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### ► **To cite this version:**

Christophe Ballouard, Marc Poujol, Philippe Boulvais, Yannick Branquet, Romain Tartese, et al..  
Nb-Ta fractionation in peraluminous granites: A marker of the magmatic-hydrothermal transition.  
Geology, 2016, 44 (3), pp.231-234. 10.1130/G37475.1 . insu-01270578

**HAL Id: insu-01270578**

**<https://insu.hal.science/insu-01270578v1>**

Submitted on 17 Dec 2021

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# Geology

## Nb-Ta fractionation in peraluminous granites: a marker of the magmatic-hydrothermal transition

--Manuscript Draft--

<b>Manuscript Number:</b>	
<b>Full Title:</b>	Nb-Ta fractionation in peraluminous granites: a marker of the magmatic-hydrothermal transition
<b>Short Title:</b>	Nb-Ta fractionation in peraluminous granites
<b>Article Type:</b>	Article
<b>Keywords:</b>	Nb-Ta fractionation, peraluminous granites, magmatic-hydrothermal transition, mineralization-bearing granites
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<b>Order of Authors Secondary Information:</b>	
<b>Manuscript Region of Origin:</b>	
<b>Abstract:</b>	<p>In their late stages of evolution, peraluminous granitic melts exsolve a large amounts of fluids which can modify the chemical composition of granitic whole rocks samples. The Nb/Ta ratio is expected to decrease during magmatic differentiation of granitic melts, but the behavior of both elements at the magmatic-hydrothermal transition remains unclear. Using a compilation of whole rock geochemical data available in the literature, we demonstrate that fractional crystallization alone is not sufficient to explain the distribution of Nb-Ta in most peraluminous granites. However, we notice that most of the granitic samples displaying evidence of interactions with fluid, regardless of their age or their emplacement conditions, have Nb/Ta &lt; 5. We propose that the decrease of the Nb/Ta ratio in highly evolved melts is the consequence of both fractional crystallization and sub-solidus magmatic-hydrothermal alteration. We suggest that the value Nb/Ta = 5 in peraluminous granite fingerprints the magmatic-hydrothermal transition. Furthermore, a Nb/Ta ratio of 5 appears to be a good marker to discriminate mineralized from barren peraluminous granites.</p>
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1 Nb-Ta fractionation in peraluminous granites: a marker of the  
2 magmatic-hydrothermal transition

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14

15 **ABSTRACT**

16 In their late stages of evolution, peraluminous granitic melts exsolve a large amounts of fluids  
17 which can modify the chemical composition of granitic whole rocks samples. The Nb/Ta ratio is  
18 expected to decrease during magmatic differentiation of granitic melts, but the behavior of both  
19 elements at the magmatic-hydrothermal transition remains unclear. Using a compilation of whole  
20 rock geochemical data available in the literature, we demonstrate that fractional crystallization  
21 alone is not sufficient to explain the distribution of Nb-Ta in most peraluminous granites.

22 However, we notice that most of the granitic samples displaying evidence of interactions with  
23 fluid, regardless of their age or their emplacement conditions, have Nb/Ta < 5. We propose that  
24 the decrease of the Nb/Ta ratio in highly evolved melts is the consequence of both fractional  
25 crystallization and sub-solidus magmatic-hydrothermal alteration. We suggest that the value  
26 Nb/Ta = 5 in peraluminous granite fingerprints the magmatic-hydrothermal transition.

27 Furthermore, a Nb/Ta ratio of 5 appears to be a good marker to discriminate mineralized from  
28 barren peraluminous granites.

29

## 30 **INTRODUCTION**

31 In granitic systems, the magmatic-hydrothermal transition separates a purely magmatic system  
32 dominated by crystal-melt interaction from a system dominated by crystal-melt-magmatic fluid  
33 phase interaction (Halter and Webster, 2014). Hydrothermal activity in peraluminous granites  
34 can be either localized, as evidenced by pegmatites and/or quartz veins, or pervasive, leading to  
35 significant element mobility and, in the most extreme cases, to the formation of greisens  
36 (Pirajno, 2013). Such alteration events occur during the sub-solidus stage of the granitic melt  
37 emplacement and may lead to the deposition of economically significant mineralization such as  
38 Sn or W.

39 Nb and Ta are lithophile elements considered as “geochemical twins” because they have the  
40 same charge and similar ionic radius. As a result they have similar geochemical properties and  
41 should not be fractionated during most geological processes (Goldschmidt, 1937). However, in  
42 granitic rocks, Nb/Ta ratios are highly variable (< 2 - 25; Green, 1995). Some authors have  
43 demonstrated that the Nb/Ta ratios decrease in granites during fractional crystallization  
44 (Raimbault et al. 1995; Linnen and Keppler, 1997; Stepanov et al., 2014). Other studies have  
45 suggested that Nb and Ta could be fractionated in highly evolved peraluminous granites during  
46 the interaction with late magmatic fluids (Dostal and Chatterjee, 2000; Tartèse and Boulvais,  
47 2010; Ballouard et al., 2015; Dostal et al., 2015).

48

49 In order to decipher the specific role of the magmatic and hydrothermal processes on the  
50 evolution of the Nb/Ta ratios, we compiled whole rock geochemical data available in the  
51 literature for peraluminous granites emplaced at different times and in various tectonic contexts.  
52 Based on these data, we show that fractional crystallization of granitic melts alone is not  
53 sufficient to account for the Nb-Ta behavior observed in most peraluminous granites and that  
54 hydrothermal processes are necessarily involved.

