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1 **Understanding preservation of primary signatures in apatite by**
2 **comparing matrix and zircon-hosted crystals from the Eoarchean**
3 **Acasta Gneiss Complex (Canada)**

4
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9
10 **Keywords:** Acasta; apatite; zircon; Archean; primary composition

11
12
13 **Abstract**

14 A novel way to investigate the petrogenesis of ancient poly-metamorphosed terranes is to study
15 zircon-hosted mineral inclusions, which are sensitive to melt evolution such as apatite. Recent
16 contributions on such inclusions in unmetamorphosed granitoids can provide valuable petrogenetic
17 information and, in turn, represent a way to circumvent effects of metamorphism. Yet, the impact
18 of metamorphism on apatite inclusion has never been studied in detail. To address the issue of
19 chemical and isotopic preservation of primary signals in apatite crystals both in the matrix and
20 armored within zircons, we have studied apatite crystals from four 3.6-4.0 Ga TTG granitoids from

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21 the Acasta Gneiss Complex (Canada). Our results demonstrate that U-Th-Pb isotope systematics
22 in matrix apatite crystals were reset at 1.8-1.7 Ga (Wopmay orogen) whereas primary REE
23 signatures were preserved in many crystals. In contrast, zircon-hosted apatite inclusions all
24 preserved primary REE signatures despite variable ages between 1.7 and 4.0 Ga. We interpret reset
25 ages to be a consequence of metamorphism that managed to affect U-Th-Pb systematics because
26 of advanced radiation damage accumulation in host-zircon lattices. Only the most pristine zircon
27 crystal has an apatite inclusion with a concordant age consistent with the magmatic age of the
28 zircon (4.0 Ga). In addition, our results show that apatite crystals from TTG have distinct REE
29 composition from post-Archean granitoids apatites, that is preserved even in some apatites with
30 reset ages. This capacity to retain primary information and discriminate granitoid types makes
31 apatite a very valuable tool for reconstructing the nature and evolution of ancient crustal rocks
32 through the use of detrital minerals.

33

34 **1. Introduction**

35 Rare-Earth bearing minerals such as apatite ($\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{Cl}, \text{F})$), have proven to be extremely
36 valuable in retrieving the nature of their host magmas and the crystallization history of granitoids
37 (Chu et al., 2009; Jennings et al., 2011; Bruand et al., 2016). Hence, they can be very useful
38 complements to zircon in crustal evolution studies (e.g., Iizuka and Hirata, 2005; Belousova et al.,
39 2010; Dhuime et al., 2012). Apatite is ubiquitous in different rock types, and contains measurable
40 amounts of a large variety of trace elements (e.g., LREE-MREE, Sr, Pb, Mn, halogens; e.g.,
41 Prowatke and Klemme, 2006; Gregory et al., 2009; Miles et al., 2014). The concentration of trace
42 elements in apatite is sensitive to melt evolution (*in-situ* crystal fractionation, mixing, SiO_2 and
43 ASI contents; e.g., Sha and Chappell, 1999; Belousova et al., 2001; Prowatke and Klemme, 2006;

44 Zirner et al., 2015). Furthermore, apatite is also datable via U-Pb geochronology although prone
45 to resetting during metamorphism, which makes it problematic to recover meaningful information
46 about the magmatic history of old crustal segments. One way to overcome this limitation is to
47 study apatite inclusions armored within zircon and, thus, combine the potential of apatite in
48 retrieving magmatic information with the resilience of zircon to metamorphic processes. Previous
49 workers have shown that zircon-hosted apatite inclusions can indeed retain important information
50 about its host-rock (Jennings et al., 2011; Bruand et al., 2016; Emo et al., 2018). For instance,
51 Bruand et al. (2016) have studied an unmetamorphosed suite of granitoids and showed that zircon-
52 hosted inclusions shared the same trace element signatures as cogenetic apatite crystals within the
53 matrix. They have also shown that Sr/Sm ratio in apatite can discriminate felsic magmas from
54 mafic ones and, as previously suggested by Belousova et al. (2001), that Sr content in apatite
55 inclusions can be used as a proxy for the degree of differentiation of their parental magma
56 (evaluation of the SiO₂ and Sr contents).

57 Very recently, Emo et al. (2018) demonstrated that zircon-hosted and matrix apatite
58 crystals in two 3.6-3.7 Ga orthogneisses from the Acasta Gneiss Complex (AGC, Canada) exhibit
59 a general discrepancy in their Sr isotope signatures. The authors interpreted the Sr isotopic
60 signature in apatite inclusions as the first direct estimate of initial ⁸⁷Sr/⁸⁶Sr for these ancient rocks
61 whereas Sr isotope signatures in matrix apatite were reset during later metamorphic event. This
62 interpretation is in line with recent findings of Fisher et al. (2019) who demonstrated that Sm-Nd
63 isotope systematics in matrix apatite from Acasta gneisses were reset during the Wopmay orogen
64 at about 1.85 Ga. However, it is presently unclear to which extent zircon-hosted apatite inclusions
65 can resist metamorphic resetting, especially in ancient zircon crystals that experienced significant
66 radiation damage such as those in the AGC (e.g. Guitreau et al., 2018). Consequently, the aim of

67 this paper is to study the preservation potential of trace element and U-Th-Pb isotope signatures in
68 zircon-hosted inclusions and, hence, better constrain the extent to which such approach can allow
69 retrieval of information about the formation of Earth's first crusts. For this purpose, we carefully
70 and systematically measured trace element contents and U-Th-Pb isotope systematics in zircon-
71 hosted apatite as well as in matrix apatite crystals in well-characterized 3.6-3.96 Ga samples from
72 the Acasta Gneiss Complex (Guitreau et al., 2012, 2014, 2018; Mojzsis et al., 2014).

73

74 **2. Geological background and sample description**

75 The Acasta Gneiss Complex (AGC) is located on the western edge of the Slave craton (Northwest
76 Territories, Canada; Fig.1; e.g. Bowring et al., 1989). It is bordered to the west by the Wopmay
77 orogen (1900-1700 Ma; Bleeker and Hall, 2007). The key outcrop locality of the AGC covers an
78 area of ~30 km² although its true extent is presently unknown (e.g. Iizuka et al., 2007). This latter
79 is divided into a western and an eastern domain by a major northeast-trending shear-zone with the
80 western part being highly-strained and the eastern part being less deformed (Iizuka et al., 2007;
81 Reimink et al., 2016a, 2016b, 2018). The AGC is mostly made of orthogneisses of dioritic to
82 granitic affinity but some mafic-ultramafic gneisses are also present. (Bowring et al., 1989; Iizuka
83 et al., 2007; Guitreau et al., 2014; Mojzsis et al., 2014; Koshida et al., 2016; Reimink et al., 2016b).
84 The earliest magmatic events that occurred in the AGC had been dated between 3962 ± 3 (Bowring
85 et al., 1989) and 4031 ± 3 Ma (Bowring and Williams, 1999), and recently revised to 4019.6 ± 1.8
86 Ma by (Reimink et al., 2016b) The AGC, therefore, hosts Earth's oldest rocks but also exhibits
87 evidence for a crustal pre-history as argued by the presence of a 4200 Ma inherited zircon core
88 (Iizuka et al., 2006) and by signatures of both short- and long-lived isotope systematics (e.g.,
89 Bowring and Housh 1995; Iizuka and Hirata 2005; Iizuka et al., 2009; Guitreau et al., 2014;

