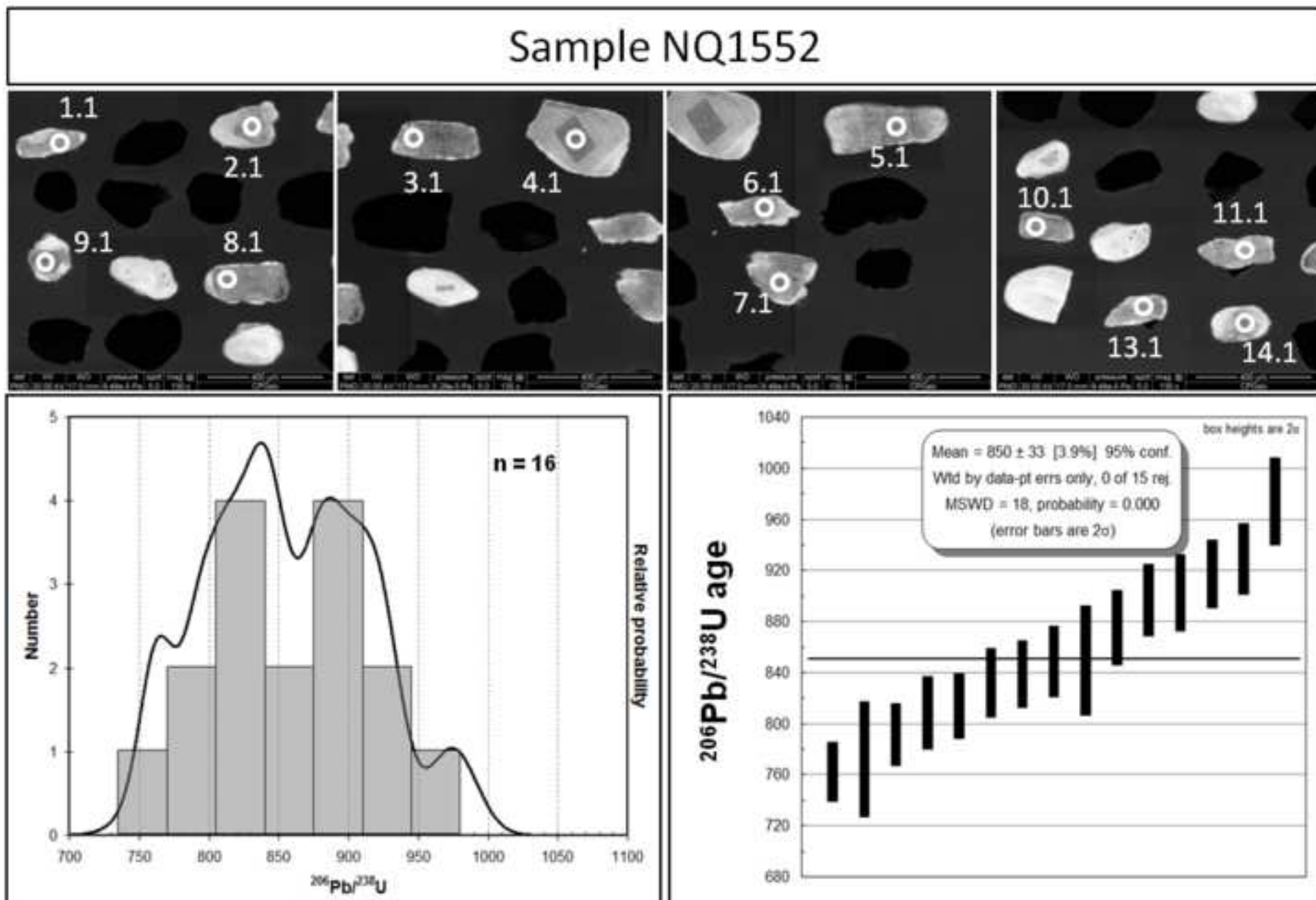


Figure 9
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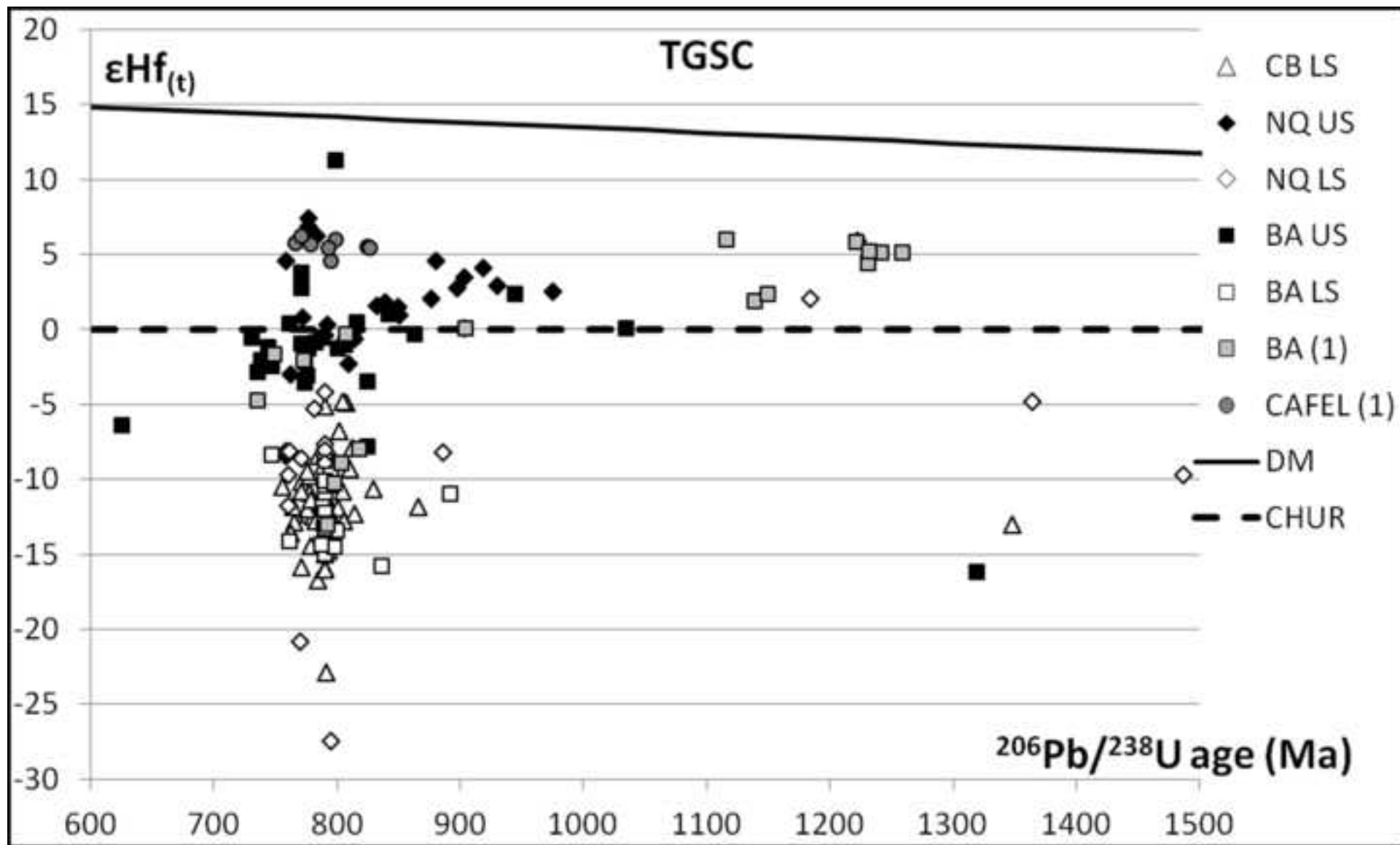


