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## Multiple crustal and mantle inputs in post-collisional magmatism: evidence from late-Variscan Sàrrabus pluton (SE Sardinia, Italy)

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Abstract:	<p>The Sàrrabus pluton is formed by multiple short-lived intrusions emplaced at about 286 Ma at shallow crustal levels within the external part of the South Variscan Orogenic Belt. A chemical and Sr and Nd isotopic study on the Variscan post-collisional magmatism from the Sàrrabus pluton reveals the repeated bimodal character of the intrusions, in which heterogeneous crustal sources and mantle-derived calcalkaline magmas are involved. Products of this magmatic activity occur as intrusive units and mafic/felsic dykes intruded in post-collisional regime along extensional faults during tectonic exhumation. Pluton growth started with an early stage of emplacement of broadly granodioritic magma with subordinate mafic magma batches (stage 1) followed by large intrusions of metaluminous to subaluminous and subordinately peraluminous granites (stage 2). In stage 1, the occurrence of remnants of stratified olivine-bearing gabbroic rocks indicates the intrusion of mafic magmas which experienced low-pressure crystal/liquid fractionation. Mafic magmas may represent an external heat supply for melting of different crustal materials belonging to an inferred Precambrian crystalline basement underlying the Paleozoic rocks of the Variscan nappe pile. Strong evidence for heterogeneous crustal sources is constrained by isotope data. Peraluminous granites and felsic dikes display initial <math>87\text{Sr}/86\text{Sr}</math> in the range of <math>0.7140\pm0.7215</math> and a roughly constant <math>\epsilon\text{Nd}_{286}</math> (<math>-7.4</math> to <math>-7.5</math>). Conversely, a peculiar less radiogenic character, in the range of <math>0.7030\pm0.7067/-5.5\pm-6.2</math>, is observed for metaluminous to subaluminous varieties. Calculated Neodymium Crustal Index (NCI) confirmed a progressive increase in crustal magmas generation during the pluton growth, from stage 1, recording minor mixing processes between mantle- and crustal-derived peraluminous melts, to stage 2, where extensive crustal melting occurred, originating metaluminous to subaluminous granites. Possible crustal sources for metaluminous/subaluminous and peraluminous granites are (Pan-African) amphibolites and metasedimentary rocks, respectively. Two-stage depleted-mantle Nd model ages cluster at 1.4 and 1.6 Ga for metaluminous/subaluminous and peraluminous granites, respectively, well comparable with other segments of the European Variscan belt. Remarkably, last magmatic pulses resulted in widespread subalkaline bimodal mafic/felsic dykes that overlapped the Sr–Nd signature recorded by major intrusions. This similar geochemical affinity between late dykes and the first intrusives may be related to decreasing temperature in the crust, which inhibited extensive mixing processes with the upwelling melts. At the same time, the presence of felsic intrusions in the shallow crust would have prevented the rise of more primitive basic magmas, which would have consolidated at depth. Finally, the high radiogenic character of</p>