90 Mojzsis et al., 2014; Roth et al., 2014; Bauer et al., 2017; Emo et al., 2018; Reimink et al., 2018);

91 The AGC evolution was marked by several geological events that started out with the
92 formation of the Idiwhaa unit at 4020 Ma (Reimink et al., 2016b) and ended around 1700-1800
93 Ma with a pervasive metamorphic event related to the Wopmay orogen (Hoffman et al., 2011; St-
94 Onge and Davis, 2017; Table A.1). The igneous activity of the AGC essentially consists in several
95 granitic pulses that occurred between 4020 and 2900 Ma, with a major event at 3600 Ma that
96 involved both juvenile addition and crustal anatexis (Table A.1). The metamorphic history of the
97 AGC is less constrained and mostly derived from U-Pb dating of zircon, apatite and titanite (e.g.,
98 Hodges and Bowring, 1995; Bleeker and Stern, 1997; Sano et al., 1999; Iizuka et al., 2007; Mojzsis
99 et al., 2014; Guitreau et al., 2018; Fisher et al., 2019; Kirkland et al., 2020). However, with the
100 available dataset, it clearly appears that during the AGC geological history, most metamorphic
101 events are closely linked to the magmatic activity (e.g., Bleeker and Stern, 1997). Major identified
102 metamorphic events occurred at 3750-3700 Ma, 3400-3300 Ma, 3200-2900 Ma, and the latest
103 important metamorphic event identified is linked to the Wopmay orogeny (1800-1700 Ma) with
104 Wopmay associated P-T estimates ranging from 3.3-9 kbar and 575-745 °C (Sano et al., 1999; St-
105 Onge and Davis, 2017). Some more discrete events also likely occurred afterwards (e.g. Hodges
106 and Bowring, 1995; Guitreau et al., 2018).

107 The samples studied in this contribution (AG09009, AG09014, AG09015, and AG09016)
108 are orthogneisses located in the eastern domain of the AGC (Fig. 1) and have been already
109 described and characterized in Guitreau et al. (2012) and Mojzsis et al. (2014). Samples AG09014,
110 AG09015, and AG09016 have major and trace element compositions that are similar to typical
111 TTG series (e.g., low K₂O/ Na₂O, high La/Yb, and strong depletion in heavy REE; e.g. Moyen and
112 Martin, 2012) and they fall within the field of tonalite and trondhjemite in a normative An-Ab-Or

113 diagram (Barker, 1979). Sample AG09009 is more potassic ($K_2O= 3.64$ wt %; $K_2O/ Na_2O \sim 1$)
114 despite high La/Yb, and strong depletion in HREE, and therefore falls within the field of granite
115 in a normative An-Ab-Or plot. Samples AG09009, AG09014, and AG09015 were dated by zircon
116 U-Pb geochronology at 3600 Ma (Guitreau et al., 2012), whereas AG09016 was dated at 3947 Ma
117 (Guitreau et al., 2012, 2018).

118

119 **3. Analytical Methods**

120 **3.1. Sample preparation**

121 Samples were crushed with a jaw crusher and sieved to recover the fraction $< 400 \mu m$. This fraction
122 was subsequently run on a Wilfley table and heavy mineral further sorted using heavy liquids.
123 Recovered zircon crystals were handpicked, mounted in epoxy resin, and polished to their
124 approximate center. Zircons and apatites in mounts and thick sections were imaged for back-
125 scattered electrons (BSE) and cathodoluminescence (CL) using a scanning electron microscope
126 (SEM) JEOL JSM-5910 LV at Laboratoire Magmas et Volcans (LMV; Clermont-Ferrand,
127 France). The accelerating voltage was set to 15 kV during image acquisition.

128

129 **3.2. Electron probe microanalysis (EPMA)**

130 Apatite crystals occurring as zircon-hosted inclusions and matrix grains were analyzed for major
131 and minor elements with an EPMA CAMECA SX100 at LMV. Analyses were made with an
132 accelerating voltage of 20kV and a 10 nA beam current. The crystals used for analysis were PET
133 for Ca, Ce and S, TAP for Si, Na and Y, LPET for P, Cl, La and Sr, and PC0 for F and O. Apatite
134 analysis was done with a defocused beam of $5 \mu m$ to minimize potential halogen migration (Pyle
135 et al., 2002). Durango apatite reference material was used as a secondary standard for quality

136 control during analysis (Marks et al., 2012).

137

138 **3.3. Trace element analysis by LA-ICP-MS**

139 Trace element analysis of zircon-hosted apatite inclusions was done by laser ablation-inductively
140 coupled plasma mass spectrometry (LA-ICP-MS) using the Resonetics Resolution M-50E 193nm
141 excimer laser coupled to the Thermo Element XR at LMV. The spot sizes used ranged between
142 4 and 12 μm (depending on the phases analyzed) with a repetition rate of 1 Hz and a fluence of
143 2.88 J/cm². We purposely set a low frequency to avoid drilling through apatite too quickly. Each
144 run lasted 2 minutes with 20 seconds of background acquisition. Each sequence was bracketed by
145 two analyses of GSE-1G standards (9 μm spot size) at the beginning and at the end of the sequence,
146 and one GSC-1G in the middle of the sequence (Jochum et al., 2005). Hf content was monitored
147 during analysis of apatite inclusions in order to identify potential concurrent sampling of the host
148 zircon. All analyses with Hf content above the background values were discarded.

149 Matrix apatites were analyzed by LA-ICP-MS using the same laser as for inclusions but
150 coupled to an Agilent 7500 ICP-MS with a spot size of 40 μm , a frequency of 4 Hz, and a fluence
151 of 4.5 J/cm². The same amount of time as for inclusion apatites was used for data acquisition and
152 each run started and finished with two measurements of NIST 610 standard (Pearce et al., 1997).
153 For all runs (matrix and inclusions), Durango apatite (Marks et al., 2012) was regularly analyzed
154 throughout the analytical session to monitor data quality at the same spot size as the analyzed
155 unknowns to account for downhole fractionation (Table A.2). Internal normalization for LA-ICP-
156 MS data was done using ⁴³Ca and data processing was conducted using the GLITTER software
157 (Griffin, 2008).