55

## 56 **PRESENT KNOWLEDGE**

### 57 **Magmatic behavior of Nb-Ta**

58 In highly evolved granites and pegmatites, columbite ((Fe,Mn)Nb<sub>2</sub>O<sub>6</sub>) and tantalite ((Fe,  
59 Mn)Ta<sub>2</sub>O<sub>6</sub>) are the main mineral phases hosting Nb and Ta. Experimental studies have shown  
60 that the solubility of these two minerals in granitic melts increases with temperature, but  
61 decreases with increasing the Aluminium Saturation Index (ASI), a parameter related to the  
62 degree of polymerization of the melt (Linnen and Keppler, 1997; Aseri et al., 2015). The Li  
63 content of granitic melts also increases the solubility of columbite and tantalite (Linnen, 1998;  
64 Aseri et al., 2015).

65 Partial melting can produce granitic peraluminous melts with Nb/Ta ratios higher or lower than  
66 their source, depending on the temperature. Melts formed during high temperature anatexis tend  
67 to have high Nb/Ta ratios, as a result of the complete consumption of biotite and the high  
68 abundance of Ti-bearing oxides in the residue, which preferentially incorporate Ta over Nb  
69 (Stepanov et al., 2014). Conversely, low temperature partial melting generates melts with low  
70 Nb/Ta ratios because residual biotite incorporates preferentially Nb over Ta (Stepanov et al.,  
71 2014). Since biotite and Ti-bearing minerals can also be involved during differentiation of

72 granitic melts, fractional crystallization also changes Nb/Ta ratios: Nb/Ta increases during high  
73 temperature fractional crystallization of Ti-rich melts due to the preferential saturation of Ti-  
74 oxide minerals over biotite, whereas Nb/Ta ratios decrease during low temperature  
75 differentiation of granitic melts due to the fractionation of biotite and/or muscovite (Stepanov et  
76 al., 2014). In the most evolved peraluminous melts, the lower solubility of manganocolumbite  
77 ( $\text{MnNb}_2\text{O}_6$ ) compared to manganotantalite ( $\text{MnTa}_2\text{O}_6$ ) also enhances the decrease of the Nb/Ta  
78 ratio in the melt (Linnen and Keppler, 1997).  
79 Melt inclusions in Li-F granites (Orlovka massif, Eastern Transbaikalia) indicate a separation of  
80 an immiscible F-rich hydrosaline melt that can induce a decrease of the Nb and Ta contents in  
81 the residual melt (Badanina et al., 2010).

82

### 83 **Nb-Ta behavior in hydrothermal systems**

84 Nb and Ta are poorly soluble in aqueous solutions, Ta being even less soluble than Nb (Zaraisky  
85 et al., 2010). Experiments with aqueous F-rich fluids and aluminosilicate melt indicate that Nb  
86 and Ta preferentially partition in the melt (Chevychelov et al., 2005). However, the solubility  
87 and hydrothermal transfer of Ta and Nb are greatly enhanced in F-rich solutions under reducing  
88 conditions (Zaraisky et al., 2010). These experimental results are consistent with the fact that  
89 several F-rich cupolas of greisenized peraluminous granites are significantly enriched in both Nb  
90 and Ta (e.g. Zaraisky et al., 2009).

91

### 92 **VARIATIONS OF WHOLE ROCK NB/TA RATIOS IN PERALUMINOUS GRANITES**

93 We compiled data for peraluminous granites (i.e., with a A/CNK ratio > 1) as well as for some  
94 greisens of different ages (Archean to Mesozoic) and emplaced in various geodynamical contexts  
95 (see Table DR1 in the GSA Data Repository).

96

### 97 **Nb-Ta fractionation during magmatic processes**

98 In Figure 1, the Nb/Ta ratios are highly variable between ~15 and ~0 when reported as a function  
99 of Nb and Ta, the lowest values being recorded by whole rocks displaying the highest Nb and Ta  
100 contents. Mica fractionation in granitic melt induces a decrease of the Nb/Ta ratios (Stepanov et  
101 al., 2014). In Figure 1, we modeled the evolution of a melt with an initial Ta and Nb contents of  
102 1.5 ppm and 12 ppm (Nb/Ta = 8), respectively, undergoing fractionation of a cumulate made of  
103 80 wt.% (quartz + feldspar) + 10 wt.% muscovite + 10wt.% biotite, using the Rayleigh  
104 distillation law and the silicate-melt partition coefficients compiled by Stepanov et al. (2014).  
105 The modeling qualitatively reproduces the behaviors of Nb and Ta, but it requires an unrealistic  
106 rate of mineral fractionation (over 90 wt.%) to reach low Nb/Ta ratios around 2 and Nb and Ta  
107 contents around 20 and 10 ppm, respectively (Fig. 1). The addition of 0.5 wt.% Fe-Ti oxide  
108 (e.g. ilmenite or rutile) in the cumulate, in which Ta and Nb are highly compatibles (Stepanov et  
109 al., 2014), makes things even worse. Indeed, the fractionation of this cumulate causes a decrease  
110 of the Nb content (Fig. 1A), resulting in a trend opposite to the trend displayed by the  
111 peraluminous granites.

112 If crystal-melt fractionation is likely to occur during the crystallization of granitic melts in  
113 magmatic bodies (Dufek and Bachmann, 2010) and during the magma ascent in dykes (Tartèse  
114 and Boulvais, 2010; Yamato et al., 2012), numerical modeling shows that the efficiency of  
115 crystal-melt segregation is restricted to cases where crystals represent a low percentage of the

116 total magma volume (Yamato et al., in press). Indeed, 70-75% of crystallization marks the  
117 particle locking threshold (PLT in Figure 1B, Vigneresse et al., 1996) where the liquid becomes  
118 totally locked, precluding any crystal-melt segregation. The model presented here thus suggests  
119 that fractional crystallization alone is not sufficient to explain the behaviors of Nb and Ta in  
120 peraluminous granitic rocks.