	<p>Sàrrabus mafic products, compared to coeval Variscan mafic rocks of Corsica and northern Sardinia, may be indicative of previous fractionation and mixing processes, possibly related to magmatic underplating of the lower crust. The Sàrrabus pluton is formed by multiple short-lived intrusions emplaced at about 286 Ma at shallow crustal levels within the external part of the South Variscan Orogenic Belt. A chemical and Sr and Nd isotopic study on the Variscan post-collisional magmatism from the Sàrrabus pluton reveals the repeated bimodal character of the intrusions, in which heterogeneous crustal sources and mantle-derived calcalkaline magmas are involved. Products of this magmatic activity occur as intrusive units and mafic/felsic dykes intruded in post-collisional regime along extensional faults during tectonic exhumation. Pluton growth started with an early stage of emplacement of broadly granodioritic magma with subordinate mafic magma batches (stage 1) followed by large intrusions of metaluminous to subaluminous and subordinately peraluminous granites (stage 2). In stage 1, the occurrence of remnants of stratified olivine-bearing gabbroic rocks indicates the intrusion of mafic magmas which experienced low-pressure crystal/liquid fractionation. Mafic magmas may represent an external heat supply for melting of different crustal materials belonging to an inferred Precambrian crystalline basement underlying the Paleozoic rocks of the Variscan nappe pile. Strong evidence for heterogeneous crustal sources is constrained by isotope data. Peraluminous granites and felsic dikes display initial <math>^{87}\text{Sr}/^{86}\text{Sr}</math> in the range of <math>0.7140 \pm 0.0015</math> and a roughly constant <math>\epsilon_{\text{Nd}}^{286}</math> (<math>-7.4</math> to <math>-7.5</math>). Conversely, a peculiar less radiogenic character, in the range of <math>0.7030 \pm 0.0007</math> to <math>-5.5</math> to <math>-6.2</math>, is observed for metaluminous to subaluminous varieties. Calculated Neodymium Crustal Index (NCI) confirmed a progressive increase in crustal magmas generation during the pluton growth, from stage 1, recording minor mixing processes between mantle- and crustal-derived peraluminous melts, to stage 2, where extensive crustal melting occurred, originating metaluminous to subaluminous granites. Possible crustal sources for metaluminous/subaluminous and peraluminous granites are (Pan-African) amphibolites and metasedimentary rocks, respectively. Two-stage depleted-mantle Nd model ages cluster at 1.4 and 1.6 Ga for metaluminous/subaluminous and peraluminous granites, respectively, well comparable with other segments of the European Variscan belt. Remarkably, last magmatic pulses resulted in widespread subalkaline bimodal mafic/felsic dykes that overlapped the Sr–Nd signature recorded by major intrusions. This similar geochemical affinity between late dykes and the first intrusives may be related to decreasing temperature in the crust, which inhibited extensive mixing processes with the upwelling melts. At the same time, the presence of felsic intrusions in the shallow crust would have prevented the rise of more primitive basic magmas, which would have consolidated at depth. Finally, the high radiogenic character of Sàrrabus mafic products, compared to coeval Variscan mafic rocks of Corsica and northern Sardinia, may be indicative of previous fractionation and mixing processes, possibly related to magmatic underplating of the lower crust.</p>
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## Highlights

- The Sàrrabus pluton is formed by multiple short-lived intrusions at ca. 286 Ma;
- Pluton growth started with an early stage of broadly granodioritic composition;
- Large intrusions of metaluminous to subaluminous granites follow the granodiorites;
- During the pluton growth, a progressive increase in crustal magmas generation occurred;
- Last magmatics are subalkaline mafic/felsic dikes with major intrusions signature;

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# Multiple crustal and mantle inputs in post-collisional magmatism: evidence from late-Variscan Sàrrabus pluton (SE Sardinia, Italy)

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**Keywords:** (Late-Variscan magmatism, bimodal magmatism, dilatant shear zones, crustal sources, Sr-Nd isotopes, Neodymium crustal index)

## Abstract

The Sàrrabus pluton is formed by multiple short-lived intrusions emplaced at about 286 Ma at shallow crustal levels within the external part of the South Variscan Orogenic Belt. A chemical and Sr and Nd isotopic study on the Variscan post-collisional magmatism from the Sàrrabus pluton reveals the repeated bimodal character of the intrusions, in which heterogeneous crustal sources and mantle-derived calcalkaline magmas are involved. Products of this magmatic activity occur as intrusive units and mafic/felsic dykes intruded in post-collisional regime along extensional faults during tectonic exhumation. Pluton growth started with an early stage of emplacement of broadly granodioritic magma with subordinate mafic magma batches (stage 1) followed by large intrusions of metaluminous to subaluminous and subordinately peraluminous granites (stage 2). In stage 1, the occurrence of remnants of stratified olivine-bearing gabbroic rocks indicates the intrusion of mafic magmas which experienced low-pressure crystal/liquid fractionation. Mafic magmas may represent an external heat supply for melting of different crustal materials belonging to an inferred Precambrian crystalline basement underlying the Paleozoic rocks of the Variscan nappe pile. Strong evidence for heterogeneous crustal sources is constrained by isotope data. Peraluminous granites and felsic dikes display initial  $^{87}\text{Sr}/^{86}\text{Sr}$  in the range of  $0.7140 \div 0.7215$  and a roughly constant  $\epsilon\text{Nd}_{286}$  ( $-7.4$  to  $-7.5$ ). Conversely, a peculiar less radiogenic character, in the range of  $0.7030 \div 0.7067/-5.5 \div -6.2$ , is observed for metaluminous to subaluminous varieties. Calculated Neodymium Crustal Index (NCI) confirmed a progressive increase in crustal magmas generation during the pluton growth, from stage 1, recording minor mixing processes between mantle- and crustal-derived peraluminous melts, to stage 2, where extensive crustal melting occurred, originating metaluminous to subaluminous

