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Benjamin Gehres, Guirec Querré

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1 *Analysis of mica inclusions using LA-ICP-MS:*
2 *a new approach for sourcing raw material of ceramics*

3
4 Dr. Benjamin GEHRES
5 Doctor - University of Rennes 2 (France)
6
7 UMR 6566 CReAAH
8 263, Avenue du général Leclerc
9 Campus de Beaulieu
10 Building 24-25
11 University of Rennes 1
12 CS74205
13 35042 Rennes Cedex – France

14
15 Email : benjamin.gehres@gmail.com

16
17 Dr. Guirec QUERRÉ
18 Research engineer - French Ministry of Culture and Communication
19
20 UMR 6566 CReAAH
21 263, Avenue du général Leclerc
22 Campus de Beaulieu
23 Building 24-25
24 University of Rennes 1
25 CS74205
26 35042 Rennes Cedex – France

27
28 Email : guirec.querre@univ-rennes1.fr

29
30 **Abstract:**

31
32 The analytical methods used for determining the origin of archaeological ceramics, such as
33 petrography, X-ray powder diffraction, X-ray fluorescence spectrometry, attain their limits for
34 differentiating bodies of similar composition, especially when they derive from the alteration of
35 granitoid rocks. Our new approach is based on the chemical analysis of biotite inclusions in ceramic
36 bodies using laser ablation-inductively coupled plasma-mass spectrometry, and enables us to identify
37 the geological origin of the clay used. Spot analysis of the biotite inclusions contained in ceramics
38 made from clay derived from the alteration of rocks can be linked to the original granitic massif. The
39 thin section or rock analysis of biotite inclusions is relatively fast. The dosage of trace elements, such
40 as lithium and vanadium establishes a filiation between the rocks and ceramics. Using this
41 geochemical base, it is possible to establish a link between a granitic batholith and early ceramics and
42 to propose a circumscribed production area. This article will focus on occupations located on islands
43 from western France.

44
45 **Keywords:** LA-ICP-MS, Sourcing, Ceramic, Raw material, Biotite

47 **1. Introduction**

49 In archaeology, the study of the origin of objects and of the raw materials in which they were made
 50 provides invaluable information for tracking relationships between different human groups for a given
 51 region and period, as well as recording the evolution of procurement throughout time. This is
 52 particularly true for archaeological ceramics, for which typochronology, but also composition and
 53 fabrication techniques are provenance criteria. At the present time, the most frequently used analytical
 54 methods for determining ceramic raw material sources are mineralogical and petrographic analyses
 55 with polarized light microscopy, X-ray powder diffraction (XRD), elementary chemical analyses using
 56 several techniques: pXRF (Hunt and Speakman, 2015), INAA (Speakman *et al.*, 2011), ICP-OES
 57 (Tsolakidou and Kilikoglou, 2004), ICP-MS (Kennett *et al.*, 2004). Other methods can be used and a
 58 more comprehensive list of these and their applications can be found in the literature (Rice 2006;
 59 Quinn 2009; 2013). The development of spectrometric spot analysis methods over the past few years
 60 paves the way for new perspectives in archaeometry (Sourcing of fluviatile shell temper: Peacock *et*
 61 *al.* 2007; elementary analyses of ceramics: Kennett *et al.* 2004; Golitko and Terrel 2012; U/Pb dating
 62 of inclusions of detrital zircons: Tochilin *et al.* 2012; distinction between fossil inclusions and shell
 63 temper: Gehres *et al.* 2015; characterization of archaeological materials: Speakman *et al.* 2002 ; 2011).
 64 We used the laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) method to
 65 characterize mineral phases included in ceramic bodies in order to determine their origin. In
 66 archaeology, the study of ceramic bodies is particularly interesting for tracing where they were made,
 67 among other aspects. In this way, these objects can be used to better evaluate exchange networks.

68 Apart from some organic tempers (ground bone, plants), the inclusions contained in ceramic bodies
 69 are mineral and these grains are characteristic of a specific geological source. The mineralogical and
 70 petrographic composition of archaeological ceramics generally reflects the geology of the place where
 71 they were produced, as workshops and production zones are generally close to raw materials sources.
 72 There are cases where the minerals, or assemblages of minerals from ceramic bodies are sufficiently
 73 rare and original to find their origin and define a presumably very restricted or even once-off
 74 production zone (Peacock 1988; Martineau *et al.* 2007; Quinn and Day 2007; Ixer and Vince, 2009),
 75 or where is a contrast in the composition of the geological substratum and the mineralogical
 76 composition of the bodies (Boileau *et al.* 2009).

77 When we work on archaeological sites located on crystalline bedrock with granite-gneissic rocks, it is
 78 very difficult to determine the massif or the formation of the original crystalline rocks from the
 79 alteration clays used to make ceramics, as a whole complex of formations have identical or close
 80 mineralogical compositions. In the geological formations existing on Earth, ancient cratons are
 81 generally composed of granite-gneissic rocks: like for example the Canadian Shield or the Baltic
 82 Shield.

83 This is the case in the Massif Central and the Armorican Massif in France (Fig. 1). There are
 84 numerous granite-gneissic formations in these cratons with very similar mineralogical composition,
 85 mainly made up of essential minerals such as quartz, plagioclase, potassium feldspar, micas such as
 86 biotite, muscovite) and at times smaller quantities of amphiboles and secondary minerals such as
 87 zircon, opaque minerals, rutile.

88 In order to develop our methodology, we worked on archaeological ceramics discovered in occupation
 89 sites mainly located in the Armorican Massif (Fig. 1), dating from the Neolithic and protohistory, from
 90 the end of the 5th millennium to the 1st century before our era. We used the LA-ICP-MS technique on
 91 thin sections to chemically characterize the biotite inclusions in ceramics and different rocks from the
 92 Armorican Massif (Fig. 1), where weathered and decayed rocks are likely to have been used by

93 potters. Indeed, chemical variations in the composition of these minerals are known to be very
94 susceptible to the physico-chemical conditions of different magmas (Wones and Eugster 1965;
95 Czamanske and Wones 1973; Helz 1973; Speer 1984; Haslam, 1968).

97 2. Origins of the studied ceramics (Table 1 / Fig. 2)

98
99 In order to test our method, we chose to work on ceramic productions issued from insular sites. By
100 working on islands, we have access to local, slightly diversified geological formations, creating more
101 favourable conditions than on the mainland. The studied ceramics are from two archipelagos in the
102 south of Brittany, one in the region of Carnac in Morbihan (Table 1, Fig. 2), the other in Finistère near
103 Pont-Aven (Table 1, Fig. 2).

104
105 For the Houat-Hoedic archipelago, Belle-Île-en-Mer (Fig. 2), two ceramics from the Middle Neolithic
106 I standing stone alignment (4700 - 4300 BCE) from Douet (Large *et al.* 2014) and one pottery from
107 the salt fabrication workshop from the Second Iron Age (700 - 1st century BCE) from Port Blanc were
108 used. A Bronze Age urn (850 - 700 BCE) with a granitic body from Belle-Île-en-Mer, completes the
109 corpus from this archipelago. This pot was used as a container for a deposit of metallic objects
110 (Audouard *et al.* 2010). One Hoedic granite sample, which is the only rock type on this island, is used
111 as a reference sample to define the geological source. The petrographic analysis of these ceramics
112 enabled us to observe inclusions characteristic of clays derived from the alteration of granite: grains of
113 quartz, potassium feldspar and plagioclase, but also biotite and muscovite tablets. Rock fragments
114 combining quartz, potassium feldspar and micas and presenting a grainy texture were also detected.
115 Therefore, these potteries were made from granitic clay. However, it is not possible to determine
116 whether they were made from the same clay, or clay from different sources.