121

## 122 **Nb-Ta fractionation during magmatic-hydrothermal processes**

### 123 *Mineralogical markers*

124 Secondary muscovitization and greisenization occur under sub-solidus conditions during the  
125 interaction between crystallized granites and acidic late magmatic fluids (Pirajno, 2013). The  
126 Figure 2 shows that the Nb/Ta ratios of whole rock granites and greisens are anti-correlated with  
127 the average  $\text{MgO}/(\text{Na}_2\text{O} + \text{TiO}_2)$  ratios of the muscovite they host (a chemical marker for  
128 secondary muscovitization, Miller et al., 1981). This observed anti-correlation suggests that the  
129 fluids involved in the secondary muscovitization processes could also be responsible for the  
130 decrease of the Nb/Ta whole-rock values. Whole rock hydrothermal enrichment of Ta during  
131 secondary muscovitization is, for example, observed in ongonites (topaz-bearing  
132 microleucogranites) from the Ongon Kairkhan (Mongolia) and this process is associated with the  
133 crystallization of late Ta-rich overgrowth on Nb-Ta oxides (Dostal et al., 2015).

134

### 135 *Geochemical markers*

136 The whole rock Nb/Ta ratios of peraluminous granites are anti-correlated with their Sn contents,  
137 an element highly mobilized at the magmatic-hydrothermal transition (Fig. 3A): high Sn contents  
138 above ~30 ppm are only encountered in granitic samples (or greisens) with low Nb/Ta (< 5).

139 These samples also display high contents in Cs, F, Li, W and Rb. Because such incompatible  
140 elements present a strong affinity for magmatic fluids, their enrichment is commonly used as a  
141 marker of a magmatic-hydrothermal alteration in highly evolved crustal granites. Indeed,  
142 increasing the abundance of highly incompatible elements, with a bulk partition coefficient  $K_d$   
143 between the mineral phases and the melt close to 0, by two orders of magnitude, as observed in  
144 Figure 3A (from ~10 to ~1000 ppm), during fractional crystallization requires a unrealistic  
145 degree of fractional crystallization up to 99 wt.%, suggesting that hydrothermal processes are  
146 also involved. Such enrichments in highly incompatible element, attributed to interaction with  
147 magmatic fluids, have been noticed in the Erzgebirge massif (Förster et al., 1999), in the South  
148 Mountain Batholith (e.g. Dostal and Chatterjee, 2000), or in the French Armorican Massif  
149 (Tartèse and Boulvais, 2010; Ballouard et al., 2015).

150

151 The Nb/Ta ratios also correlate with the K/Rb ratios (Fig. 3B). Most granites with low Nb/Ta  
152 display K/Rb values lower than 150, characteristic of the pegmatite-hydrothermal evolution  
153 (Shaw, 1968). Such a tendency is observed in the South Mountain Batholith, where it was  
154 interpreted as evidence for a magmatic-hydrothermal alteration (Dostal and Chatterjee, 2000).

155

156 Finally, the whole rock Nb/Ta ratios can be compared with the magnitude of the tetrad effect,  
157 which corresponds to the intra-REE fractionation observed in the REE patterns of highly  
158 fractionated magmatic rocks and hydrothermal precipitates (e.g. Irber, 1999). Although Duc-Tin  
159 and Kepller (2015) have recently suggested that the tetrad effect could result from monazite and  
160 xenotime fractionation, most authors have argued that such REE patterns actually reflect a  
161 selective complexation of the REE during the interaction of granitic melts with F- and Cl-rich

162 aqueous fluids (e.g. Bau, 1996; Irber, 1999; Monecke et al., 2007). Irber (1999) quantified the  
163 degree of tetrad effect ( $TE_{1-3}$ ) by determining the deviation of the first and the third tetrad of  
164 granites REE-patterns from a hypothetical tetrad effect-free REE pattern. The large majority of  
165 the samples with significant tetrad effect ( $TE_{1-3} > 1.1$ ) are also characterized by low Nb/Ta ratios  
166 below ~5 (Fig.3C).

167

### 168 *Metallogenic markers*

169 The Nb/Ta ratio is commonly compared to the Zr/Hf ratio, as the latter has been proposed as  
170 either a marker of magmatic-hydrothermal interactions (Bau, 1996) or of fractional  
171 crystallization (Linnen and Keppler, 2002; Claiborne et al., 2006). The Zr/Hf ratio is a  
172 geochemical indicator of the fertility of granitic rocks as a Zr/Hf ratios below ~25  
173 (corresponding to the lower limit of the CHARGE and RADIUS Control range; Bau, 1996) are  
174 expected in granites where Sn, W, Mo, Be and Ta mineralization are described (Zaraisky et al.,  
175 2009). In a Nb/Ta vs. Zr/Hf diagram (Fig. 4), most barren granites plot in the field defined by  
176  $< Zr/Hf < 46$  (CHARAC range of Bau, 1996) and by  $5 < Nb/Ta < 16$ , whereas peraluminous  
177 granites associated with Sn, W and/or U deposits have  $18 < Zr/Hf < 46$  with Nb/Ta ratio lower  
178 than 5. Rare metals granites are characterized by even lower Zr/Hf ratios ( $< 18$ ) with Nb/Ta  
179 ratios that are still lower than 5.

180

181 From the diagrams presented in Figures 2, 3 and 4, we highlight significant mineralogical  
182 (secondary muscovitization), geochemical (Sn contents, K/Rb ratio, tetrad effect) and  
183 metallogenic (Sn-W-U and rare metal mineralization) evidence that magmatic-hydrothermal  
184 processes account for the decrease of the Nb/Ta ratio in peraluminous granites. The solubility

185 and hydrothermal transfer of Nb and Ta are greatly enhanced, by up to three orders of  
186 magnitude, in reduced F-rich aqueous solutions (Zaraisky et al., 2010). Therefore, in  
187 peraluminous granites affected by sub-solidus alteration, the Nb/Ta ratios can be lowered by an  
188 increase of the Ta content in Ta-Nb-bearing minerals due to the lower mobility of Ta compared  
189 to Nb in aqueous solutions. As a consequence, we suggest here that the decrease of the Nb/Ta  
190 ratios to values lower than ~5 in peraluminous granites reflects the concomitant effect of  
191 fractional crystallization and sub-solidus magmatic-hydrothermal alteration, likely by F-rich  
192 acidic reduced fluids of magmatic origin.