158

3.4. U-Th-Pb geochronology by LA-ICP-MS

159 Apatite crystals were dated by LA-ICP-MS at LMV using a Resonetics Resolution M-50E laser-
160 ablation system coupled to a Thermo Element XR ICP-MS. During U-Th-Pb measurements, the
161 laser frequency was set to 2 Hz, the fluence to 2.5 J.cm^{-2} and the spot size between 40 and 9 μm
162 so as to adapt to the size of the crystals targeted for analysis. Analyses consisted in ~20s
163 background counting followed by 60s of signal acquisition in peak-jumping mode (5 ms dwell
164 time and 20 μs settling time). Bahia and Xuxa apatite were analyzed for quality check (Rosa et al.,
165 2017; Schuch, 2018). The apatite standard MAD (Thomson et al., 2012) was used for external
166 normalization. Unknowns were analyzed as batches of 6 and were bracketed by analyses of MAD
167 apatite. Data were processed using in-house spreadsheets based on the t_0 intercept method (Chew
168 et al., 2011, 2014). Because we do not know the true $^{207}\text{Pb}/^{206}\text{Pb}$ of MAD apatite, which is a
169 combination of radiogenic Pb and common Pb, and that it is not reported in Thomson et al. (2012),
170 one cannot determine the mass bias for $^{207}\text{Pb}/^{206}\text{Pb}$ during LA-ICP-MS analyses. Consequently,
171 we derived the Pb isotope mass bias by using the $^{208}\text{Pb}/^{206}\text{Pb}$ expected from the “true” $^{232}\text{Th}/^{238}\text{U}$
172 and the age of MAD apatite. Similarly, we estimated the amount of common Pb within analyzed
173 apatite crystals using the difference between the mass-bias corrected $^{208}\text{Pb}/^{206}\text{Pb}$ and that expected
174 from the mass-bias corrected $^{232}\text{Th}/^{238}\text{U}$ in a way akin to that of Chew et al. (2011). Common Pb
175 corrections were further done using the Pb evolution model of Stacey and Kramers (1975) and a
176 convergence method similar to that of Thomson et al. (2012) except that we monitored $^{206}\text{Pb}/^{238}\text{U}$
177 and $^{208}\text{Pb}/^{232}\text{Th}$ for convergence. U-Th-Pb age calculations were done using a present-day
178 $^{238}\text{U}/^{235}\text{U}$ of 137.818 (Hiess et al., 2012) and decay constants for ^{238}U , ^{235}U and ^{232}Th of
179 $1.55125 \cdot 10^{-10}$, $9.8485 \cdot 10^{-10}$, and $4.9475 \cdot 10^{-11}$, respectively (Jaffey et al., 1971; Le Roux and
180 Glendenin, 1963). The Isoplot software (Ludwig 2008) was used to build Tera-Wasserburg plots.
181

182 The 2056 ± 3 Ma Bahia (Rosa et al., 2017) and 573.0 ± 0.8 Ma Xuxa (Schuch, 2018) apatite
183 standards were analyzed using 40, 20, 15, and 9 μm spot sizes. The results for apatite standards
184 are detailed in Table A.3 and Fig. A.1. With all spot sizes combined, we obtained U-Pb Concordia
185 intercept and weighted average $^{206}\text{Pb}^*/^{238}\text{U}$ and $^{208}\text{Pb}^*/^{232}\text{Th}$ ages of 2048 ± 31 (2σ ; MSWD = 2.7;
186 $n = 30$), 2086 ± 34 (2σ ; MSWD = 1.5; $n = 13$), and 2127 ± 40 Ma (2σ ; MSWD = 2.7; $n = 13$),
187 respectively, for Bahia, and 569.4 ± 2.9 (2σ ; MSWD = 1.1; $n = 20$), 574.9 ± 4.4 (2σ ; MSWD =
188 0.39; $n = 17$), and 575.1 ± 3.2 Ma (2σ ; MSWD = 0.97; $n = 17$), respectively, for Xuxa. Therefore,
189 our measurements are in good agreement with previously reported ages.

190 As illustrated in Fig. A.1, common Pb correction results in migration of data points towards
191 the Concordia curve but not complete converge to a concordant age, especially for Bahia apatite
192 data. This can be explained by our correction method, which is well suited for minerals with low
193 Th/U but becomes less precise and less accurate as Th/U increases as a result of radiogenic
194 $^{208}\text{Pb}/^{206}\text{Pb}$ getting closer to that of common Pb (Ireland and Williams, 2003). Consequently, the
195 influence of common Pb becomes less detectable in high Th/U mineral. As an illustration, a 10%
196 contamination of a 2056 Ma Bahia apatite (Th/U = 15), a 573 Ma Xuxa apatite (Th/U = 30), and
197 a 1700 Ma Acasta apatite (Th/U = 0.5) decreases determined $^{208}\text{Pb}/^{206}\text{Pb}$ ratios by 5 and 7 % in
198 Bahia and Xuxa apatites, respectively, while increasing the $^{208}\text{Pb}/^{206}\text{Pb}$ by almost 150% in the
199 Acasta apatite. This observation can explain why, later in the manuscript, the common Pb
200 corrections work much better for Acasta apatites, which commonly have low Th/U, as most data
201 points become concordant once corrected for common Pb.

202 Apatite crystals from Acasta gneisses were analyzed in three different contexts: (1) as
203 separate grains within an epoxy mounts (40, 20, and 9 μm spots on the same apatite crystals), (2)
204 as grains within polished sections (matrix apatite), and (3) as inclusions within zircon crystals

205 mounted in epoxy. All results are available in Table A.4.

206

207 **4. Petrography**

208 **4.1. Sample AG09009**

209 Sample AG09009 is mainly made of quartz, alkali feldspar, plagioclase, biotite, muscovite,
210 chlorite and accessory phases such as zircon, apatite, monazite, allanite, thorite, ilmenite and rutile
211 (Fig. 2A). Locally, chlorite partly replaces micas and can occur as small veins. Felspars are slightly
212 sericitized. In this sample, apatite is the main accessory phase and most commonly occurs as
213 euhedral crystals (<150 microns in length) either directly in contact with biotite or as inclusions in
214 quartz and feldspar. Apatite can be zoned from light gray (core) to dark gray (rim) in
215 cathodoluminescence (Fig. 2D) and can contain zircon inclusions. Apatite occasionally appears as
216 secondary mineral associated with allanite and monazite. In these rare cases, a monazite grain is
217 surrounded by a corona of apatite, itself surrounded by a corona of fibrous allanite (Fig. 2B).
218 Numerous small inclusions of monazite are persistent inside the apatite corona.

219 Biotite, alkali feldspar, plagioclase, chlorite, apatite, chromite and chalcopyrite have been
220 identified as inclusions in zircon (Fig. 2C) and are usually < 20 microns. Most zircon crystals are
221 metamict (damaged by radioactivity), which leads to the formation of fractures that can be filled
222 by several minerals (e.g. biotite, chlorite, plagioclase) thereby forming polymineraleic inclusions.
223 Most apatite inclusions are monomineralic and euhedral except for one case where apatite is
224 surrounded by chlorite (Fig. 2C).