117
118 For the Glénan Archipelago and Île aux Moutons (Fig. 2): three ceramics from the Middle Neolithic
119 occupation II (4200 - 3800 BCE) from Île aux Moutons, three from the Second Iron Age settlement
120 from Île aux Moutons (Daire and Hamon 2013) and two pottery from the Recent Neolithic settlement
121 (3800 - 2800 BCE) from the Glénan Archipelago were used. These pots were made from clays with
122 inclusions corresponding to the mineralogical composition of granitic rock. However, due to the
123 marked similarity of the inclusions, it was not possible to differentiate the origin of these ceramics.
124 Granite samples from Île aux Moutons and the Glénan Archipelago (one sample for each rock) were
125 then used as local references and samples of granites from Beg Meil and Trégunc served as continental
126 markers.

127 2.1. Geological context of the two archipelagos

128
129 Hoedic Island is mainly made up of granite with muscovite and biotite belonging to the family of
130 granites from the south of the Armorican Massif formed during variscan tectogenesis (340 - 300 Ma)
131 (Audren and Plaine 1986). The Belle-Île-en-Mer substratum is separated from the Houat-Hoedic
132 complex by a NW-SE fault line, and is very different from the neighbouring islands. It is mainly made
133 up of slightly metamorphic volcanic-sedimentary rocks: fine tuffs or porphyroids with a green schist
134 facies (Table 2; Audren and Plaine 1986). Île aux Moutons and the Glénan Archipelago are the most
135 northern islands off the southern coast of Brittany. Île aux Moutons is formed of a granitic base
136 characterized by coarse feldspar grains (Delanoë and Pinot 1977). It is to highlight that this granite
137 could be the same as the granite of Trégunc on the mainland, according to the 1/250000^e geological
138 map (Thinon *et al.* 2009). The Glénan Archipelago is made up of at least two types of rock: a

140 porphyroid leucogranite carved by granitic rock with muscovite and granite with muscovite and biotite
141 (Table 2; Béchennec *et al.* 1996).

143 3. Method

144
145 Spot chemical analyses were carried out with a quadrupole mass spectrometer with plasma source
146 (Agilent Technologies, 7700 Series) coupled with a laser ablation system Nd:YAG of 213 nm (Cetac
147 Technologies, LSX-213, G2). Laser ablation system conditions are the following: analysis time 180s,
148 spot diameter: 20 µm, force ≈ 2.5 mJ/pulse, pulse width ≈ 5 ns, pulse frequency 20 Hz, ablation speed
149 of 20 µm/s. Ablations are carried out on thin sections for archaeological pottery and directly on rock
150 fragment references. After the drawing of the ablation layout, a quick ablation is made, with low
151 energy and high speed, in order to homogenize the layout and remove possible pollution on the
152 sample. 5 to 10 biotite tablets are analyzed per sample. The depth of the ablation is less than 30 µm
153 and the inclusions can still be observed. The analysis of the average composition of each of the biotite
154 inclusions with an average size generally ranging from 200 to 500 µm was obtained by laser scan on
155 the whole inclusion.

156 The instrument is calibrated using international geological standards: DR-N, DT-N, UB-N
157 (Govindaraju and Roelandts 1989) and MICA-Fe (Govindaraju and Roelandts 1988). Altogether, 46
158 elements were measured: Na, Mg, Al, Si, K, Ca, Ti, Mn, Fe, Li, Sc, V, Cr, Co, Ni, Cu, Zn, As, Rb, Sr,
159 Y, Zr, Nb, Cd, Sb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Tl, Pb, Th, U.
160

161 The analysis results from biotite inclusions (Tables 3 and 4) contained in rocks and ceramics reveal
162 several elements enabling us to differentiate biotites depending on their origin. Indeed, the internal
163 variation of the chemical composition within sources is low and allow to determine the origin of each
164 rocks and ceramics. The major element have been converted into oxide forms (Na₂O, MgO, Al₂O₃,
165 SiO₂, K₂O, CaO, TiO₂, MnO, and Fe₂O₃) and the REE have been chondrite-normalized (McDonough
166 & Sun 1995).

167 4. Results and discussion

168 To identify the elements who allowed us to distinguish the different granites, the results of the
169 different analysis of biotites from the granites from Île aux Moutons, the Glénan Archipelago and also
170 from Beg Meil and Trégunc on the mainland, have been grouped using the principal component
171 analysis (Fig. 3). Thus, we can observe that the granite from Île aux Moutons and Trégunc are not
172 differentiable, but the granites from the Glénan Archipelago and from Beg Meil are clearly
173 distinguishable from the other rocks (Fig. 3). A cluster analysis of the measured elements allow us to
174 determine the main elements that can distinguish the different sources: Li, V, Zn, Sr (Fig. 4). Two
175 elements are particularly relevant; lithium - known for fixing mainly in mica tablets (Siroonian *et al.*
176 1959; Kuts and Mishchenko 1963) - and vanadium.
177

178 4.1. Houat-Hoedic-Belle-Île-en-Mer complex (Fig. 2)

179
180 The analyses of the biotite inclusions in four ceramics from the sites of Hoedic and one from Belle-Île-
181 en-Mer show dispersed composition (Fig. 5; Table 3). In the V versus Li diagram, the representative
182 points of the analyses are placed along two lines corresponding to very different Li/V ratios.
183

186 The first group of analyses presents a very high Li/V ratio with biotites with low vanadium contents;
187 these analyses correspond to the pottery from Belle-Île-en-Mer. The second group of analysis presents
188 a much lower Li/V ratio with low lithium values. These analyses correspond to the pottery from
189 Hoedic. These variations in Li concentration in biotites are generally linked to the intensity of
190 hydrothermal granite alterations (Konings *et al.* 1988). Therefore, this technique enables us to
191 differentiate compositions of trace elements in two types of ceramic productions with similar
192 petrographic characteristics. Moreover, the two composition groups probably correspond to two
193 different geological origins (Fig. 5). No granitic rocks outcrop on Belle-Île-en-Mer, where the
194 geological formations are largely dominated by green schists (Audren and Plaine 1986). Thus the
195 analyzed urn can only correspond to an imported vessel. According to biotite analyses by LA-ICP-MS,
196 the hypothesis of the importation of this urn to Belle-Île-en-mer from Hoedic or Houat must be
197 rejected. Therefore, the urn was made on the mainland from clay derived from the alteration of
198 granitic rock. However, the production zone has yet to be more accurately defined.