193

#### 194 **Nb/Ta = 5: a critical ratio for granite petrogenesis and mineral exploration strategies**

195 The peraluminous granite whole rock samples with Nb/Ta ratios lower than 5 show significant  
196 evidence of interaction with fluids. We suggest that Nb/Ta = 5 represents a threshold between a  
197 purely magmatic system (Nb/Ta > 5) and a magmatic-hydrothermal system (Nb/Ta < 5). Taking  
198 a cut off value of 5 for the Nb/Ta ratio as a marker of the magmatic-hydrothermal transition in  
199 peraluminous granites bears some implications for exploration strategies as it can also help to  
200 define the economic potential of these granites. Indeed, Figure 4 demonstrates that a Nb/Ta ratio  
201 of 5 can be used as a geochemical indicator to differentiate barren granites from granites  
202 spatially related to Sn-W-(U) or rare metals mineralization. Since whole rock trace element  
203 analyses (including Nb and Ta) are routinely performed in most laboratories around the world,  
204 the simple calculation of whole rock sample Nb/Ta ratios can, therefore, help exploration  
205 geologists to define potential targets for Sn-W-(U) and rare metals deposits.

206

#### 207 **CONCLUSION**

208 The mineralogical and geochemical evidence of fluid interaction recorded in granitic whole rock  
209 samples, indicate that the value Nb/Ta = 5 is a good marker of the magmatic-hydrothermal  
210 transition in peraluminous granites. The decrease of the Nb/Ta ratio in peraluminous granites is  
211 associated with an increase of the degree of secondary muscovitization and with geochemical  
212 and metallogenic evidence of hydrothermal interactions, suggesting that sub-solidus alteration is  
213 involved in the fractionation of Nb-Ta. To further constrain the mechanisms involved in the  
214 fractionation of Nb/Ta ratios in peraluminous granites at the magmatic-hydrothermal transition,  
215 mineral-scale analyses would now be required. From an exploration point of view, and based on  
216 the large compilation of data presented in this study, the Nb/Ta ratio appears to be a good  
217 geochemical indicator to differentiate barren from ore-bearing peraluminous granites.

218

## 219 **ACKNOWLEDGMENTS**

220 We acknowledge Calvin Miller and two anonymous referees for their fruitful comments on a  
221 previous version of this manuscript.

222

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326 **FIGURE CAPTIONS**

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329 Figure 1. Nb/Ta vs. (A) Nb and (B) Ta abundances for peraluminous granites. The colored curves  
330 represent a model of evolution of Nb and Ta in a liquid  $L_0$  (Nb= 12 ppm, Ta =1.5 ppm, Nb/Ta =  
331 8) during the fractionation of an assemblage made of 10 wt.% biotite + 10 wt.% muscovite + 80  
332 wt.% (quartz + feldspar). The numbers above the curves indicate the amount of fractional  
333 crystallization. The black dashed line represents the same model during the fractionation of an  
334 assemblage composed of 10 wt.% biotite + 10 wt.% muscovite + 0.5 wt.% ilmenite + 79.5 wt.%  
335 (quartz + feldspar). The  $K_d$  used and presented in the table in inset in the diagram are from  
336 Stepanov et al. (2014) and reference therein. PLT: Particle Locking Threshold (Vigneresse et al.,  
337 1996).

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339

340 Figure 2. (A) Mg-Na-Ti ternary classification diagram of muscovite (Miller et al., 1981). (B)  
341 Diagram reporting the evolution of Nb/Ta ratios for whole rock samples from different  
342 peraluminous granites against the average value of the  $MgO/(Na_2O + TiO_2)$  ratios of their  
343 dioctahedral micas.

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346 Figure 3: Evolution of Nb/Ta ratios of peraluminous granites as a function of selected markers of  
347 magmatic-hydrothermal alteration. The degree of tetrad effect ( $TE_{1-3}$ ) has been calculated using  
348 the equation of Irber (1999). CC: Continental Crust composition (from Rudnick and Gao, 2005).

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351 Figure 4. Nb/Ta vs. Zr/Hf diagram differentiating barren and ore-bearing peraluminous granites.