225

226 **4.2. Sample AG09014**

227 Sample AG09014 is made of quartz, biotite, plagioclase and accessory phases. These latter

228 are zircon, apatite, pyrite, monazite and rutile crystals. In this sample, apatite is the main accessory
229 phase (Fig. 2I-J), it is euhedral, small (< 100 microns) and can contain zircon inclusions. Apatite
230 can be found either as inclusion in quartz and plagioclase or in contact with biotite. Apatite is
231 usually unzoned (Fig. 2I-J). In this sample, inclusions in zircon are monomineralic and small (<
232 10 microns). They are mostly apatite (Table 1), quartz, chlorite and monazite crystals.

233

234 **4.3. Sample AG09015**

235 In sample AG09015, the main rock forming minerals are quartz, biotite, plagioclase and oxides
236 (rutile, ilmenite; Table 1). Accessory phases are zircon, apatite, sulfides (pyrite, chalcopyrite),
237 titanite and allanite. As for samples AG09014, AG09015 is only slightly altered. Apatite is the
238 main accessory phase; it is euhedral and < 200 microns. It is either in direct contact with biotite or
239 as inclusion within quartz and feldspar. Most crystals are zoned with a light gray core and a dark
240 gray rim in CL (Fig. 2H). They can also be found as clusters where zonation is oscillatory with a
241 dark gray core (Fig. 2G).

242 In this sample, inclusions found in zircon are apatite, biotite, plagioclase and chlorite.
243 These inclusions are small (< 5 microns) and monomineralic.

244

245 **4.4. Sample AG09016**

246 Sample AG09016 is made of quartz, plagioclase, biotite and muscovite. Accessory phases are
247 zircon, apatite, rutile and titanite. This sample shows limited alteration. Apatite is ubiquitous,
248 euhedral and < 250 microns in size and occurs in contact with biotite or in inclusions in quartz and
249 plagioclase. Apatite crystals have two types of zonation: (i) a light gray core with a dark rim or (ii)
250 an oscillatory zoning with a dark core (Fig. 2F). Some apatite grains are occasionally fractured
251 with biotite filling these cracks.

252 In this sample, inclusions in zircon can be either mono- or polymineralic with grain sizes
253 < 20 microns. The identified inclusions are apatite (Fig. 2E), chlorite, biotite, plagioclase, quartz
254 and thorite. For this sample, apatite inclusions are always monomineralic.

255

256 5. Results

257 5.1. Apatite chemistry

258 Apatite crystals from the studied samples are all fluorapatites (Table A.5). Based on EPMA data,
259 apatite chemistries define two groups: a first group (samples AG09009 and AG09016) with high
260 Y_2O_3 (0.04 to 0.6 wt %) and low Cl (Cl < 0.045 wt %) and a second group (AG09014 and AG0915)
261 with lower Y_2O_3 (< 0.2 wt %) and higher Cl (0.048-0.2 wt%; Table A.5).

262 Contrary to samples AG09009 and AG09016, only matrix apatite has been analyzed in
263 AG09014 and AG09015 samples because inclusions were too small (< 10 μm in size).

264 *Sample AG09009.* Chondrite-normalized REE patterns of apatites from the matrix define
265 two groups: group 1 shows depleted LREE compared to HREE and a negative Eu anomaly
266 ($Eu/Eu^* = Eu_N / \sqrt{[(Sm)_N] \cdot (Gd)_N} < 0.5$; Fig. 3A, Table 2) whereas group 2 patterns are sub-parallel
267 to group 1 but with lower REE content and no Eu anomaly. Apatite inclusions have the same REE
268 patterns as group 1 with some grains having a higher REE concentration (Fig. 3A, 4A). Overall,
269 apatites from AG09009 have the highest concentrations in La (~166 ppm) and Yb (~353 ppm,
270 Table A.4) among all samples analyzed in this study (Fig. 4A). These highest values are
271 systematically associated with analyses done within crystal cores whereas lower concentrations
272 are linked to analyses done within rims (Fig. 4B-C). On the other hand, group 2 apatite
273 compositions have only been found in the outer-part of grains that had core compositions
274 belonging to group 1 apatites (Fig. 2D) and have the lowest REE concentrations (Fig. 4A).

275 *Sample AG09014.* Chondrite-normalized REE patterns for apatite from sample AG09014
276 show similar LREE depletion compare to HREE. In this sample, two groups of apatite can be
277 distinguished. The first group (Group 1) is similar to group 1 identified in other samples from this
278 study (Fig. 3C). The second group is depleted in all REE compared to group 1 and has a distinctive
279 impoverishment in LREE.

280 *Sample AG09015.* Contrary to previous samples, apatite from AG09015 displays multiple
281 and strongly distinguishable compositions. Five groups can be defined based on chondrite-
282 normalized patterns (Fig. 3D). Group 1 REE pattern is comparable to group 1 from the other
283 samples with a depletion in LREE compared to HREE (Fig.4A) and a negative Eu anomaly ($0.4 < \text{Eu}/\text{Eu}^* < 0.6$). All other groups have a strong depletion in LREE, which distinguishes them from
284 group 1. In Fig. 4A, it can be seen that the other groups (2-5) have low La and Yb contents and are
285 undistinguishable from each other (gray dots in Fig. 4D). These groups have highly depleted LREE
286 chondrite-normalized patterns ($\text{La}_N < 100$) compared to HREE ($\text{Yb}_N < 1000$). The best chemical
287 criterion that allows these groups to be discriminated is their respective Eu anomaly (Fig.3D).
288 Group 2 has no Eu anomaly ($0.9 < \text{Eu}/\text{Eu}^* < 1.3$), Group 3 a slightly negative Eu anomaly
289 ($\text{Eu}/\text{Eu}^* \approx 0.5$) and Group 4 a positive Eu anomaly ($\text{Eu}/\text{Eu}^* > 1.2$). Group 5 apatite has slightly
290 higher LREE chondrite-normalized values compared to group 4, and a small negative Eu anomaly
291 ($\text{Eu}/\text{Eu}^* \approx 0.75$). Group 2, 3 and 5 are always neoformed (no zonation, low REE content) or
292 recrystallized grains, while group 4 can be found as new generation grains or as an overgrowth
293 surrounding group 2 apatites.

295 *Sample AG09016.* Much as for sample AG09009, chondrite-normalized REE patterns of
296 matrix apatites from AG09016 define two groups. Group 1 is depleted in LREE compared to
297 HREE (mean $(\text{La}/\text{Yb})_N = 0.14$) with a consistent negative Eu anomaly (~ 0.3 ; Fig. 3B, Table A.4.).

298 Group 2 defines a sub-parallel pattern to group 1, with lower REE content, a stronger depletion in
299 LREE compared to HREE (c.a. $(La/Yb)_N=0.03$) and small Eu anomalies ($0.6 < Eu/Eu^* < 0.7$).
300 Chondrite-normalized REE patterns of zircon-hosted apatite inclusions have strong similarities
301 with group 1 apatite, although the LREE content in the former is more variable (Fig. 3B).