199 Biotite analyzes of the Hoedic granite follow the same line as those of the biotites included in the
200 ceramics discovered on this same island (Fig. 5). Furthermore, all the analyzed biotites in a single
201 sample have the same composition range, who is broader for the rock than for ceramics, but always
202 with the same Li/V ratio for both of them. The ceramics were thus probably made from clay derived
203 from the alteration of local rock. Consequently, this is a local non-imported production.

204 205 **4.2. Glénan Archipelago - Île aux Moutons complex (Fig. 2)**

206 Eight ceramics discovered on these different islands were selected for chemical LA-ICP-MS spot
207 analyses on the basis of the presence of biotite inclusions in ceramic raw materials from the Île aux
208 moutons and the Glénan Archipelago sites. Furthermore, by comparing the analyses of biotites from
209 local and continental granites, it should be possible to find the rocks that formed these clays by
210 alteration.

212 The results show that biotite compositions of ceramic bodies are not homogeneous, but develop
213 around regression lines (Fig. 6; Table 4).

215 Biotite analyses are recorded in the same V versus Li diagram as for the previous case. The points are
216 distributed in composition groups defining the lines with different V/Li ratios.

217 The Li/V ratio is between 1.84 and 7.34 for biotites from ceramics for which the raw material comes
218 from Île aux Moutons, whereas the Li/V ratio of biotites from pottery made with clays derived from
219 the alteration of the Beg Meil granite ranges between 0.06 and 2.12. Lastly, the Li/V ratio of biotites
220 from the Glénan Archipelago granite is between 73.51 and 242.22.

221 Three sets of points can be differentiated (Fig. 6). Two are made up of ceramic and granite biotite and
222 the other only of granite biotite. The first group corresponds to biotite inclusions with little Li,
223 between 0 and 300 ppm and very dispersed V values, ranging from several tens of ppm to nearly 800
224 ppm. These inclusions correspond to Neolithic ceramics from Île aux Moutons and the Glénan
225 Archipelago, as well as vessels from the Second Iron Age from Île aux Moutons. The Beg Meil
226 continental granite, located 10 km to the north of the archaeological sites is also in this group. Indeed,
227 biotites from ceramics and rock sample have the same Li/V range ratio. However, it is possible to
228 observe that the Li concentrations is higher in the rock, because of the alteration of the biotite crystals.
229 A second set groups is composed by Neolithic ceramics discovered on the Glénan Archipelago and
230 Iron Age ceramics on the Île aux Moutons, as well as to the Île aux Moutons granite and the
231 continental granite from B, situated 12 km northwest of the archaeological sites. This observation

232 confirm that the granites from Trégunc and Île aux Moutons are the same. The last set only contains
233 granite biotites from the Glénan Archipelago.

234 Therefore, the LA-ICP-MS analyses confirm the utilization of two clay sources on these islands. By
235 extension, it is now possible to deduce the origin of the other ceramics discovered on these islands. In
236 this way, we observe that exchanges with the mainland took place during the Neolithic, but also that
237 pottery was produced on Île aux Moutons and exported into the Glénan Archipelago. During the
238 Second Iron Age, this production no longer exists and all the vases are imported from the continent to
239 Île aux Moutons. Lastly, we note that no vessels appear to have been made from the clays derived
240 from granite alteration in the Glénan Archipelago during these periods.

241 These conclusions raise questions as to the type of occupations on these islands. They may have
242 consisted of seasonal occupations by mainland populations, during the harvesting of certain marine
243 products.

244

245 **Conclusions**

246 The chemical spot analysis of mineral inclusions in archaeological ceramic bodies using LA-ICP-MS
247 opens new prospects in terms of sourcing. The comparison of the analyses of biotite inclusions in
248 ceramics and the granitic rocks liable to have supplied pottery clays by alteration, using Armorican
249 samples, validates the method. The possibility of simultaneously analyzing very light elements like
250 lithium with this technique, which is generally difficult to measure, and heavier elements on very
251 small volumes of the size of an infra millimetric inclusion, is particularly potent. This is not the case
252 with commonly used techniques, such as Castaing electron microprobe (Froh 2004), ICP-AES (Bruno
253 *et al.* 2000) or PIXE, for example (Roumié *et al.* 2006).

254 This is a rapid method that requires little sample preparation: ablation is carried out directly on
255 ceramics, rocks or uncovered thin sections, unlike methods such as ICP-AES, which necessitates
256 Frantz magnetic separation (Konings *et al.* 1988) and which can do spot analyses, in contrast to PIGE
257 (Calligaro *et al.* 2000, Bugoi *et al.* 2008).

258 Results are obtained rapidly; analysis time is 180s for measuring 46 elements. The measurement of
259 limited quantities of elements improves the analysis results and leads to the analysis of more biotite
260 inclusions.

261 In those examples, we didn't find biotites with more than one geochemical composition in a single
262 sherd. This can be explained by the utilization of non-mixed clays, coming from a unique mother rock.
263 However, it can be possible that potters used mixed clays from alluvial deposits or have added crushed
264 rocks. In this case, it is possible to obtain several geochemical composition and different Li/V ratios
265 that represent each origins (Gehres, 2016).

266 The application of this new method to archaeological ceramics could be extended to minerals other
267 than biotite from granitic rocks when this material is not sufficiently abundant in ceramic bodies and
268 source rocks. Indeed, our work has been extended to the gabbroic clay with the analyses of
269 amphibole grains and ultrabasic clay with the studies of opaque mineral (Gehres, 2016; Gehres and
270 Querré, under press).