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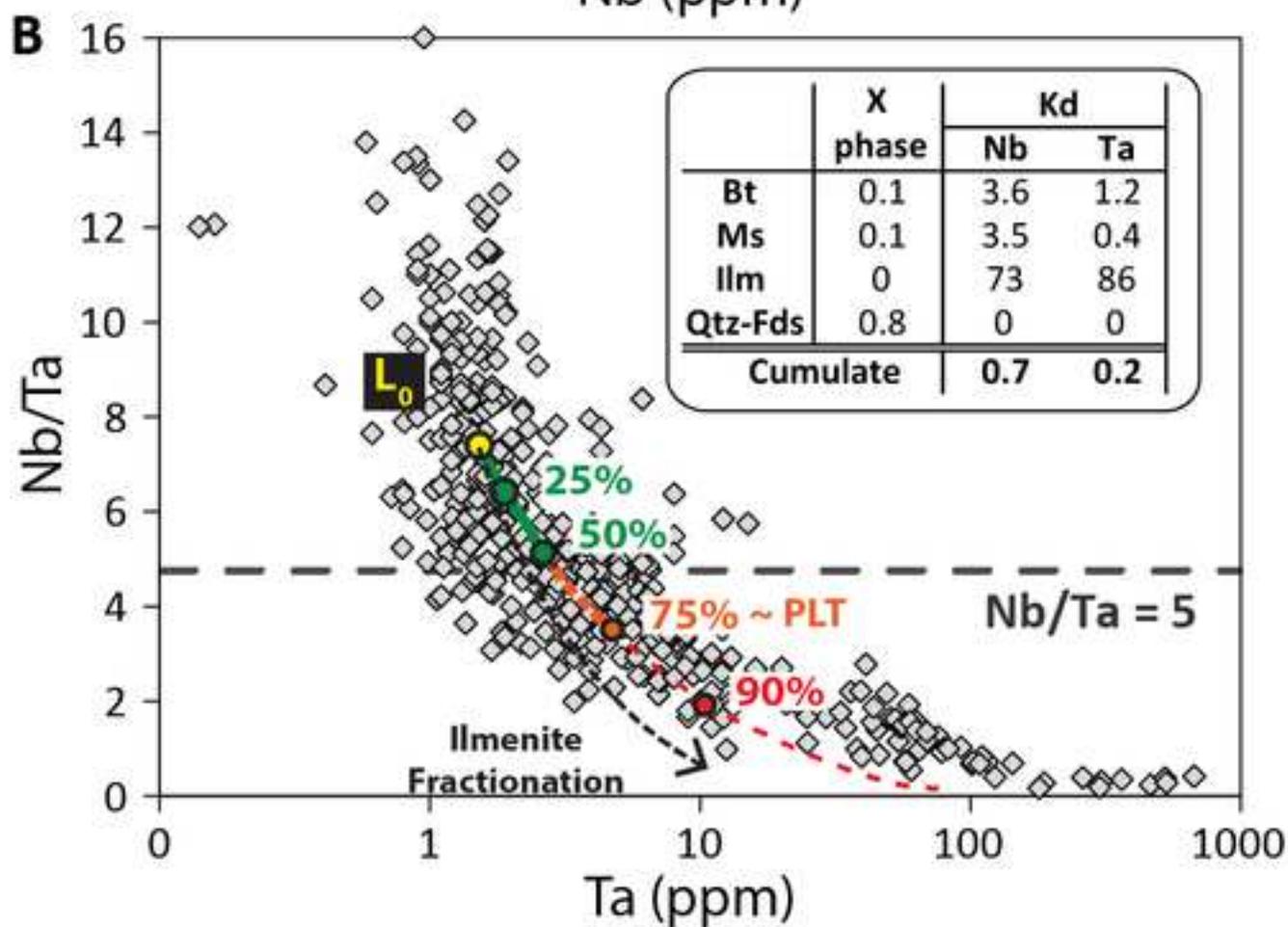
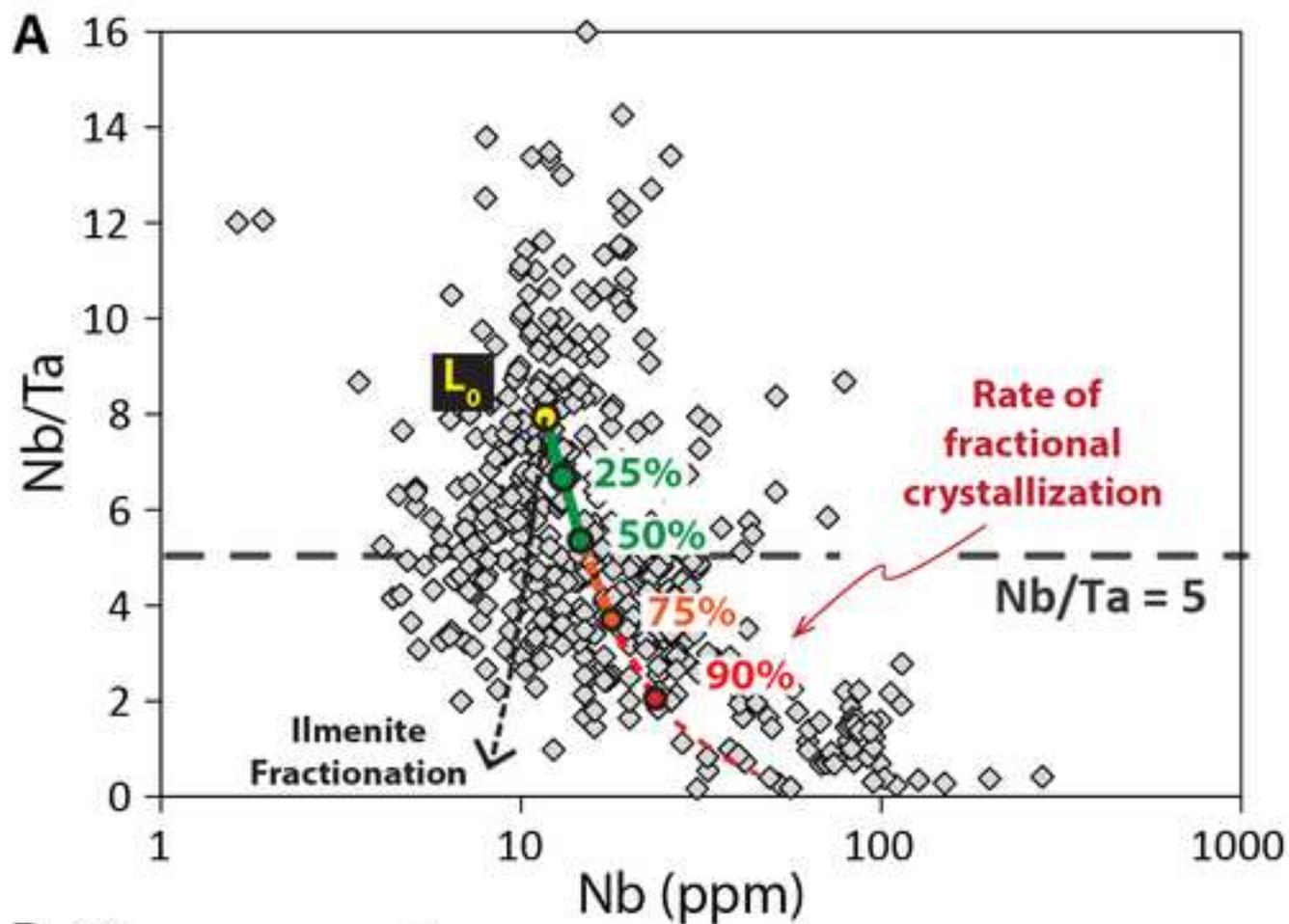
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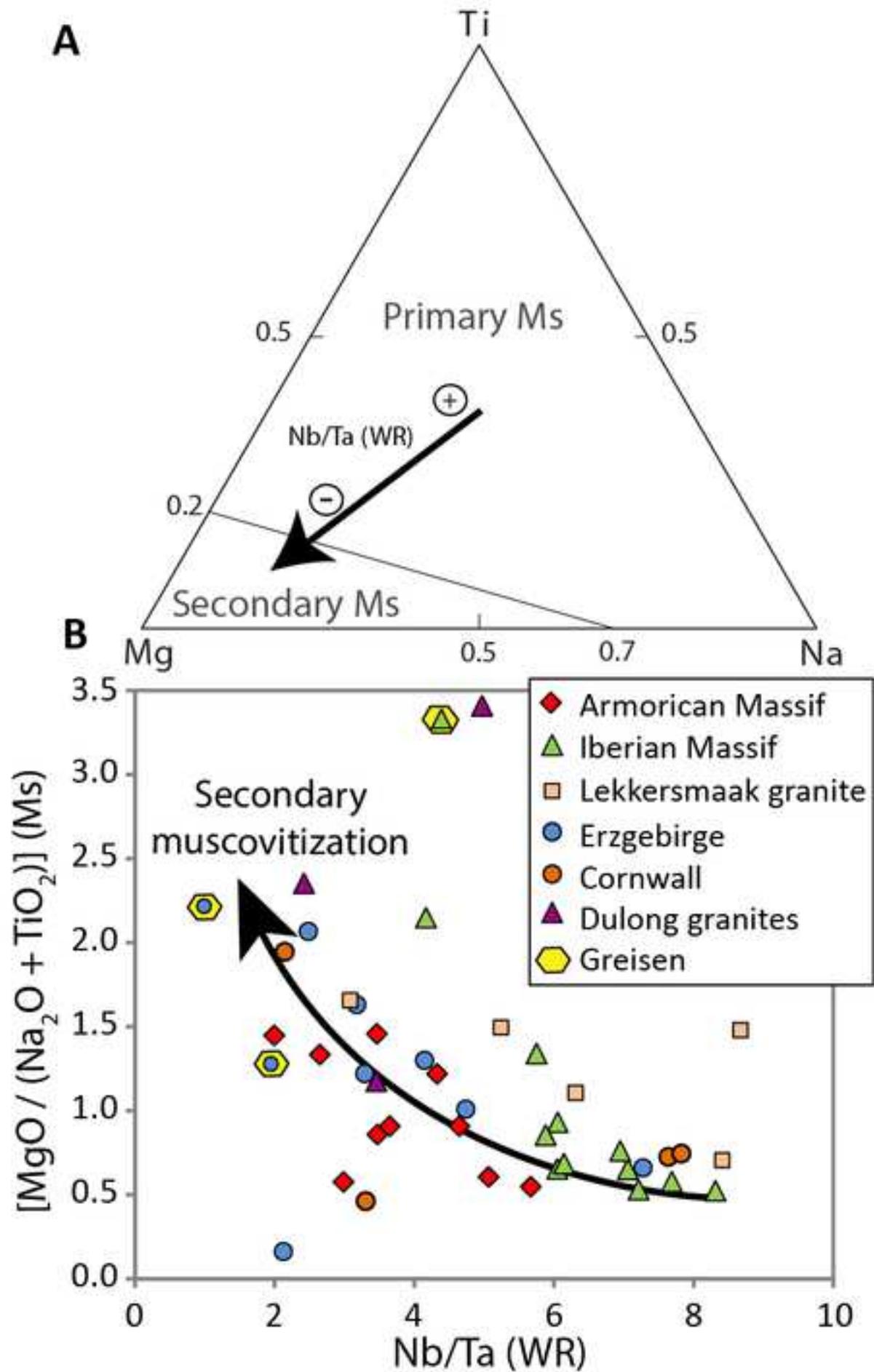
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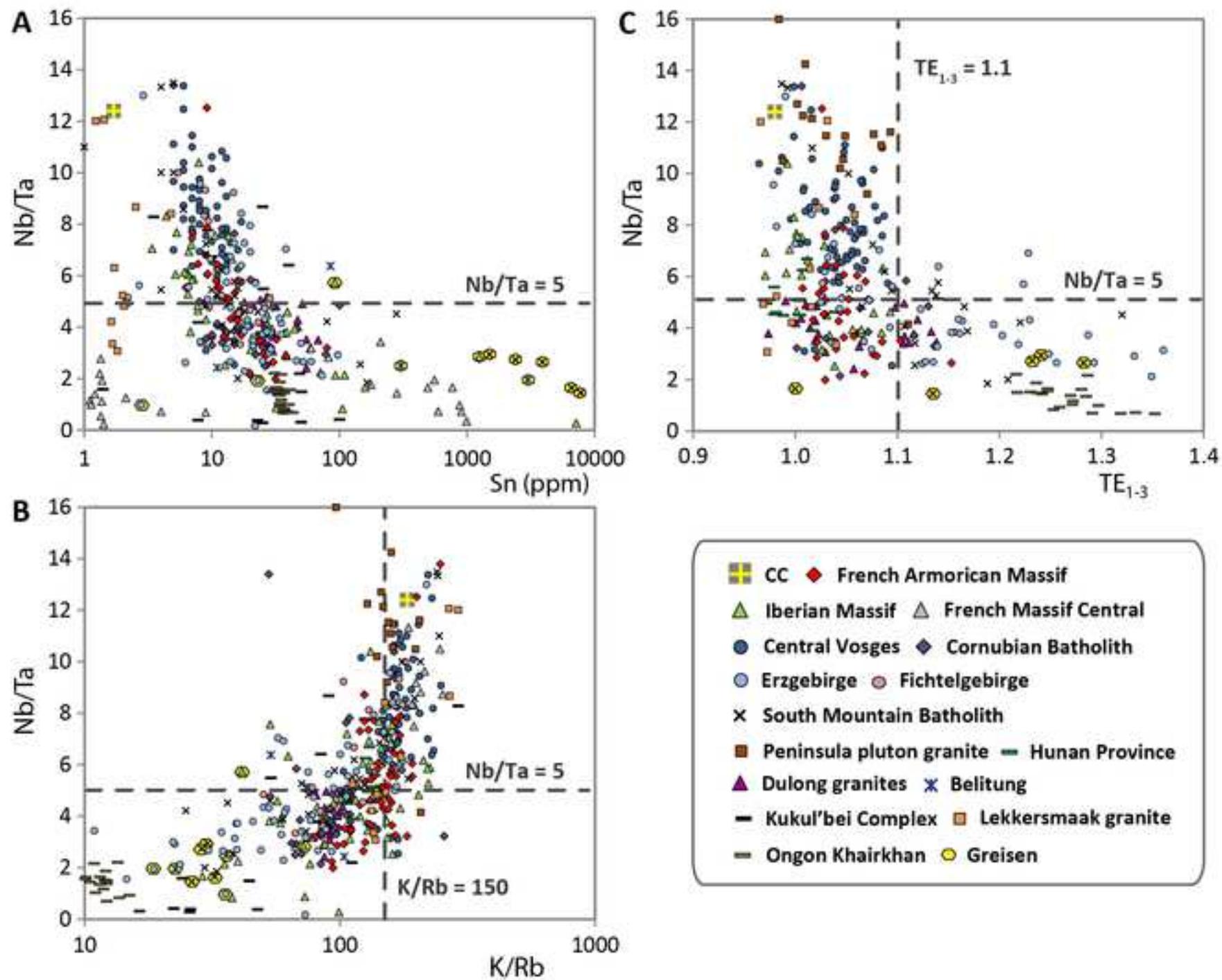