granites. Possible crustal sources for metaluminous/subaluminous and peraluminous granites are (Pan-African) amphibolites and metasedimentary rocks, respectively. Two-stage depleted-mantle Nd model ages cluster at 1.4 and 1.6 Ga for metaluminous/subaluminous and peraluminous granites, respectively, well comparable with other segments of the European Variscan belt. Remarkably, last magmatic pulses resulted in widespread subalkaline bimodal mafic/felsic dykes that overlapped the Sr–Nd signature recorded by major intrusions. This similar geochemical affinity between late dykes and the first intrusives may be related to decreasing temperature in the crust, which inhibited extensive mixing processes with the upwelling melts. At the same time, the presence of felsic intrusions in the shallow crust would have prevented the rise of more primitive basic magmas, which would have consolidated at depth. Finally, the high radiogenic character of Sàrrabus mafic products, compared to coeval Variscan mafic rocks of Corsica and northern Sardinia, may be indicative of previous fractionation and mixing processes, possibly related to magmatic underplating of the lower crust.

## Introduction

The Corsica-Sardinia Batholith (CSB) belongs to the southern Variscan belt of Europe and represents a key area for studies on post-collisional evolution of this orogenic chain (Ferrè and Leake, 2001; Paquette et al., 2003; Cocherie et al., 2005; Rossi et al., 2009, 2015; Edel et al., 2014; Casini et al., 2015a, b; Conte et al., 2017) (Fig. 1). The CSB was emplaced through a complex succession of discontinuous short-lived tectonic and magmatic episodes from the late collisional stages to the post-collisional collapse and exhumation of the orogenic roots. At present, a general agreement exists in literature in considering the control of lithospheric shear zones on the emplacement of major intrusive complexes of the CSB (Edel et al., 2014; Casini et al., 2012; 2015; Cuccuru et al., 2016), and the involvement of metaigneous and metasedimentary crustal sources with subordinate mantle contribution (Poli et al., 1989; Cocherie et al., 1994; Tommasini et al., 1995; Macera et al., 2011; Rossi et al., 2015; Conte et al., 2017). Also, the heat source necessary to generate the large volumes of crustal-derived intrusive magma in the post-collisional regime of SCB was related to lithospheric delamination and asthenospheric upwelling promoting partial melting of lower crust (Gaggero et al., 2007; Rossi et al., 2015). As a result, a wide range of crustal melts and hybrid varieties, mainly of broadly granodioritic composition, produced by mafic/felsic magma interactions, contributed to the architecture of the entire batholith. Common effect of mafic/felsic magma interaction was documented by igneous dark enclaves dispersed in granodiorites and subordinately in monzogranites (Poli et al., 1989; Zorpi et al., 1991; Barbey et al., 2008; Casini et al., 2015b). Mantle-derived magmas, commonly intruding in the final stages of the CSB growth, are represented by gabbroic

magma batches and mafic dikes. The tholeiitic and calcalkaline mafic dikes spread over the whole batholith, and partly within the host metamorphic basement. Even if recent radiometric ages point to a substantial contemporaneity among the main intrusive events and the subalkaline mafic dike swarms (Rossi et al., 2015; Conte et al., 2017), the genetic linkage between this hypabyssal activity and the plutons making the batholith was never taken into consideration.