271

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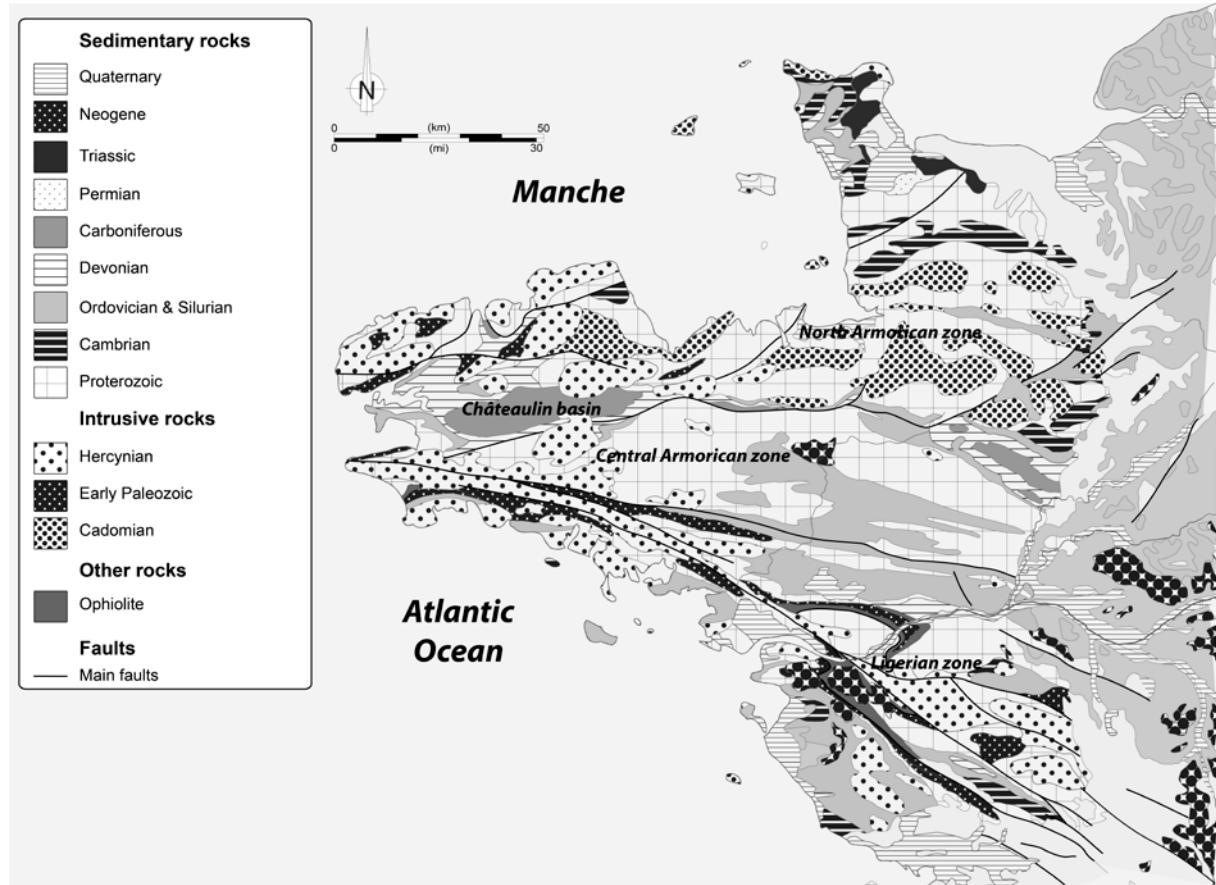
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- 432 **Captions**
- 433
- 434 **Fig.1** Simplified geological map of the Armorican massif
- 435
- 436 **Fig.2** Case study areas mentioned in the text: (1) The islands of Houat, Hoedic and Belle-Île-en-Mer – (2) The
437 Glénan Archipelago and the Île aux Moutons
- 438
- 439 **Fig.3** Results of the Principal Component Analysis of the dataset (44 elements). The percentage of the total
440 variance that is explained by the two principal components is 26.3 % and 17.5 %, respectively. The biotites from
441 the five different granites analysed in the article are represented. The ellipses represent the 95% confidence
442 ellipses.
- 443 ■ Biotite tablets from the granite of Beg Meil
- 444 ■ Biotite tablets from the granite of Île aux Moutons
- 445 ■ Biotite tablets from the granite of Glénan Archipelago
- 446 ■ Biotite tablets from the granite of Trégunc
- 447 ■ Biotite tablets from the granite of Hoedic
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- 449 **Fig.4** Hierarchical cluster analysis of the dataset with the Ward's method: Dendrogram displaying rescaled
450 distance among the different element of the biotites from the five granites analysed.
- 451
- 452 **Fig.5** Scatterplot of the concentrations obtained by LA-ICP-MS of Li and V (in ppm) of the analyzed biotites.
453 Each point corresponds to an analyzed inclusion. The ellipses represent the 95% confidence ellipses.
- 454 ■ Biotite tablets from the granite of the Hoedic island.
- 455 ● Biotite tablets from the ceramic (Douet 23) of the Middle Neolithic II site of Douet (Hoedic island)
- 456 ● Biotite tablets from the ceramic (Douet 32) of the Middle Neolithic II site of Douet (Hoedic island)
- 457 ▲ Biotite tablets from the ceramic of the Second Iron Age site of Port-Blanc (Hoedic island)
- 458 * Biotite tablets from the Bronze Age urn (Belle-Île-en-Mer).
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- 466 ● Biotite tablets from the ceramic (Île aux Moutons Neo 4) of the Middle Neolithic II site of Île aux Moutons
- 467 ● Biotite tablets from the ceramic (Île aux Moutons Neo 3) of the Middle Neolithic II site of Île aux Moutons
- 468 ● Biotite tablets from the ceramic (Île aux Moutons Neo 9) of the Middle Neolithic II site of Île aux Moutons
- 469 ● Biotite tablets from the ceramic (Saint Nicolas 3) of the Recent Neolithic site of Saint Nicolas (Glénan
470 Archipelago)
- 471 ● Biotite tablets from the ceramic (Saint Nicolas 10) of the Recent Neolithic site of Saint Nicolas (Glénan
472 Archipelago)
- 473 ● Biotite tablets from the ceramic (Île aux Moutons Iron Age 2) of the Second Iron Age site of Île aux Moutons
- 474 ● Biotite tablets from the ceramic (Île aux Moutons Iron Age 4) of the Second Iron Age site of Île aux Moutons
- 475 ● Biotite tablets from the ceramic (Île aux Moutons Iron Age 17) of the Second Iron Age site of Île aux
476 Moutons
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- 478 **Table 1** Descriptions of the geographic origin of the archaeological sites and their occupation periods and
479 location of the different granites mentioned
- 480
- 481 **Table 2** Geological description of the mentioned insular complexes
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- 483 **Table 3** Average chemical composition and standard deviation of biotite in potteries and granite from Hoedic
484 and Belle-Île-en-Mer

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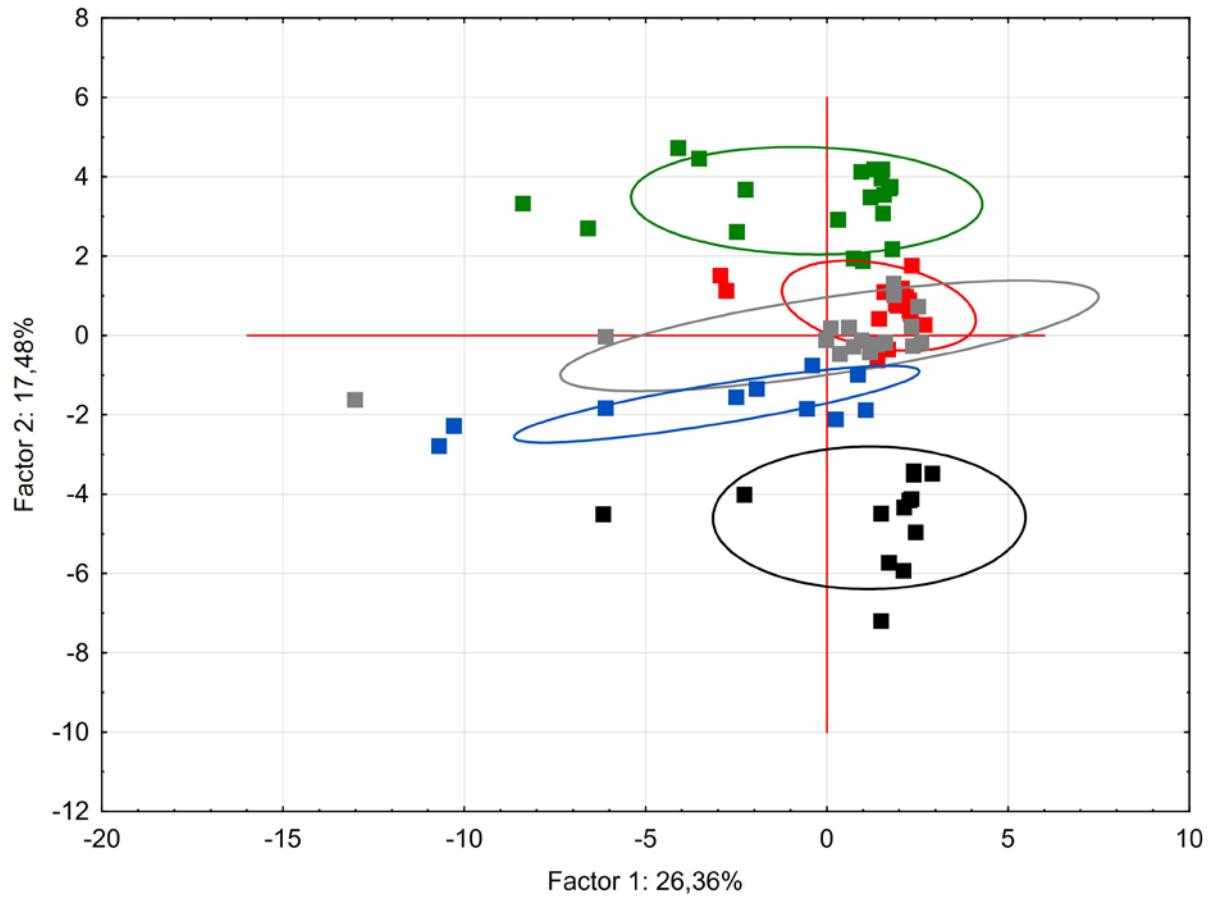
Table 4 Average chemical composition and standard deviation of biotite in potteries and granites from the Glénan