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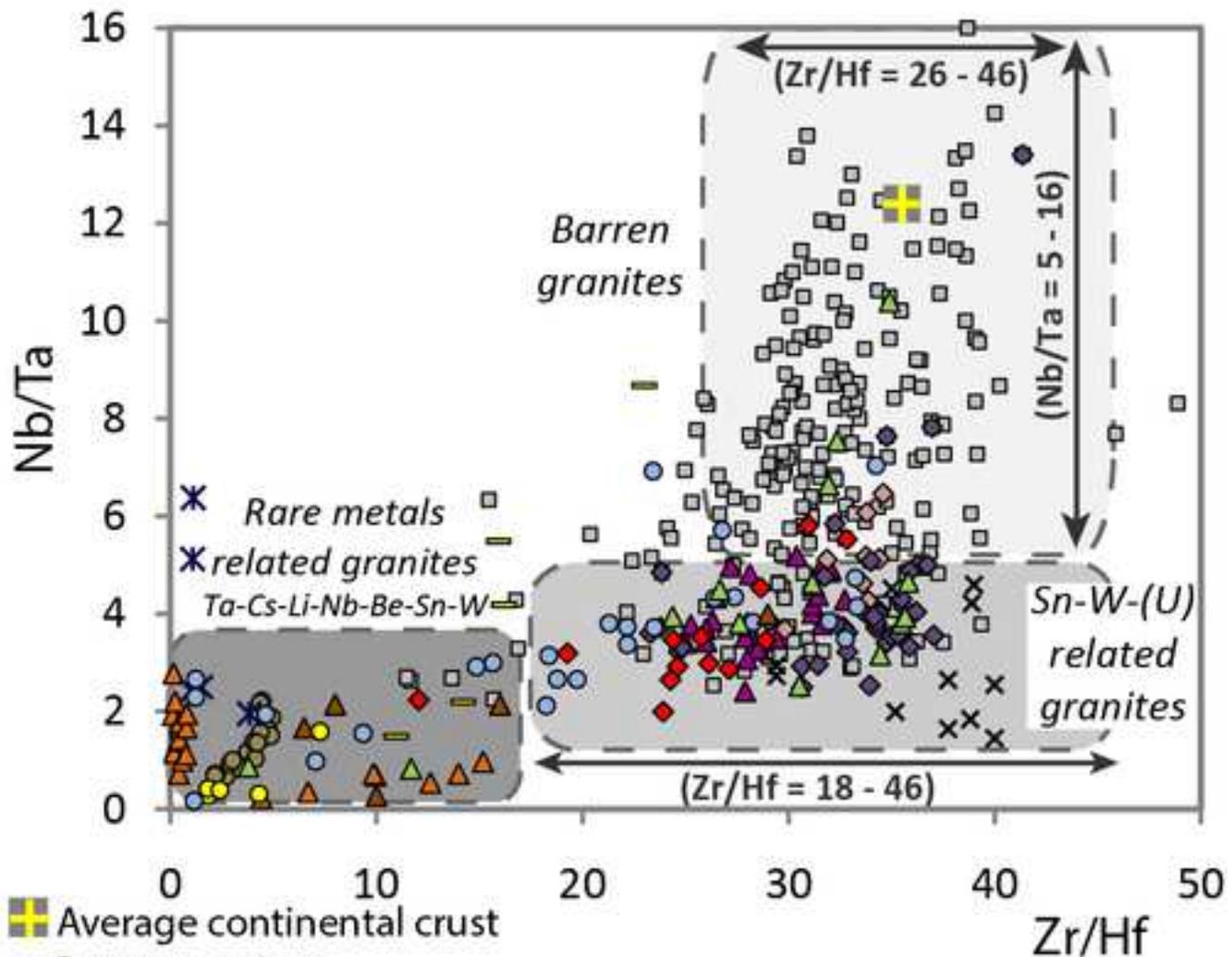
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357 <sup>1</sup>GSA Data Repository item 2015xxx, [[Synthesis of peraluminous crustal granites reported in](#)  
358 [this study](#)], is available online at [www.geosociety.org/pubs/ft2015.htm](http://www.geosociety.org/pubs/ft2015.htm), or on request from  
359 [editing@geosociety.org](mailto:editing@geosociety.org) or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301,  
360 USA.