The Sàrrabus pluton (south-eastern Sardinia), is formed by multiple intrusions emplaced within the shallow crustal levels of a fold and thrust belt along the Gondwana foreland; it shows peculiar characteristics compared to the rest of the CSB due to the different geochemical affinities of the magma intrusions and their coeval ages. Previous studies performed on the Sàrrabus pluton (Brotzu et al., 1981, 1993; Poli and Tommasini, 1999; Ronca et al., 1999; Conte et al., 2017; Franciosi et al., 2019) focused on single aspects of the pluton without proposing a global genetic model. In a recent study, Secchi et al. (2021) firstly recognized the substantial contemporaneity of a wide spectrum of magma pulses concentrated in a short time span, forming a relatively small pluton (400 km<sup>2</sup>), which differentiate the Sàrrabus pluton with respect to others in CSB.

In this work, field evidence and chemical and isotopic data (Sr and Nd bulk rock and Hf in zircons) are presented and discussed with data from previous studies, to constrain the petrogenesis of the entire Sàrrabus pluton. We will focus on the nature of involved crustal sources which originated the granitic units of the pluton and their interactions with mantle derived melts. We will propose a genetic model of growth of the Sàrrabus pluton by magma ascending through lithospheric-scale shear zones active in an extensional post-collisional setting which could be applied to other shallow crustal magmatic complexes rooted on lithospheric shear zones.

## Geological setting

### *The Variscan orogenic wedge*

The Variscan collisional frame of Sardinia and Corsica results in a high-grade, inner, anatectic complex retaining remnants of eclogite and high-pressure mafic granulite well exposed in Corsica and northern Sardinia (Cruciani et al., 2015), which overthrusts a complex pile of nappes showing low- to medium- grade metamorphic imprint (Fig. 1). The nappe pile in turn overrides, with general top- to- southwest transport, a non-metamorphic foreland located in southern Sardinia (Carmignani et al., 1994), which is commonly interpreted as a Gondwana foreland (Edel et al., 2014; Rossi et al., 2015 and reference therein). This frame is the result of the early Carboniferous collision between the northern Gondwana margin, and the ribbon-like collage of terranes interposed between Gondwana and Laurussia after the (present time) north-directed subduction of an oceanic domain, namely the

115 Paleo-Tethys or South-Armorican Ocean (Stampfli et al., 2003; Oggiano et al., 2010; Gaggero et al.,  
116 2012). The Variscan crust was thus highly heterogeneous, consisting of several assembled terranes  
117 and syn-collisional plutonic intrusions. During the post-collisional evolution of the chain, the  
118 Variscan crust was widely reworked in the general context of a strike slip dextral mega shear zone  
119 (Casini and Funedda, 2014; Rossi et al., 2015; Edel et al., 2016). This reworking was coeval with the  
120 collapse (Ruben Diez and Preira, 2016) of the previously thickened crust and by heating related to  
121 slab breakoff of the north-directed subducting oceanic lithosphere as well as to shear heating (Casini  
122 et al., 2012). This post collisional frame in Sardinia, similarly to the entire Variscides, went on with  
123 *HT/LP* metamorphism (Kröner and Willner, 1998; Casini and Oggiano, 2008) and was accompanied  
124 by intensive magmatic activity giving rise to the CSB. The magmatic activity is coeval with  
125 lithospheric-scale shear zones and anatexis in the 320÷305 Ma wide interval, as well as to extension  
126 and to the clockwise rotation of Corsica-Sardinia microplate (Rossi et al., 2009, 2015; Edel et al.,  
127 2014).

128

#### 129 *The Corsica-Sardinia Batholith*

130 The CSB resulted from the succession of discrete, short-lived plutonic and volcanic events of  
131 broadly calcalkaline affinity, which may be grouped into three main magmatic peaks based on  
132 geographic, geochronological and magmatic criteria as follows:

133 (1) late-collisional magmatic peak, only documented in western and northwestern Corsica within a  
134 short time span of 344 ÷ 335 Ma (Cocherie et al., 2005);

135 (2) older post-collisional magmatic peak (hereafter OMP, *sensu* Conte et al., 2017), poorly  
136 represented in southern Sardinia lasting from 322 ± 8 Ma (northern Sardinia; Casini et al., 2015a) to  
137 299 ± 3 Ma (central Sardinia; Meloni et al., 2017);

138 (3) younger post-collisional magmatic peak (hereafter YMP, *sensu* Conte et al., 2017) widespread in  
139 Sardinia and Corsica and referred to the short time span of 291÷286 Ma (Cocherie et al., 2005; Casini  
140 et al., 2015a).