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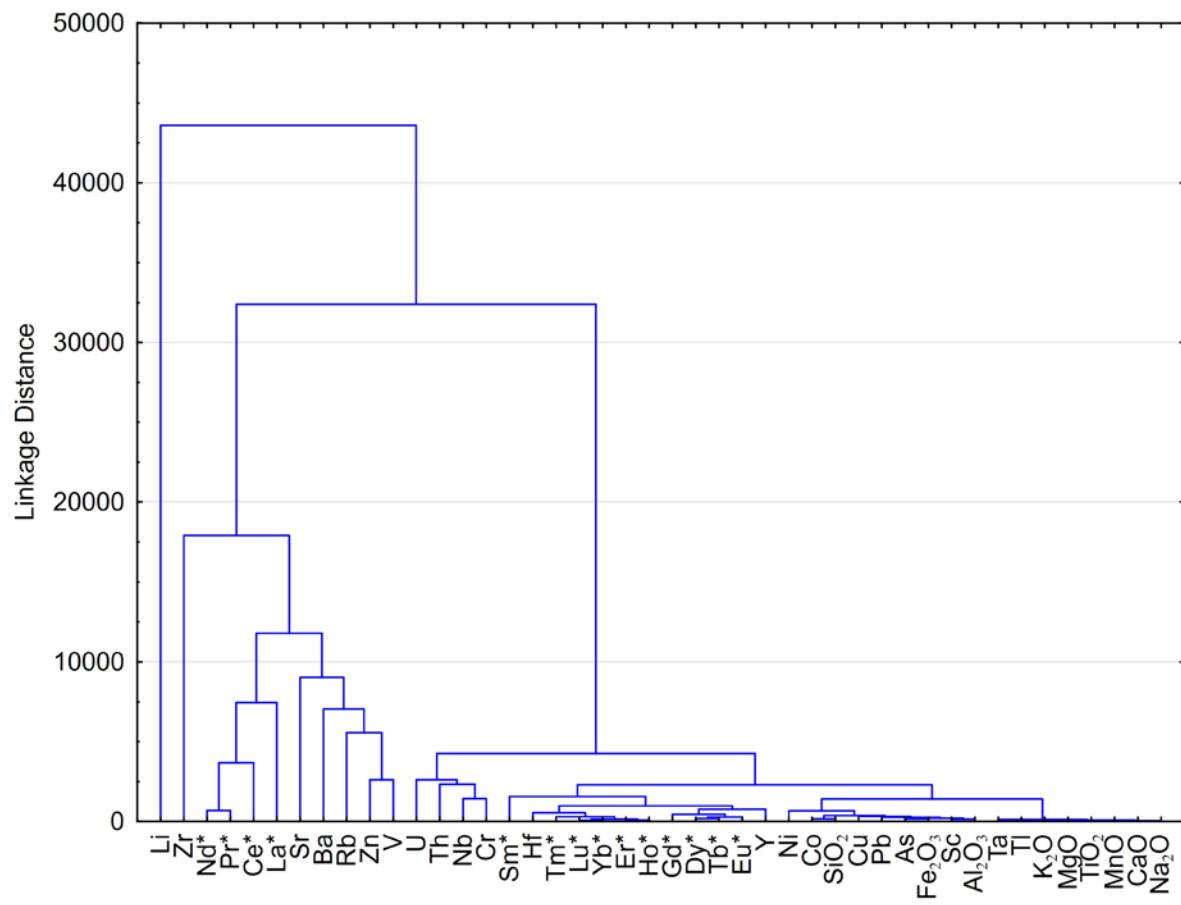
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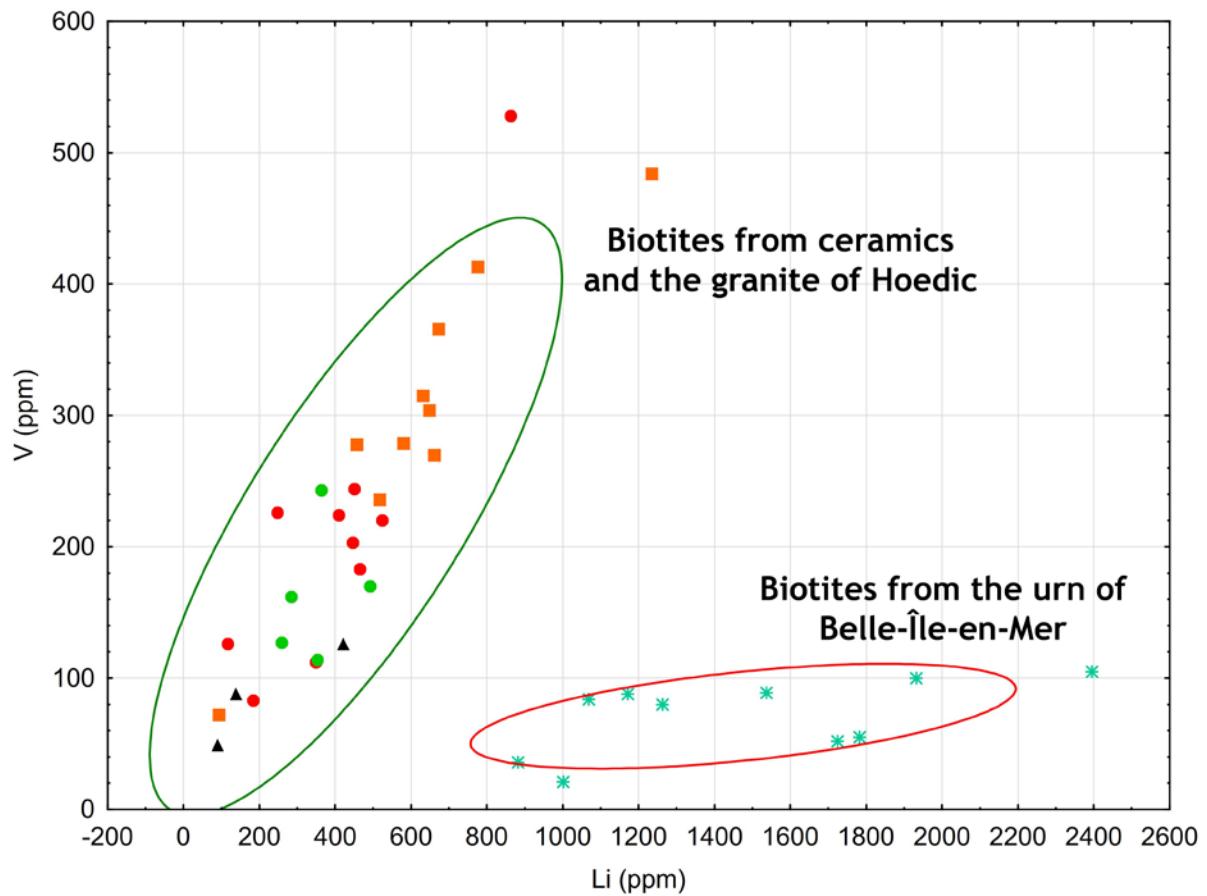
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- Biotite tablets from the granite of Glénan Archipelago
- Biotite tablets from the granite of Trégunc
- Biotite tablets from the granite of Hoedic