302

303 **5.2. Apatite U-Th-Pb geochronology**

304 **5.2.1. Matrix apatite**

305 Most of matrix apatite crystals in AG09009 define a major trend that intersects the Concordia
306 curve in a Tera-Wasserburg plot (Fig. 5A) at 1797 ± 27 Ma (MSWD = 3.6; n = 27). Once corrected
307 for common Pb (red ellipses in Fig. 5A), most data points plot onto the Concordia curve with a
308 weighted average $^{206}Pb^*/^{238}U$ age of 1794 ± 24 Ma (MSWD = 1.4). One data point lingers outside
309 the major trend and has a Concordia age of 3197 ± 82 Ma (MSWD = 0.09) and 3184 ± 120 Ma
310 (MSWD = 0.11; Fig. 5A) before and after common Pb correction, respectively.

311 Data for AG09014 apatite crystals form a robust trend with a lower intercept at 1700 ± 15
312 Ma (MSWD = 1.6; n = 12; Fig. 5B). Once corrected for common Pb, most data points plot on the
313 Concordia curve and exhibit a weighted average $^{206}Pb^*/^{238}U$ age of 1710 ± 20 Ma (MSWD = 0.92).

314 With the exception of one data point, all analyses from AG09015, show a trend that gives
315 a lower-intercept age of 1713 ± 21 Ma (MSWD = 4.1; n = 35; Fig. 5C). Once corrected for common
316 Pb, all data points plot on or very near the Concordia curve and give a weighted average $^{206}Pb^*/^{238}U$
317 age of 1723 ± 20 Ma (MSWD = 1.9). One data point plots on the Concordia and gives an age of
318 2721 ± 63 Ma.

319 All data points for apatites from AG09016 plot along a linear trend towards a lower-
320 intercept of 1746 ± 46 Ma (MSWD = 3.7; n = 37; Fig. 5D). Once corrected for common Pb, most

321 data points are concordant and have a weighted average $^{206}\text{Pb}^*/^{238}\text{U}$ age of 1721 ± 23 Ma (MSWD
322 = 2.2).

323

324 **5.2.2. Zircon-hosted apatite**

325 Over the large quantity of zircons mounted in epoxy and examined within thin sections (~200),
326 only a few apatite inclusions larger than 10 μm were found. One apatite was analyzed in sample
327 AG09009 whereas eight were analyzed in sample AG09016. Most zircon crystals in which we
328 found apatite inclusions have non-pristine internal textures, except for zircon AG09016-88 which
329 exhibits fine-oscillatory zoning. Ages for 6 of the 9 host-zircons are reported in Figure 6. The 3
330 remaining zircon crystals were not dated because of their disturbed internal zoning which would
331 have resulted in meaningless discordant ages. Apatite ages mentioned in this section correspond
332 to data corrected for common Pb unless specified otherwise. Overall, U-Pb isotope systematics in
333 apatite inclusions exhibit contrasting behavior compared to matrix apatite. The former essentially
334 distribute along the Concordia curve between 1700 and 4000 Ma whereas the latter forms a robust
335 trend between 1700-1800 Ma and common Pb (Fig. 7). In detail, zircon-hosted apatite inclusions
336 display three distribution behaviors: (i) on or close to the Concordia curve, (ii) on the matrix apatite
337 trend, and (iii) inverse discordance.

338 The oldest inclusion (AG09016-88) has a concordant age of 4003 ± 89 Ma ($^{207}\text{Pb}/^{206}\text{Pb}$ age
339 corrected for common Pb; 2 SE; 0.7% discordance; Fig. 7) which is consistent with data obtained
340 on the pristine-looking host-zircon (3967 ± 49 My, Guitreau et al., 2018). A second analysis in the
341 rim of the same inclusion shows a reversely discordant age, though consistent with the first one
342 (4111 ± 90 Ma). Two other data points from apatites AG09016-100 and 108 plot on the left of the
343 Concordia curve at $^{207}\text{Pb}/^{206}\text{Pb}$ ages corresponding to ~4000 Ma. Apatites AG09016-24 and 37

344 show concordant ages between 3200 and 4000 Ma. Apatite AG09016-15 is the biggest inclusion
345 and is not fully enclosed within the host-zircon (Fig. 6). The zircon exhibits a dark patchy zoning
346 indicative of advanced radiation damage accumulation. In this apatite inclusion, 3 analyses from
347 core to rim were done. Obtained U-Th-Pb ages decrease progressively from core (~3200 My) to
348 rim (~1800 My old; Fig. 7). Apatite AG09016-62 displays two ages consistent with the oldest
349 domains of apatite AG09016-15 (i.e., 3200 Ma and 2400 Ma). The single data point for AG09009
350 (08) corresponds to an age of 1867 ± 143 Ma ($^{207}\text{Pb}/^{206}\text{Pb}$ age; 2 SE) and comply well with the
351 major trend defined by matrix apatites, much as inclusion AG09016-11 (Fig. 7). It is important to
352 note that inclusion AG09009-08 is surrounded by chlorite and chlorite-filled cracks, suggesting
353 later fluid circulation within the zircon crystal (Fig.6). Similarly, apatite AG09016-11 is traversed
354 by a major crack that runs through the zircon.

355

356 **6. Discussion**

357 **6.1. Preservation of magmatic chemical signature**

358 In all studied TTG samples, apatite exhibits at least two chemical groups of which Group 1 has the
359 same characteristics across the entire range of samples. Group 1 apatites are characterized by
360 chondrite-normalized REE patterns depleted in LREE compare to HREE and a negative Eu
361 anomaly (Fig. 3). In a Nd vs Eu/Eu* diagram, group 1 apatites (both matrix and inclusions) have
362 systematically lower Eu/Eu* values and higher Nd content than that of other apatite groups (Fig.
363 8). Texturally, this group corresponds to core composition when a core to rim systematic is present
364 (Fig. 4B, C). Moreover, all zircon-hosted inclusions have group 1 chemical characteristics. Finally,
365 recent data on apatite from adakite (TTG-like signature; Bruand et al., 2020 and TTGs from two
366 other cratons (Kaalvaal, South Africa and Karelia, Finland) show comparable chemistry to group

367 1 apatite. All these results indicate that group 1 apatite composition represents primary (magmatic)
368 apatite REE signature.