141 The igneous activity belonging to the syn-collisional peak resulted in a rock-association made up  
142 of quartz monzonites to syenogranites with enclaves of ultrapotassic mafic rocks (the so-called Mg-  
143 K rock-suite; Cocherie et al., 1994 and reference therein), emplaced from deep crustal levels up to  
144 shallow conditions.

145 The architecture of CSB is instead closely related to the post-collisional stages of the Variscan  
146 orogen. With the exception of the earlier andalusite-bearing foliated granodiorites and leucogranites  
147 occurring in northernmost of Sardinia (i.e., Barrabisa and Santa Maria Island: 321 ± 8 ÷ 313 ± 6 Ma;  
148 Oggiano et al., 2007; Casini et al., 2012), the OMP is characterized by repeated sequences of  
149 monzogranitic and granodioritic pulses with subordinate mafic rocks, which represent the dominant



150 intrusive activity in the internal nappe zone of northern-central Sardinia. Overall, magma pulses  
151 emplaced almost constantly at shallow crustal levels (about 2–4 kbar; Casini et al., 2012; Conte et al.,  
152 2017; Bosi et al., 2019). Shallow conditions are constrained by the common development of narrow  
153 contact aureoles with andalusite-cordierite hornfelses around the plutons, as well as by geobarometric  
154 results (Conte et al., 2017; Bosi et al., 2019 and reference therein); in addition, andalusite and  
155 cordierite may occur as fundamental phases in peraluminous varieties (e.g., Barrabisa and  
156 Gennargentu, Fig. 1; Casini et al., 2012; Gaeta et al., 2013).

157 In the external nappe zone and in the Gondwanan foreland of southern Sardinia, the OMP is only  
158 represented by small plutons with inverse zonation belonging to an ilmenite rock-*series* and ranging  
159 from granodiorites to peraluminous cordierite-bearing granites (e.g., Arbus and Grighini) with local  
160 small amounts of olivine-bearing monzo-gabbronorites (Arbus, Capo Pecora and Burcèi) (Secchi et  
161 al., 1991; Brotzu et al., 1993; Musumeci et al., 2014) (Fig. 1).

162 The intrusive bodies belonging to YMP are dominated by voluminous (mainly NE-trending)  
163 peraluminous to subaluminous felsic and minor mafic intrusions emplaced at the shallowest crustal  
164 levels (about 1 kbar; Gaggero et al., 2007; Conte et al., 2017 and reference therein). Granodioritic  
165 sequences associated to mafic bodies cover a restricted time span of  $286 \pm 1 \div 279 \pm 1$  Ma (Paquette  
166 et al., 2003; Casini et al., 2015a). The age of these late intrusions overlaps that of peralkaline granites  
167 which are only exposed in northern Corsica (Cocherie et al., 2005). In southern Sardinia,  
168 metaluminous to sub-aluminous granites are dominant over peraluminous granites. They mainly  
169 belong to ilmenite rock-*series* and show a F-rich ferroan character as well as a peculiar metallogenic  
170 signature as testified by Sn-W-Mo and F ores (Naitza et al., 2017).

171 Exposed rock-types are dominantly felsic (over 90% granodiorites and granites), with only minor  
172 amounts of gabbroic rocks commonly associated with tonalites mingled with host granodiorites  
173 (Zorpi et al., 1991). The production of magmas in the CSB is largely interpreted as related to  
174 contemporaneous partial melting of crustal materials and interactions of felsic melts with mafic  
175 magmas at several levels in the crust (Secchi et al., 1991; Zorpi et al., 1991; Tommasini and Poli  
176 1992; Cocherie et al., 1994; Tommasini et al., 1995; Di Vincenzo et al. 1996; Poli and Tommasini,  
177 1999; Renna et al., 2006; Barbey et al., 2008). According to Rossi et al. (2015), the voluminous felsic  
178 activity marking the end of YMP in the entire CSB reflects a phase of intense crustal heating triggered  
179 by lithospheric delamination and intrusion of mafic magmas in the lower crust. Heating contribution  
180 in this phase has also been related to intense shearing (Casini et al., 2012; 2015b) and radiogenic  
181 heating (Puccini et al., 2013).