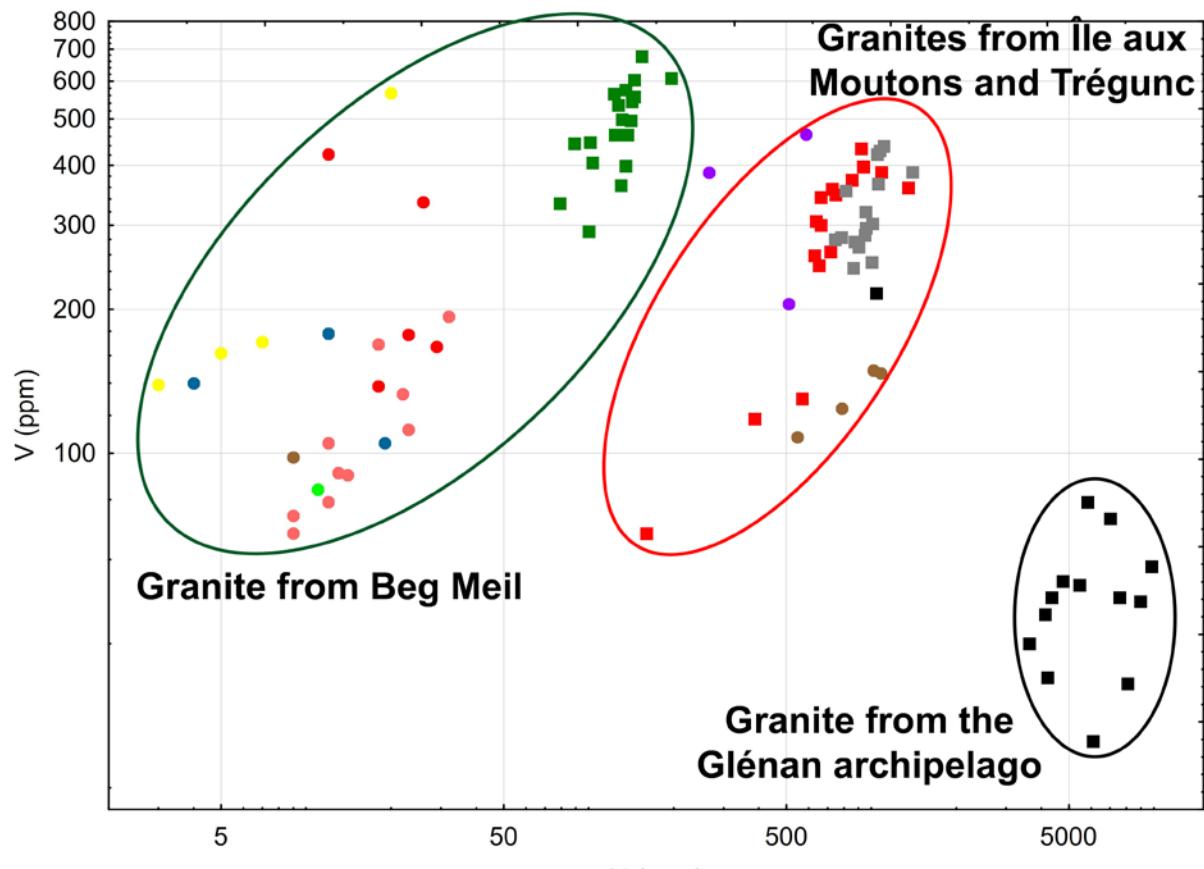
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544 ● Biotite tablets from the ceramic (Île aux Moutons Neo 3) of the Middle Neolithic II site of Île aux Moutons
545 ● Biotite tablets from the ceramic (Île aux Moutons Neo 9) of the Middle Neolithic II site of Île aux Moutons
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547 Archipelago)
548 ● Biotite tablets from the ceramic (Saint Nicolas 10) of the Recent Neolithic site of Saint Nicolas (Glénan
549 Archipelago)
550 ● Biotite tablets from the ceramic (Île aux Moutons Iron Age 2) of the Second Iron Age site of Île aux Moutons
551 ● Biotite tablets from the ceramic (Île aux Moutons Iron Age 4) of the Second Iron Age site of Île aux Moutons
552 ● Biotite tablets from the ceramic (Île aux Moutons Iron Age 17) of the Second Iron Age site of Île aux
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		Island	Ceramic / Rock	Site	Period
Morbihan	Houat-Hoedic Archipelago and Belle-Île-en-Mer	<i>Hoedic</i>	C	Le Douet	Middle Neolithic II
			C	Port-Blanc	Second Iron Age
			R	Hoedic Granite as a standard	
		<i>Belle-Île-en-Mer</i>	C	Bordustard	Late Bronze Age III
Finistère	Glénan Archipelago, Île aux Moutons	<i>Île aux Moutons</i>	C	Île aux Moutons	Middle Neolithic II
			C	Île aux Moutons	Second Iron Age
			R	Granite from Île aux Moutons as a standard	
		<i>Glénan Archipelago</i>	C	Saint-Nicolas des Glénan	Recent Neolithic
	Continent		R	Glénan granite as a standard	
			R	Granite from Beg Meil as a standard	
			R	Granite de Trégunc as a standard	

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565 **Table 1** Descriptions of the geographic origin of the archaeological sites and their occupation periods and location of the different granites mentioned

	Island	Geology
Houat-Hoedic Archipelago and Belle-Île-en-Mer	<i>Houat-Hoedic</i>	Granite with muscovite and biotite
	<i>Belle-Île en mer</i>	Tuffs / porphyroid green schist facies
Glénan Archipelago, Île aux Moutons	<i>Île aux Moutons</i>	Porphyroid granite
	<i>Glénan Archipelago</i>	Granite with muscovite and biotite