Figure 10
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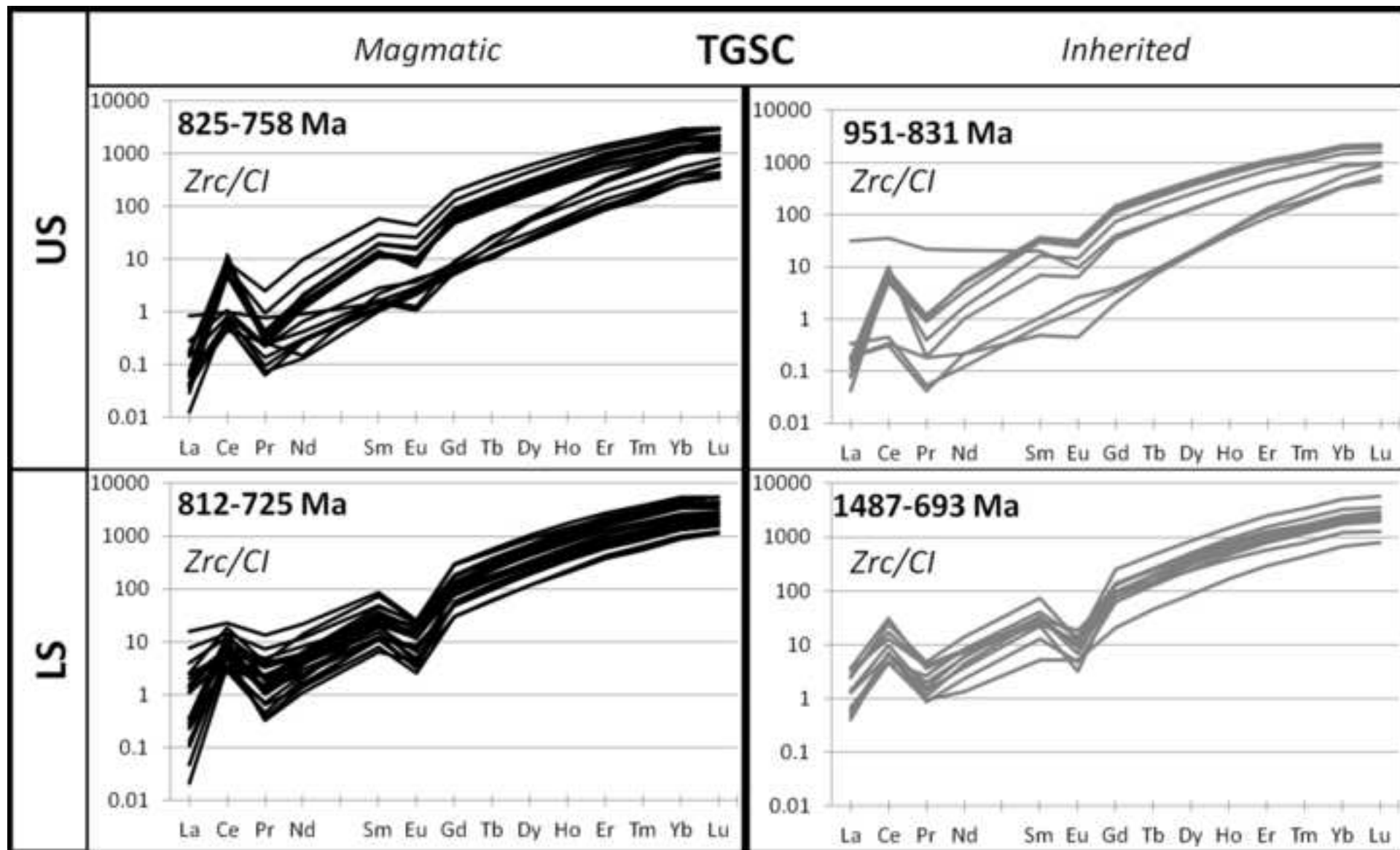