182 The 291÷286 Ma emplacement age interval identified for YMP overlaps with U/Pb data  
183 determined for *HT-LP* granulites from the Variscan deep crust exhumed along the “European” margin

184 of the thinned Tethys margin from Corsica and Calabria, which are in the range of 285÷280 Ma (Rossi  
185 et al., 2015).

186 Furthermore, the early Permian intrusive magmatism is coeval with calcalkaline felsic/intermediate  
187 volcanism associated to the onset of continental basins in an extensional/transtensional regime  
188 (Cortesogno et al., 1998; Gaggero et al., 2017).

189 Based on SHRIMP analyses on zircons, the late calcalkaline mafic dykes from Corsica provided age  
190 values of  $279 \pm 1$  Ma (Cocherie et al., 2005).

191

#### 192 *The Sàrrabus pluton*

193 The Sàrrabus pluton -exposed for over 400 km<sup>2</sup>- is formed by multiple, short-lived pulses  
194 emplaced at shallow crustal levels within an anchi-metamorphosed Cambro-Ordovician volcano-  
195 sedimentary sequence in the frontal part of the orogenic wedge of the SE Sardinia (Fig. 1). Its original  
196 extension and shape are unknown, as the contact with the host rocks is limited to its northern boundary  
197 (Fig. 2) even if small roof pendants of metamorphic basement are locally exposed along the southern  
198 Sardinian coastline. The pluton may be framed in a dilatant extensional/transtensional shear zone  
199 bordering the Sardinia-Corsica tectonic microplate to the E (Secchi et al., 2021). It consists of  
200 different generations of granodiorites, associated to gabbroic rocks and tonalites, and of  
201 metaluminous, subaluminous and subordinately peraluminous granites, all referable to the YMP. The  
202 pluton shows abundant mafic and felsic dikes crosscutting the main intrusions, thus representing the  
203 later igneous activities.

204 The available geochronological data support a restricted time interval of emplacement for the  
205 whole pluton, with ages clustered around 286 Ma (Secchi et al., 2021). In detail, U/Pb data on single  
206 zircons yielded overlapping ages at  $287 \pm 1$  Ma for the S. Vito leucogranite satellite intrusion (Dack,  
207 2009) and at  $286 \pm 9$  Ma for the Cala Regina granodiorites (Secchi et al., 2021). These ages are in  
208 good agreement with Ar-Ar and Rb/Sr data available for S. Vito leucogranite and Cala Regina  
209 granodiorites yielding  $285 \pm 1$  and  $292 \pm 17$  Ma, respectively (Dini et al., 2005; Secchi et al., 2021).

210 The geology of the pluton has been recently outlined by Secchi et al. (2021; Fig.2). The intrusive  
211 sequence may be schematized as follows. The older part of Sàrrabus pluton (hereafter the *stage 1*) is  
212 an intrusive sequence of EW/ENE trending pulses of granodiorites and coeval mafic batches, well  
213 exposed along the southern Sardinian coastline (Fig. 2). The granodioritic pulses have been defined  
214 by Secchi et al. (2021) as Cala Regina, Monte Cresia and Monte Nai units; in this study they are  
215 hereafter reported together as the Cala Regina Group. In the field, size and abundance of  
216 microgranular dark enclaves and frequency of mafic bodies in granodiorite increase from N to S. In  
217 their southernmost outcrops, where they are intruded by the NE trending, peraluminous granite of  
218 Monte Maria-Unit, granodiorites contain in addition hololeucocratic felsic enclaves (Fig. 3a).