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568 **Table 2** Geological description of the mentioned insular complexes
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		Port Blanc	Standard deviation	Douet 23	Standard deviation	Douet 32	Standard deviation	Belle-Ile	Ecart type	Granite Hoedic	Standard deviation
Na ₂ O	%	0,42	0,18	0,66	0,2	0,89	0,11	0,8	0,17	5,55	9,03
MgO	%	2,72	2,07	3,43	0,48	3,09	0,24	2,68	0,3	4,23	1,62
Al ₂ O ₃	%	50,53	7,23	46,41	3,21	45,38	1,31	48,31	2,5	45,35	6,29
SiO ₂	%	38,35	3,89	39,43	2,62	39,1	0,74	37,9	1,56	35,42	9,99
K ₂ O	%	1,87	0,35	1,5	0,41	1,83	0,32	1,54	0,19	1,11	0,53
TiO ₂	%	0,98	0,63	1,34	0,5	1,47	0,21	1,1	0,22	1,01	0,63
MnO	%	0,07	0,05	0,1	0,06	0,1	0,05	0,09	0,03	0,06	0,05
Fe ₂ O ₃	%	5,07	4,11	7,13	0,91	8,13	0,85	7,58	1,05	4,79	2,08
Li	ppm	560	503,9	406	208,35	351	90,69	1476	482,39	627	283,29
V	ppm	126	62,36	215	122,86	163	50,6	71	28,27	302	110,14
Co	ppm	23	19,68	38	15,2	34	6,05	45	19,22	43	19,6
Ni	ppm	30	15,65	47	12,98	48	5,54	45	13,93	29	29,54
Cu	ppm	3	0,33	9	7,11	4	1,64	1304	1771,55	53	38,32
Zn	ppm	257	247,17	425	188,54	371	140,9	621	237,41	502	232,59
As	ppm	1	1,23	4	2,88	2	1,37	38	56,35	21	14,14
Rb	ppm	664	450,74	911	398,01	700	229,05	1019	316,43	677	490,46
Sr	ppm	158	63,62	323	227,33	189	95,51	366	307,15	1039	1741,94
Y	ppm	6	12,36	76	98,51	12	7,57	21	19,54	41	53,85
Zr	ppm	34	45,57	1089	2375,9	26	16,9	430	594,9	1963	3298,49
Nb	ppm	60	42,19	73	35,94	84	28,08	91	25,4	56	33
Sb	ppm	0	0,03	0	0,1	0	0,32	1	0,71	1	1,6
Ba	ppm	403	127,13	952	1389,3	704	669,25	333	203,26	450	312,65
La	ppm	2	2,29	400	550,92	17	15,99	30	28,1	118	205,31
Ce	ppm	6	8,36	1191	1754,14	58	49,22	62	54,28	177	350,1
Pr	ppm	1	1,05	93	133,14	7	5,72	7	6,94	20	37,93
Nd	ppm	4	6,82	388	526,41	17	14,35	25	20,66	101	183,95
Sm	ppm	1	1,13	66	93,51	4	2,94	4	3,22	21	33,1

Eu	ppm	0	0,24	3	2,31	1	0,85	1	0,89	3	4,34
Gd	ppm	1	1,28	41	59,89	5	4,56	3	2,84	18	25,04
Tb	ppm	0	0,32	6	7,95	1	0,54	1	0,72	2	2,42
Dy	ppm	1	1,41	24	26,25	3	2,32	4	3,12	9	9,87
Ho	ppm	0	0,12	3	2,26	0	0,35	1	0,45	1	1,67
Er	ppm	0	0,83	6	5,06	1	1,12	2	1,33	5	5,65
Tm	ppm	0	0,08	1	0,47	0	0,11	0	0,16	1	0,79
Yb	ppm	0	0,41	3	1,95	1	0,44	1	0,95	3	4,79
Lu	ppm	0	0,11	1	0,44	0	0,1	0	0,14	1	0,93
Hf	ppm	1	1,31	38	64,17	2	2,81	10	9,41	33	48,42
Ta	ppm	7	6,59	8	3,75	8	3,8	14	4,16	6	3,34
Tl	ppm	5	3,38	5	2,1	5	1,5	8	2,6	5	3,98
Pb	ppm	9	7,98	33	26,45	16	3,62	2205	5499,82	70	29,58
Th	ppm	1	0,81	167	289,05	11	18,13	9	6,23	18	27,17
U	ppm	1	1,75	35	52,41	2	1,88	12	9,06	12	12,1

Table 3 Average chemical composition and standard deviation of biotite in potteries and granite from Hoedic and Belle-Île-en-Mer