- ✚ Average continental crust
- Barren granites
- ◇ Lizio granite - Armorican Massif : **Sn**
- ◆ Questembert and Guérande granites - Armorican Massif : **U - (Sn)**
- ▲ Beariz, Jalama and Carbalinno granites - Iberian Massif : **Sn - W - (Nb - Ta)**
- ◆ Cornubian batholith : **Sn - W - (Cu)**
- Li - mica granites and greisens from the Erzgebirge : **Sn - W**
- × Leucogranites and greisens from the Davis Lake pluton - SMB : **Sn**
- ✚ Tanjungpandan pluton - Belitung - Indonesia: **Sn-W**
- Leucogranites from the Kukul'bei Complex - Transbaikalia: **W - Sn**
- ▲ Dulong granites - Yunnan Province - South China: **Sn**
- Ongonites from Ongon Kairkhan, Central Mongolia : **W**
- Li - F granites from the Kukul'bei Complex - Transbaikalia : **Ta**
- ▲ Beauvoir granite - Massif Central: **Ta - Be - Sn - Li**
- ▲ Ponte Segade granite - Iberian Massif : **Sn - Ta - Nb - Li - Be - Cs**

Location	Igneous province	Granite	Age	Related deposit	Reference	
Western Europe	French Armorican Massif	Lizio	ca. 316 Ma	Sn	U leached during hydrothermal alteration Apical zone facies	Tartèse and Boulvais, 2010 Tartèse and Boulvais, 2010; Tartèse et al., 2013 Ballouard et al., 2015 Georget, 1986 Georget, 1986
		Questembert	ca. 316 Ma	(U)		
		Guérande	ca. 310 Ma	U - Sn		
		Huelgat	Late Carboniferous	-		
	Iberian massif	Brignogan	Late Carboniferous	-		
		Ponte Segade	Late Carboniferous	Sn - Ta - Nb - Li - Be - Cs	Canosa et al., 2012 Ramírez and Grundvig, 2000 Gloaguen, 2006 Gloaguen, 2006 Gloaguen, 2006 Gloaguen, 2006 Gloaguen, 2006 Bea et al., 1994 Nieva, 2002 Nieva, 2002	
		Jalama	Late Carboniferous	Sn-W-(Nb-Ta)		
		Beariz (Avion)	Late Carboniferous	-		
Beariz	Late Carboniferous	Sn -W				
Boboraz	Late Carboniferous	-				
Carballino	Late Carboniferous	Sn-W-(Nb-Ta)				
Irixo	Late Carboniferous	-				
Pedrobernardo	c.a. 300 Ma	-				
S. Mamede de Ribatua	Hercynian	Sn-W				
Panasqueira	Hercynian	Sn-W				
French Massif Central	Colette	ca. 310 Ma	-	Ta - Be -Sn - Li	Raimbault et al., 1995 Raimbault et al., 1995 Rolin et al., 2006	
	Beauvoir	ca. 310 Ma				
	Guéret	ca. 350 Ma	-			
	Cornubian Batholith	-	295-275 Ma	Sn - W - (Cu)	Chappell and Hine, 2006; Müller et al., 2006	
	Erzgebirge	-	Late Carboniferous - Early Permian	Sn - U -W	Li - mica granites and greisens Förster et al., 1999; Breiter, 2012; Štemprok et al., 2005	
	Fichtelgebirge	-	Late Carboniferous - Early Permian	?	Hecht et al., 1997	
	Central Vosges	-	329 - 322 Ma	-	Tabaud et al., 2015	
Nova Scotia - Canada	South Mountain Batholith	-	Late Devonian	-	MacDonald et al., 1992	
	Davis Lake	Late Devonian	Sn	Topaz muscovite leucogranites and greisens	Dostal and Chatterjee, 1995	
South Africa	Kaapvaal Craton	Lekkersmaak granite suite	ca. 2800 Ma	-	Jaguin, 2012	
	Cape Granite Suite	Peninsula pluton	556-534 Ma	-	Farina et al., 2012	
South China	Hunan Province	Indosinian granites	210 – 243 Ma	?	Wang et al., 2007	
	Yunnan Province	Dulong granites	ca. 90 Ma	Sn	Xu et al., 2015	
Indonesia	Belitung	Tanjungpandan pluton	ca. 215 Ma	Sn - W	Schwartz and Surjono, 1990	
Eastern Transbaikalia	-	Kukul'bei complex	ca. 140 Ma	W – Sn Ta	Muscovite leucogranites (phase 2) Albite-amazonite Li-F granites (phase 3) Zaraisky et al., 2009	
Central Mongolia	-	Ongon Khairkhan	Ca. 120 Ma	W	Ongonites (topaz bearing albite-rich microleucogranites) Dostal et al., 2015	

Table DR1: Synthesis of the peraluminous granites reported in this study with their location, their age, their associated metal deposits when available and the corresponding references.

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