369

370 **6.1.1. Matrix apatite**

371 Our new U-Th-Pb ages on matrix apatite indicate that the vast majority of analyzed crystals exhibit
372 ages that are consistent with the latest pervasive metamorphic event recorded by Acasta gneisses,
373 i.e., the 1800-1700 Ma Wopmay orogen (Fig. 5). This is in line with apatite ages obtained by Sano
374 et al., 1999) and Fisher et al. (2019) and indicate that metamorphic conditions associated with the
375 Wopmay orogen exceeded the closure temperature of apatite ($> 350\text{-}600^{\circ}\text{C}$ e.g. Cherniak et al.,
376 1991; Chamberlain and Bowring, 2001; Cochrane et al., 2014). We can, therefore, assume that any
377 previously recorded metamorphic events had been overprinted by that related to the Wopmay
378 orogen (Table A.1). Rare concordant matrix apatite ages at 3197 ± 82 and 2721 ± 63 Ma can point
379 to possible local preservation of older ages, in line with titanite geochronology (Davidek et al.,
380 1997; Fisher et al., 2019; Fig. 5), but overall magmatic ages are not preserved in matrix apatites
381 despite the local preservation of primary REE signature in the same apatites (group 1). The
382 dichotomy between the primary chemical signature of group 1 matrix apatite and the secondary
383 record of its U-Th-Pb data is consistent with diffusion work done on REE by Cherniak (2000) who
384 showed that REE in apatite can diffuse relatively slowly even in the case of high temperature
385 metamorphic events. This study demonstrates that two different types of substitution are
386 responsible for diffusion in apatite; simple substitution ($\text{REE}^{3+} \leftrightarrow \text{REE}^{3+}$) and coupled
387 substitutions (i.e. $\text{REE}^{3+} + \text{Si}^{4+} \leftrightarrow \text{Ca}^{2+} + \text{P}^{5+}$). In diffusion experiments, Cherniak (2000) showed
388 that Sr, Pb and O are more readily reset in apatite but can keep their primary signature in the core
389 of the crystal ($10\ \mu\text{m}$ zoning) for metamorphic episodes below 750°C and for a duration of $1.05 \cdot 10^4$

390 years. On the other hand, apatite grains (100 μ m in size) keep their primary REE signature for
391 metamorphic episodes of less than 10⁵ years in simple substitutions and 10⁷ years in coupled
392 substitutions for the same temperature.

393

394 **6.1.2. Apatite inclusions**

395 Zircon-hosted apatite inclusions within AG09016, all exhibit primary REE signatures and,
396 contrary to matrix apatites, essentially distribute along the Concordia curve with ages ranging
397 between ~1700 and 4000 Ma (Fig. 7; Table A.6). This demonstrates that apatite inclusions have
398 not been completely overprinted by the Wopmay orogen but, on the contrary, kept the memory of
399 older metamorphic events and even original igneous U-Pb ages in some cases. This is precisely
400 the case for apatite AG09016-88 which displays a concordant age of 4003 \pm 89 Ma (²⁰⁷Pb/²⁰⁶Pb
401 age, 0.7% discordant) that is very consistent with that obtained on the host-zircon (3967 \pm 49 Ma;
402 Guitreau et al., 2018). The large range of ages exhibited by apatite inclusions is consistent with
403 the fact that the AGC recorded several tectono-thermal events from 3750 to 1700 Ma, although it
404 is difficult to associate all ages to specific events (Table 2). Yet, three data points correspond to an
405 age of ~3200 Ma consistent with that of titanite and garnet within Acasta samples (Maneiro, 2016;
406 Fisher et al., 2019). We interpret the general distribution to represent punctual thermally activated
407 resetting during metamorphic events (e.g., Cochrane et al., 2014). Three other data points are
408 consistent with the matrix apatite trend, which suggest that the U-Pb system in these crystals were
409 reset in a similar way as matrix apatite, despite encapsulation within zircon. Therefore, apatite
410 inclusions have been either reset within zircon without any influence from the external media, or
411 in connection with this latter via cracks and porous zircon domains.

412 Reversely discordant data can be seen as either analytical artifacts or evidence for Pb

413 contamination, which would significantly lower the measured U/Pb ratio. An analytical artifact
414 would mean odd fractionation between U and Pb, which is inconsistent with the relatively good
415 agreement between U, Th, and Pb concentrations determined during trace element analyses and
416 U-Th-Pb isotope measurements. In addition, such extreme displacement from the Concordia curve
417 would mean an instrumental fractionation much too large compared to the rest of our U/Pb data.
418 Therefore, we think that the U-Pb isotope signatures of these inclusions are real and come from
419 Pb contamination of apatite inclusions. Common Pb cannot be responsible for this contamination
420 because the $^{208}\text{Pb}/^{206}\text{Pb}$ of reversely discordant apatite inclusions is too low. Figure 9 shows that
421 matrix apatite Pb isotope composition is controlled to a large extent by common Pb contamination
422 because data points form a positive correlation towards the common Pb end-member. In contrast,
423 apatite inclusions have a horizontal distribution and, hence, no visible influence from common Pb,
424 except for a few apatites that exhibited U-Pb data distribution consistent with the matrix apatite
425 trend in Figure 7. Therefore, we conclude that common Pb contamination cannot account for the
426 reversely discordant apatite data. Instead, we propose that reversely discordant apatite inclusions
427 were contaminated by radiogenic Pb coming from the host zircon during a thermal event such as
428 the Wopmay orogen. Radiogenic Pb migration has already been described in Archean zircons,
429 notably from the Napier Complex, Antarctica (Williams et al., 1984; Kusiak et al., 2013; Lyon et
430 al., 2019). The evolution of the Pb isotope composition of a zircon with a Th/U of 0.5 is presented
431 in Figure 9 and it is clearly visible that contamination by such radiogenic Pb would result in
432 horizontal spread of data in a $^{208}\text{Pb}/^{206}\text{Pb}$ versus $^{207}\text{Pb}/^{206}\text{Pb}$ plot.

433 The zircons that host apatite inclusions analyzed in this study are often not pristine-looking
434 (Fig. 6). Instead, they show advanced signs of radiation damage, a common feature in Archean
435 zircon, have variably discordant ages, and some of them even display metamorphic ages (See BSE

436 images in Fig. 6). Because zircons underwent disturbances in their U-Pb isotope systematics by
437 thermal events (Guitreau et al., 2018), one can easily expect that apatite inclusions might also be
438 affected. This would be consistent with our geochronological results. An important conclusion
439 from our apatite dating is that compared to matrix apatite, no common Pb seems to influence the
440 data distribution in AG09016 (Table A.6. and Fig. 9). This means that host-zircons satisfactorily
441 isolated apatite inclusions from external fluids possibly bringing common Pb, which accounts for
442 both the resetting of U-Pb ages, the existence of reversely discordant U-Pb data and the fact that
443 Sr isotope data for apatite inclusions from Emo et al. (2018) are less radiogenic than those in the
444 matrix despite zircons showing advanced radiation damage in CL images. If external fluids were
445 to penetrate within zircon, apatite Sr isotope composition should be influenced by the fluids, which
446 are more radiogenic. In summary, our results highlight that U-Th-Pb ages can be compromised in
447 apatite inclusions hosted in zircons with advanced radiation damage but this is not the case for
448 REE concentrations.

449

450 **6.2. Secondary apatite signatures**

451 The secondary groups of apatites are chemically distinct from the primary group described above.
452 All of them show a strong decrease in REE compared to group 1 apatites (or magmatic apatites),
453 with HREE depleted to a lesser extent than LREE. All apatites from groups 2 and more (except
454 AG09014), display no or more rarely a positive Eu anomaly (Fig.3D). These groups texturally
455 appear as new or recrystallized grains or are rimming group 1 cores. Their growth are related to
456 secondary processes such as metamorphism and/or metasomatism which in the light of current
457 literature on those phases are sometimes difficult to distinguish (Bau, 1991; Henrichs et al., 2018).