Figure 11
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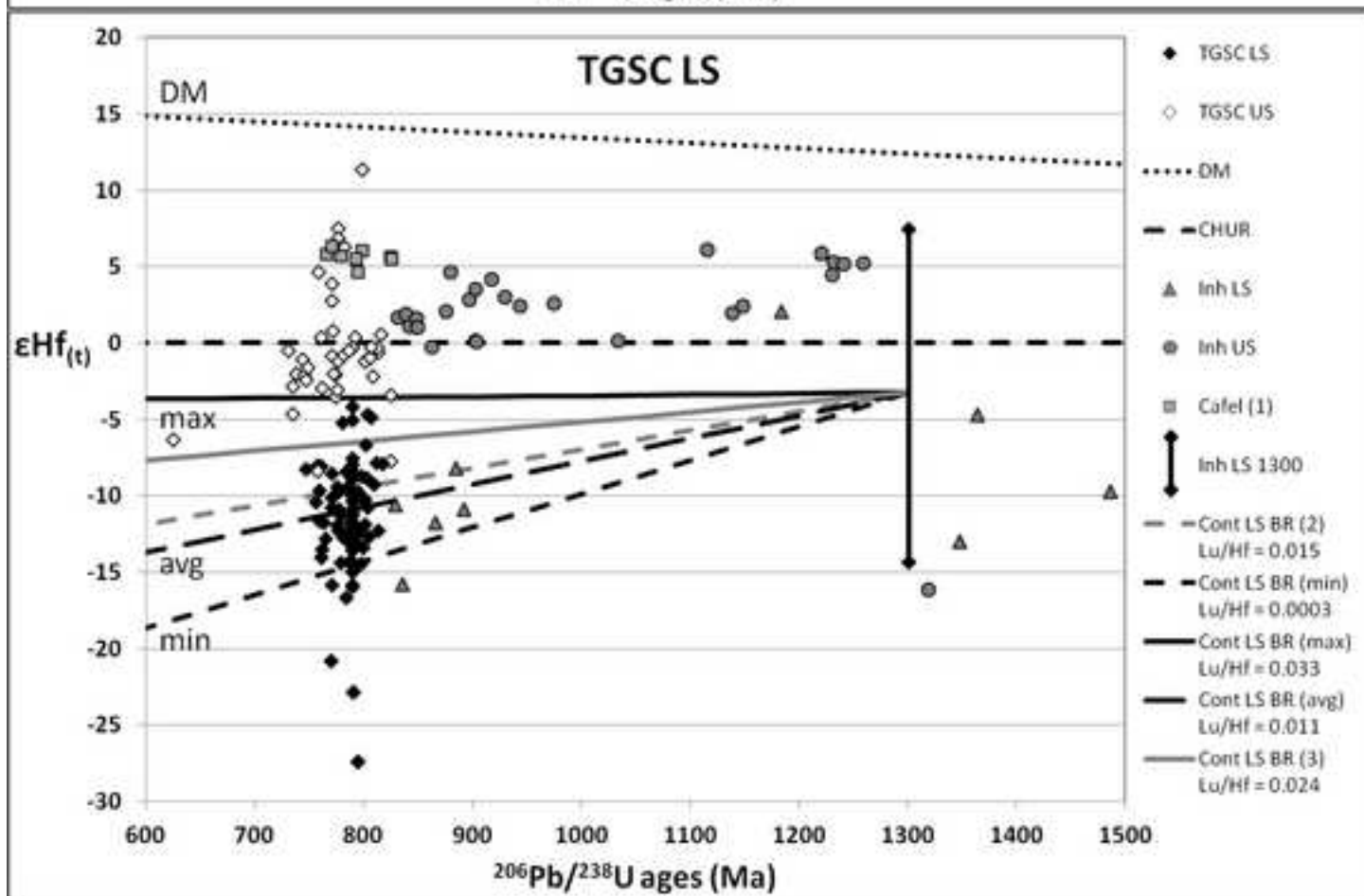
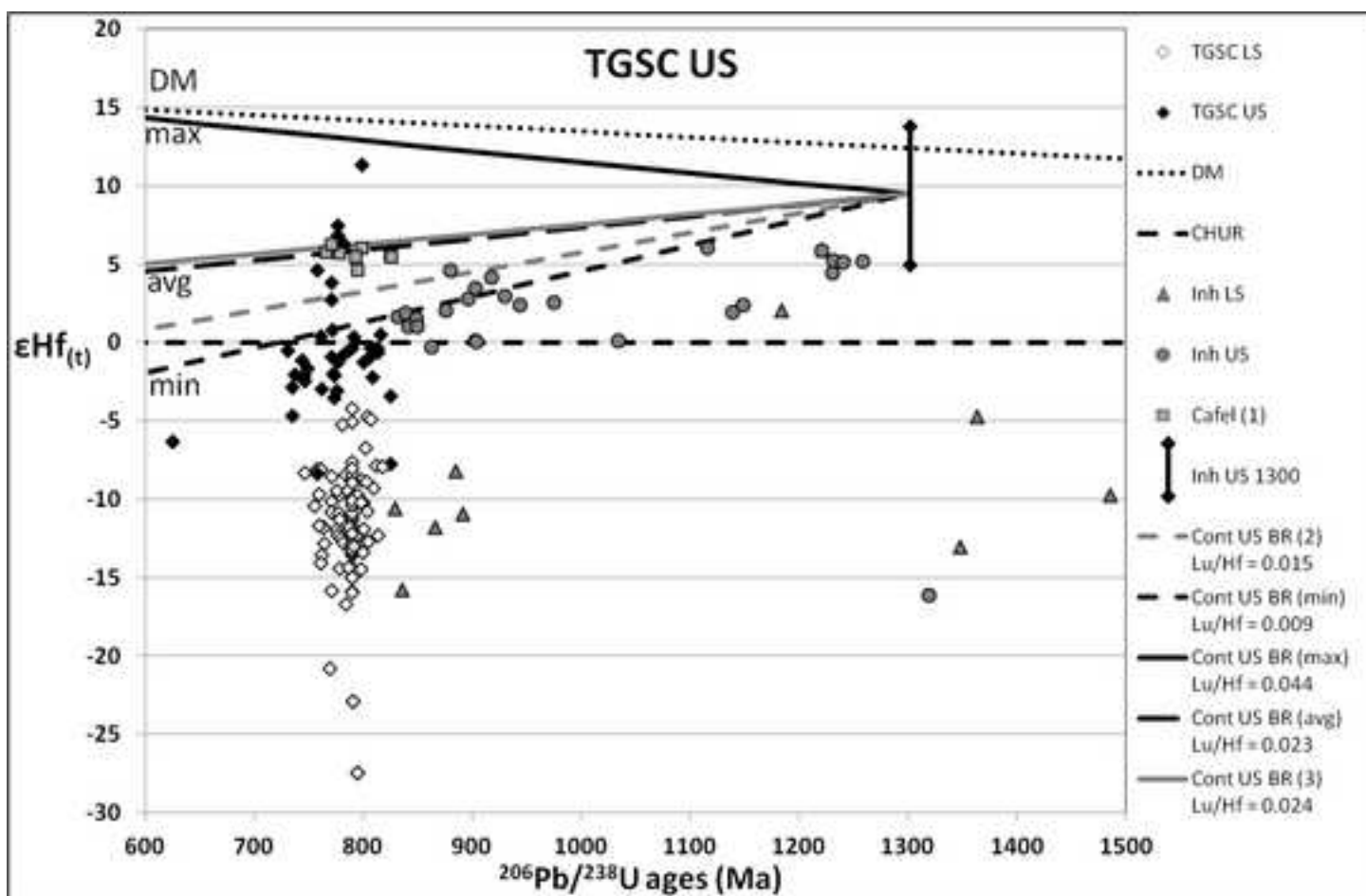