		Ile aux Moutons Neo 4	Standard deviation	Ile aux Moutons Neo 3	Standard deviation	Ile aux Moutons Neo 9	Standard deviation	Ile aux Moutons Iron age 2	Standard deviation	Ile aux Moutons Iron age 4	Standard deviation	Ile aux Moutons Iron age 17	Standard deviation	Saint Nicolas 3	Standard deviation	Saint Nicolas 10	Standard deviation	Granite Ile aux Moutons	Standard deviation	Granite Archipel des Glénan	Standard deviation	Granite continental (Beg Meil)	Standard deviation	Granite continental (Trégunc)	Standard deviation
Na ₂ O	%	1,6	0,81	0,28	0,26	0,48	0,17	2,37	2,8	0,3	0,09	2,48	1,63	1,2	0,66	0,61	0,48	0,16	0,10	0,37	0,11	0,20	0,09	0,11	0,08
MgO	%	3,35	1,1	2,39	1,04	3,15	1,17	1,11	1,47	4,21	0,61	2,84	1,07	3,21	1,69	0,96	0,44	5,77	0,66	1,47	0,19	5,69	0,60	5,51	0,20
Al ₂ O ₃	%	44,63	5,31	44,86	3,41	42,74	2,69	48,96	8,47	39,48	2	46,52	5,07	47,3	8,63	27,77	12,56	19,38	1,63	23,38	1,60	19,07	0,86	19,11	0,95
SiO ₂	%	41,58	5,67	36,52	3,67	42,84	2,73	42,27	5,02	40,55	3,94	37,9	2,9	39,99	5,81	31,47	7,43	44,16	2,57	42,47	4,94	44,18	1,59	42,06	0,85
K ₂ O	%	1,15	0,21	1,83	0,87	1,48	0,5	1,3	0,72	1,74	1,1	1,38	0,58	1,41	0,68	1,6	0,8	3,71	0,76	1,96	0,84	4,11	0,21	3,50	0,80
TiO ₂	%	0,06	0,02	1,24	0,42	1,36	0,37	0,45	0,51	1,26	0,77	1,03	0,49	0,88	0,56	9	17,68	1,65	0,46	1,09	0,41	1,27	0,14	1,83	0,21
MnO	%	6,49	1,75	0,07	0,03	0,09	0,07	0,06	0,08	0,06	0,01	0,04	0,02	0,12	0,08	0,41	0,77	0,25	0,06	0,69	0,15	0,20	0,05	0,47	0,04
Fe ₂ O ₃	%	645,8	286,1	12,26	2,16	7,86	2,38	3,49	3,1	12,4	5,26	7,81	1,62	5,9	2,64	13,15	4,89	24,72	2,85	28,51	4,35	25,25	1,68	27,34	0,98
Li	ppm	646	286,02	1409	1196,59	179	65	131	103,76	58	24,86	85	47,91	596	419,52	1568	1564,14	743	267,65	6144	1995,01	128	26,37	975	151,74
V	ppm	214	62,43	217	187,43	222	88,53	73	37,72	488	219,23	243	100,99	202	121,29	492	325,7	299	106,72	50	15,08	488	101,56	319	68,54
Co	ppm	16	4,39	16	2,73	10	3,06	5	4,11	16	6,58	17	5,86	21	12,47	77	39,35	43	13,29	17	4,60	60	12,59	48	7,64
Ni	ppm	37	15,06	29	13,98	35	22,51	11	14,91	44	9,19	27	14,57	44	29,33	59	30,91	45	14,14	24	7,19	130	25,81	45	7,63
Cu	ppm	75	23,75	49	15,49	44	14,85	21	13,01	72	38,55	40	14,61	54	21,55	272	180,13	17	16,19	14	9,13	54	27,35	8	7,86
Zn	ppm	8	3,57	98	58,93	53	23,74	48	24,04	40	34,98	4	2,03	49	65,88	9	3,89	397	128,38	527	149,41	199	33,46	564	76,81
As	ppm	285	128,52	927	547,62	148	97,15	109	134,47	215	97,4	73	72,75	413	285,73	1597	2523,75	8	7,71	31	11,10	10	12,08	6	5,09
Rb	ppm	6	4,82	27	20,2	29	16,58	6	4,83	39	48,91	13	3,28	6	3,97	31	24,91	527	193,60	418	209,32	291	51,18	1146	799,43
Sr	ppm	609	168,89	845	542,19	400	281,49	287	269,02	357	242,33	252	154,32	709	514,74	954	1320,08	99	65,52	65	16,18	22	8,59	21	11,33
Y	ppm	139	94,79	179	126,58	227	204,37	513	819,65	88	62,95	368	484,84	428	263,06	3125	3611,85	10	11,69	24	25,57	37	113,81	37	48,04
Zr	ppm	21	28,78	6	4,43	16	7,07	5	0,91	36	48,57	21	10,79	52	97,89	186	181,71	174	445,94	183	361,12	210	611,84	79	269,92
Nb	ppm	322	247,22	109	94,46	225	397,29	157	166,88	51	28,37	98	50,11	1264	2888,86	840	1101,5	66	23,20	218	142,51	59	12,94	118	27,58
Sb	ppm	56	20,11	104	51,62	30	12,87	32	39,74	33	20,75	32	16,88	72	48,63	243	276,61	0	0,15	1	0,32	0	0,10	0	0,10
Ba	ppm	0	0,18	1	0,26	1	0,46	0	0,06	1	0,42	0	0,04	0	0,08	0	0,17	430	275,23	167	223,70	1163	247,07	694	816,35
La	ppm	294	173,27	240	139,32	301	101,55	169	59,2	295	225	155	45,08	856	815,45	666	537,74	196	589,59	216	613,78	611	1010,96	547	1208,48
Ce	ppm	11	9,86	16	19,69	29	11,36	19	20,99	72	102,69	40	24,65	50	77,49	148	138,7	127	335,39	166	514,72	302	525,85	352	799,46
Pr	ppm	21	18,83	29	34,37	57	22,2	29	28,08	147	214,93	104	85,14	109	140,78	497	539,11	68	148,44	91	244,18	159	255,39	216	387,07
Nd	ppm	2	1,79	4	4,35	8	3,31	5	2,67	24	35,77	9	5,58	11	14,24	60	67,45	59	125,93	64	160,79	123	200,56	170	275,61

Sm	ppm	13	12,97	13	15,69	32	14,5	12	8,65	104	154,73	37	22,22	54	82,21	246	300,9	34	70,98	45	106,49	70	107,59	90	136,83
Eu	ppm	2	1,95	5	7,05	6	3,03	3	1,58	19	28,5	6	3,42	9	10,7	87	98,69	7	5,62	21	34,67	38	54,75	31	34,47
Gd	ppm	1	0,26	0	0,37	1	0,6	0	0,26	4	5,03	2	1,06	2	2,88	4	3,86	22	44,68	30	53,28	43	69,27	60	77,58
Tb	ppm	2	3,77	2	1,41	5	2,17	2	0,85	12	18,07	4	2,51	9	9,33	65	78,38	18	35,12	27	37,22	41	55,04	44	58,57
Dy	ppm	0	0,72	0	0,37	1	0,31	0	0,06	2	2,63	1	0,45	2	2,59	7	7,74	13	23,81	20	24,04	31	49,73	34	48,20
Ho	ppm	5	8,68	2	1,73	4	1,7	1	0,51	10	14,14	4	1,75	12	17,13	36	42,82	10	17,63	15	17,37	26	44,26	25	35,42
Er	ppm	0	0,49	0	0,29	1	0,28	0	0,03	1	1,76	1	0,2	2	3,22	5	7,18	7	11,17	12	15,27	21	33,90	21	31,09
Tm	ppm	1	0,86	1	0,64	1	0,42	0	0,09	3	4,04	2	0,93	7	11,69	17	22,17	6	9,20	12	16,58	29	75,96	26	35,39
Yb	ppm	0	0,21	0	0,11	0	0,08	0	0,04	0	0,66	0	0,06	1	2,03	2	2,26	7	9,83	15	20,66	18	28,99	19	30,08
Lu	ppm	1	1,06	0	0,58	1	0,51	0	0,16	3	3,85	1	0,59	7	15,11	21	28,57	6	9,95	14	21,83	18	37,85	16	25,45
Hf	ppm	0	0,2	0	0,13	0	0,1	0	0,05	0	0,44	0	0,09	2	3,49	3	3,9	16	25,38	29	44,70	33	88,64	23	40,59
Ta	ppm	7	4,59	4	2,43	3	2,5	3	2,39	1	0,74	4	2,69	44	99,58	115	230,22	1	0,50	15	15,69	1	0,26	2	1,01
Tl	ppm	6	1,74	22	17,68	3	0,96	5	5,58	3	2,07	3	1,92	10	7,89	27	25,01	6	1,77	7	3,29	3	0,49	11	4,27
Pb	ppm	4	0,81	8	5,27	3	1,65	2	2,28	3	1,8	2	0,82	5	3,87	6	8,1	11	5,40	38	16,85	8	2,94	32	17,61
Th	ppm	16	4,11	29	26,46	52	29,75	27	2,34	54	53,8	40	38,22	22	13,16	42	27,36	56	150,29	105	349,23	91	294,49	68	141,29
U	ppm	5	4,48	27	41,66	25	13,39	14	6,04	75	43,5	48	21,15	26	28,68	229	281,92	4	5,38	117	329,00	5	11,18	113	395,19

Table 4 Average chemical composition and standard deviation of biotite in potteries and granites from the Glénan