458 In the studied samples, we identified different late apatite generations:

459 (i) In one sample (AG09009), a core (group 1) to rim (group 2) systematic has been
460 identified (Fig. 4B). The depletion in LREE and the absence of Eu anomaly characterizing the rim
461 is interpreted as metamorphic (Fig. 3A). This type of overgrowth is also observed in
462 metamorphosed post-Archean apatites and has similar low REE+Y, U+Th rims around igneous
463 apatite cores (Henrichs et al., 2018).

464 (ii) For the three other samples, second generation of apatite crystals (Fig. 3 group 2 to 5
465 depending on samples have been observed. In samples AG09015 and AG09016, these groups are
466 interpreted as metamorphic and/or metasomatic. On the other hand, group 2 from sample AG09014
467 is the only second generation displaying a strong negative Eu anomaly and rather magmatic
468 characteristics. This could be related to a late magmatic interaction with a different magma or the
469 consequence of the crystallization of another LREE-mineral during the crystallization of the
470 granitoid (Hoskin et al., 2000; Bruand et al., 2014; Table 2). Here it probably points to a lower
471 grade of metamorphism (than for AG09015) because of its higher content in Cl and lower content
472 in Y (Table A.5.).

473 (iii) Apatites derived from primary monazite. These secondary apatites have only been
474 identified in sample AG09009 (Fig. 2B). In this case, primary monazite is destabilized in a
475 metamorphic corona of apatite and fibrous allanite. This type of secondary textures has been
476 described occasionally in natural samples (Gasser et al., 2012 in metapelite under amphibolite
477 facies; Finger et al., 1998 metamorphosed I and S-type granites under amphibolite facies) and in
478 experimental studies (Budzyń et al., 2017), and is characteristic of amphibolite facies metamorphic
479 conditions.

480 All secondary apatite compositions have U-Th-Pb ages corresponding to the Wopmay
481 orogen 1800-1700 Ma and have nucleated or were reset during this event (Fig. 5). Again, this is

482 consistent with young ages obtained by Sano et al. (1999) and Fisher et al. (2019).

483

484 **6.3. Apatite chemistry and identification of host-granitoid**

485 Archean TTGs are known for their specific geochemical signature, notably their high $(La/Yb)_N$
486 and low HREE concentrations (Fig. 10C; e.g., Moyen and Martin, 2012). They can be easily
487 discriminated from post-Archean granitoids in $(La/Yb)_N$ vs Yb_N diagrams. In this study, we found
488 that the same diagram discriminates very well TTG apatite from Post-Archean granitoid apatite
489 (Fig. 10A) alike in Bruand et al. 2020. However, the chemical characteristics define an opposite
490 trend when compared to the whole rock data. Indeed, apatites from TTGs have systematically low
491 $(La/Yb)_N$ ratios, high HREE contents and notably high Y concentrations, whereas apatites from
492 post-Archean granitoids commonly show the opposite. Interestingly, apatite chemistry from
493 peraluminous post-Archean granitoids are marginally overlapping with the apatite from TTG (Fig
494 10a-d). Their $(La/Yb)_N$ are nonetheless systematically higher than apatite TTG from Archean
495 cratons (Fig. 10D). Yet, a very important conclusion of our study is that we observed distinct
496 generations of apatite that we attribute to magmatic, late-stage, metamorphic and/or metasomatic
497 processes. The late events affecting the AGC have an impact on the LREE chemistry of apatite
498 whereas the HREE signature is similar. The consequence of this, is that the $(La/Yb)_N$ ratio of
499 secondary apatite in TTG will be even lower than the magmatic one (Fig. 10B). However, no
500 matter which generation analyzed apatites belong to, they all show the peculiar chemistry of TTG
501 apatite in a $(La/Yb)_N$ vs Yb_N diagram, hence, allowing identification of their source rock (Fig.
502 10). This signature is not specific to Acasta samples as shown by Bruand et al. (2020). Apatites
503 analyzed in TTG from Kaapvaal and Karelia cratons (South-Africa and Finland respectively) have
504 the same chemical characteristics.

505 Sr/Y vs Y diagram is another well-known discriminating diagram for TTG whole-rock. However,
506 this diagram only moderately discriminates the TTG from other granitoids when using apatite
507 chemistry. Indeed, Sr and Y contents in apatite have been shown to be strongly influenced by SiO₂,
508 Sr and the ASI of the melt (Bea and Montero, 1999; Sha and Chappell, 1999; Belousova et al.,
509 2002; Jennings et al., 2011; Bruand et al., 2014). Consequently, in a Sr/Y vs Y diagram, apatite
510 from peraluminous and TTG granitoid are undistinguishably defining the same field. REE
511 partitioning in apatite are intimately thlinked to the host rock ASI, substitutions and co-crystallizing
512 phases. To explain the dichotomy between the LREE depleted and enriched HREE characters of
513 TTG apatite and the LREE-enriched and HREE-depleted characters of TTG (whole rock; Fig. 10
514 A-C), we need to invoke the presence of other LREE-bearing phases. Recently, Bruand et al. 2020
515 have highlighted that the presence of monazite is not rare in TTG granitoids. In the studied
516 samples, only few occurrences of monazite interpreted as primary have been identified. The
517 occurrences of monazite in one of the samples suggest that the presence of monazite could be
518 partially responsible for the specific chemistry of TTG apatite. In post Archean granitoids co-
519 crystallizing monazite would mean a reduced host magma with ASI >1 and relatively low Ca
520 content (Hsieh et al., 2008). Trace elements allow making the distinction between mafic I-type
521 granitoids and I/S-type granitoids (Sha and Chappell, 1999) but the different types of granites can
522 only be discriminated by using Sr and Th. The concentrations in both elements are rather different
523 from the ones from post-Archean apatite, which shows that the composition of apatite in TTG are
524 most likely due to different melt composition and probably fO₂ during crystallization of the apatite
525 in the Archean granitoid. However, the competition between REE-bearing phases in TTG are not
526 well known and the absence of partition coefficient for those REE-bearing phases in such granitoid
527 preclude further interpretation of the data but highlight that more work is needed on this subject.