Table 1[Click here to download Table: Table 1.docx](#)

Sample	Complex	Sequence	Longitude	Latitude	Lithology	Reference
CB1030	Cana Brava	LS	48°15'21.99"W	13°22'9.49"S	Diorite	Giovanardi et al. 2015, 2017b
CB1100	Cana Brava	LS	48°18'38.12"W	13°29'10.48"S	Gabbro	Giovanardi et al. 2015, 2017b
CB1175	Cana Brava	LS	48°16'3.61"W	13°28'0.01"S	Gabbro	Giovanardi et al. 2015, 2017b
CB1382	Cana Brava	LS	48°15'32.05"W	13°22'6.06"S	Gabbro	Giovanardi et al. 2015, 2017b
NQ1549	Niquelandia	LS	48°29'56.40"W	14°21'49.59"S	Gabbro	This work
NQ1551	Niquelandia	US	48°31'39.40"W	14°22'4.59"S	Anorthosite	Correia et al. 2012
NQ1552	Niquelandia	US	48°31'58"W	14°22'01"S	Anorthosite	Correia et al. 2007
BA06T	Barro Alto	LS	49°11'23.94"W	15°12'51.04"S	Gabbro	Giovanardi et al. 2017b
BA01T	Barro Alto	US	48°59'17.91"W	15°05'02.13"S	Anorthosite	Giovanardi et al. 2017b
BA1541	Barro Alto	US	49°02'25"W	15°05'17"S	Anorthosite	Correia et al. 2007