528

529 **6.4. Implications**

530 The results of the present study demonstrate that matrix apatites in polymetamorphosed Acasta
531 gneisses can preserve primary REE signatures, whereas U-Th-Pb isotope systematics have been
532 fully reset. On the contrary, zircon-hosted apatite inclusions can both preserve primary REE
533 signatures and U-Th-Pb isotope systematics provided that the host-zircon experienced limited
534 radiation damage and remained isolated from the external medium. Interestingly, apatite can be
535 used as a discriminating tool for different granitoid types (This study; Jennings et al., 2011; Bruand
536 et al., 2014, 2016, 2020). Therefore, our results strongly suggest that the geochemistry and
537 geochronology of detrital apatite and/or detrital zircon-hosted apatite inclusions can be used as a
538 new tool to unravel the origin, nature and evolution of complex multistage Archean cratons as well
539 as the type of granitoid Hadean detrital zircons crystallized from. However, one needs to be aware
540 of the limitations of this approach that essentially pertain to metamorphic resetting of isotope
541 systematics. This limits the use of detrital apatite but also suggests that when one focuses on
542 zircon-hosted inclusions, the host-zircon should be well characterized for, at least, internal textures
543 and U-Pb ages so as to understand the pristineness of the information encapsulated in the apatite
544 inclusion. This is because all inclusions within zircon are not systematically primary but could
545 grow within old radiation-damaged detrital zircons (e.g. Rasmussen et al., 2011). Consequently,
546 analyzed inclusions should be monomineralic to avoid perturbation from later events and should
547 be contained within a zircon with limited radiation-damage.

548

549 **7. Conclusions**

550 The aim of this study was to decipher whether or not, matrix apatites and apatite inclusions in

551 zircons from Archean TTGs from the Acasta Gneiss Complex (Canada) preserved primary
552 compositions. Here, we were able to demonstrate that primary REE composition of apatite in the
553 matrix can be preserved for large crystals (in this study mostly over 40 μm), whereas their U-Th-
554 Pb isotope systematics were fully reset by HT metamorphism around 1.8-1.7 Ga (Wopmay
555 Orogen). Our study also shows that apatites from TTGs have geochemical signatures $(\text{La}/\text{Yb})_{\text{N}}$
556 vs Yb_{N}) that are very distinct from those of apatite from other granitoid type, regardless of their
557 primary or secondary origin. In addition, our results show that Archean apatites trapped within
558 zircon that have withstood multiple HT metamorphic events were effectively protected and kept
559 their primary isotopic and geochemical signature, provided that zircon lattice underwent moderate
560 radiation damage. Altogether, these new results have important implications for studies of Archean
561 and Hadean crustal evolution because this tool can be applied to detrital apatites, knowing the
562 limitations of such an approach, but more importantly to detrital zircon-hosted apatites. In the latter
563 case, it is important to target the most pristine-looking zircon crystals, to characterize them for, at
564 least, U-Pb ages, and look for monomineralic apatite inclusions in priority.

565

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575

576

577 **Figure Captions**

578 Figure 1: Map of the AGC with the location of the samples for this study (red dot). Map modified
579 from Guitreau et al., 2018).

580

581 Figure 2: BSE and CL images of the studied samples A) Representative picture of AG09009
582 mineral assemblage typical for TTG compositions. B) Destabilization of monazite in apatite+
583 allanite linked to metamorphism in AG09009. C) Apatite inclusion in a zircon from AG09009
584 (BSE). D) CL image of apatite zoning in the matrix from sample AG09009 E) Apatite inclusions
585 in zircons (BSE) from sample AG09016 F) Apatite from the matrix (CL) from sample AG09016
586 G) Apatite aggregate from the matrix (CL) from sample AG09015. H) Apatite from the matrix
587 (CL) from sample AG09015. I-J) Apatite from the matrix (CL) from sample AG09014.

588

589 Figure 3: Chondrite-normalized REE patterns (normalization factor : Sun and McDonough, 1989)
590 from LA-ICP-MS analysis of apatites from all samples. A) Sample AG09009 groups 1 and 2 are
591 matrix apatites; last group is inclusions in zircons. B) Sample AG09016 groups 1 and 2 are matrix
592 apatites; last group is inclusions in zircons. C) Sample AG09014, all groups are matrix apatites.
593 D) Sample AG09015, all groups are matrix apatites.

594

595 Figure 4: A) La vs Yb diagram for all samples with first and secondary groups of matrix apatites.
596 B) La vs Yb diagram for samples AG09009/14 showing the decrease in REE from core to rim. C)
597 CL image of a matrix apatite with LA-ICP-MS laser spots location. The La and Yb composition
598 of each points match the bold circles in Fig.4B.

599

600 Figure 5: Tera-Wasserburg diagrams presenting U-Pb results for matrix apatites from AG09009

601 (A), AG09014 (B), AG09015 (C), and AG09016 (D).

602

603 Figure 6: Cathodoluminescence (CL) and back-scattered-electron (BSE) images for zircons
604 containing apatite inclusions analyzed in this study. Also reported are locations and labels of U-
605 Th-Pb isotope measurements together with zircon ages, when available (Guitreau et al., 2012,
606 2018).

607

608 Figure 7: Tera-Wasserburg diagram for apatite inclusions in AG09009 and AG09016 corrected for
609 common Pb. Also reported are matrix apatite data with (black dashed-circles) and without common
610 Pb correction (grey dashed-circles). Numbers next to colored ellipses correspond to analysis
611 numbers as reported in Table A.6., and in Figure 7.

612

613 Figure 8: Discriminating Nd vs Eu/Eu* diagram for all samples, matrix and inclusions.

614

615 Figure 9: $^{208}\text{Pb}/^{206}\text{Pb}$ versus $^{207}\text{Pb}/^{206}\text{Pb}$ plot for apatite data from this study. Also reported are the
616 evolution of the terrestrial lead, as given in Stacey and Kramers (1975), and the Pb isotope
617 evolution of a 4 Ga zircon that has a present-day Th/U of 0.5. Matrix and zircon-hosted apatites
618 exhibit a clear dichotomy with the former defining a positive trend towards common Pb whereas
619 the latter distribute horizontally, except for a few data points that have U-Pb ages consistent with
620 those of matrix apatite (see Fig. 6). Note that apatite $^{207}\text{Pb}/^{206}\text{Pb}$ ratios vary between values that
621 correspond to the age of the Wopmay orogen and that of the oldest Acasta gneisses, except for
622 three data points that we surmise incorporated zircon-derived radiogenic Pb during metamorphism
623 related to Wopmay orogen (see text for details).

624

625 Figure 10: A) $(La/Yb)_N$ vs Yb_N discriminating diagram for apatites from Archean granitoids (TTG)
626 and post-Archean granitoids. Literature data from (Hoskin et al., 2000; Belousova et al., 2001;
627 Dempster et al., 2003; Chu et al., 2009; Jennings et al., 2011; Bruand et al., 2014, 2020). B) Details
628 on the distinction between magmatic and metamorphic apatites from this study. C) $(La/Yb)_N$ vs
629 Yb_N discriminating diagram between TTG and post-archean rocks modified from Hansen et al.,
630 2002). D) $\text{Log}(La/Yb)_N$ vs Yb_N discriminating diagram between TTG and post-archean granitoids.

631

632 **Table Captions**

633 Table 1: Recapitulative table of the sample characteristics.

634

635 Table 2: Representative LA-ICP-MS analysis for all apatite samples from the matrix and in
636 inclusions within zircons.

637

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