Table 2

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Sample	Complex	Sequence		$^{176}\text{Yb}/^{177}\text{Hf}$	2σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2σ	$^{178}\text{Hf}/^{177}\text{Hf}$	2σ	avg. ^{180}Hf	eHf ₍₀₎	eHf _(t)	T _{DM}	T _{DM} ^c
CB1030	CB	LS	M	0.042613	0.019526	0.000899	0.000313	0.281977	0.000111	1.467317	0.000121	1.34	-28.1	-11.4	1788	2427
CB1175	CB	LS	M	0.039609	0.048404	0.000861	0.000984	0.281995	0.000248	1.467319	0.000042	1.75	-27.5	-10.2	1761	2369
CB1382	CB	LS	M	0.074620	0.049375	0.001702	0.001208	0.281989	0.000107	1.467226	0.000097	2.29	-27.7	-11.3	1811	2459
CB1100	CB	LS	M	0.045385	0.023267	0.001043	0.000558	0.281903	0.000087	1.467259	0.000084	1.58	-30.7	-14.0	1898	2602
CB1100	CB	LS	I	0.052625	0.009577	0.001186	0.000207	0.281826	0.000414	1.467210	0.000042	1.61	-33.4	-11.8	2011	2641
NQ1549	NQ	LS	M	0.041487	0.030286	0.000970	0.000705	0.282002	0.000345	1.467325	0.000045	1.58	-27.3	-10.6	1756	2375
NQ1549	NQ	LS	I	0.044257	0.031025	0.001043	0.000723	0.281943	0.000475	1.467307	0.000034	1.53	-29.3	-3.0	1843	2233
NQ1552	NQ	US	M	0.032539	0.020619	0.000780	0.000381	0.282266	0.000088	1.467324	0.000121	1.04	-17.9	-0.9	1382	1758
NQ1552	NQ	US	I	0.037825	0.020249	0.000879	0.000423	0.282300	0.000071	1.467323	0.000085	1.00	-16.7	2.4	1340	1626
NQ1551	NQ	US	M	0.016588	0.012707	0.000466	0.000311	0.282392	0.000364	1.467318	0.000234	0.90	-13.4	3.4	1197	1467
BA06T	BA	LS	M	0.039564	0.033874	0.000901	0.000720	0.281945	0.000110	1.467307	0.000114	1.27	-29.3	-12.4	1833	2495
BA06T	BA	LS	I	0.036741	0.046638	0.000912	0.000913	0.281870	0.000131	1.467257	0.000015	1.39	-31.9	-13.4	1937	2616
BA01T	BA	US	M	0.019470	0.038147	0.000523	0.001017	0.282289	0.000306	1.467294	0.000074	1.74	-17.1	0.3	1343	1688
BA01T	BA	US	I	0.050026	0.015659	0.001247	0.000341	0.281908	0.001088	1.467327	0.000010	1.95	-30.6	-7.6	1900	2418
BA1541	BA	US	M	0.024335	0.032836	0.000595	0.000708	0.282262	0.000066	1.467317	0.000083	1.69	-18.0	-1.4	1382	1771
BA1541	BA	US	I	0.035952	0.051749	0.000879	0.001222	0.282217	0.000109	1.467306	0.000205	1.63	-19.6	0.8	1456	1778

Table 3

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Sample	Unit	$^{87}\text{Sr}/^{86}\text{Sr}$	2σ	Rb/Sr	$^{87}\text{Sr}/^{86}\text{Sr}_{(790)}$
<i>solution</i>					
BA02T	UGAZ	0.702368	0.000012	0.0020	0.702355
BA06T	MZ	0.729226	0.000012	0.0030	0.729192
<i>in situ</i>					
BA01T	UGAZ	0.702452	0.000040	0.0011	0.702430
BA02T	UGAZ	0.702444	0.000329	0.0020	0.702432
BA06T	MZ	0.729948	0.000125	0.0030	0.729914

Supplementary Material Table A

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Supplementary Material Table B

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Supplementary Material Table C

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