219 The Cala Regina Group granodiorites locally grade into foliated quartz-diorite and tonalite with  
220 highly stretched hybrid enclaves (Fig. 3b), dismembered syn-plutonic dikes and decametric bodies of  
221 elongated two pyroxene-bearing hornblende-gabbroic rocks with local remnants of olivine-bearing  
222 layers (i.e., cumulitic rocks of Solànas Complex; SO in Fig. 2). The magmatic foliation trends roughly  
223 E-W and is sub-vertical or steeply dipping to the south. It is defined by the preferred orientation of  
224 dark mica, feldspar and stretched microgranular mafic enclaves. The magmatic lineation, where  
225 observed, plunges down dip and is defined mostly by alignment of dark mica, feldspars as well as the  
226 long axis of mafic enclaves (Fig. 3b). Close to the coast, along a 2 km wide belt roughly trending E-  
227 W, extremely stretched enclaves occur in large proportion along banded mafic-felsic domains (Fig.  
228 3c), these features have been related to mingling processes (Poli and Tommasini 1989) enhanced by  
229 a normal, syn-plutonic shear zone, namely the South Sàrrabus Shear zone (SSSZ; Secchi et al 2021;  
230 Fig. 2). The coeval intrusion of mafic and felsic magmas favored localized magma mixing, which  
231 resulted in the local production of heterogeneous magmas of broadly tonalitic composition. This  
232 magma emplaced by lateral expansion in a NS direction that is common to the other pulses (Secchi  
233 et al., 2021).

234 The younger part of Sàrrabus pluton is dominated by a group of at least three different pulses of  
235 F-rich ferroan granites (hereafter as *stage 2*), which intrude the granodiorites and range from biotite  
236 granites (Bruncu Nicola Bove Unit and San Priamo Unit) to hastingsite granites (Monte Sette Fratelli  
237 Unit). The first two granitic intrusions were emplaced along an E-W trend while the Monte Sette  
238 Fratelli Unit overlaps the others emplaced as a large sub-vertical stock. Contacts of the three are  
239 parallel to the contact of stage 1 Monte Cresia unit with the surrounding Paleozoic metasediments.

240 This general frame is complicated by the occurrence of a bimodal subalkaline rock-association  
241 made up of a several generations of NNW trending mafic and (metaluminous to subaluminous) felsic  
242 dykes crosscutting an earlier generation of NE trending peraluminous felsic dikes dated at  $293 \pm 3$   
243 Ma (Ronca et al., 1999; Fig. 3e; f). Remarkably, mafic dikes consist of spessartites to hornblende-  
244 bearing granular rocks and is prevalently outcropping in Cala Regina Group granodiorites exposed in  
245 southern portion of the pluton. The end of Sàrrabus igneous activity is represented by a generation of  
246 olivine plagioclase-phyric mafic dikes with tholeiitic signature (Ronca et al., 1999) that crosscuts  
247 granite intrusions with a dominant NS trend.

248

249

## 250 **Analytical methods**

251 Whole-rock major and trace element concentrations of twelve samples representing the different  
252 Sàrrabus lithologies were determined at Activation Laboratories, Ancaster, Ontario, Canada.  
253 Powdered samples were previously fused using lithium metaborate or tetraborate, and then rapidly

254 digested in weak nitric acid solutions. Resulting solutions were analyzed by inductively coupled  
255 plasma–optical emission spectroscopy (ICP–OES) and ICP–mass spectrometry (ICP–MS)  
256 techniques. The uncertainties in major element concentrations are generally between 1% and 3%,  
257 except for MnO (5%–10%) and P<sub>2</sub>O<sub>5</sub> (>10%); most trace elements concentrations have uncertainties  
258 of <5%. Major element concentrations usually have detection limits of 0.01 wt%. Loss on ignition  
259 (L.O.I.) and FeO contents were measured using standards gravimetric techniques and titration with  
260 10N KMnO<sub>4</sub> techniques, respectively. Data are reported in Supplementary Material Table 1.

261 Additional samples were analysed for major and trace elements by *XRF* spectrometry using  
262 powder pellets, at the University of Cagliari laboratories, Italy. *X*-ray analyses were performed on an  
263 automatic Philips spectrometer (PW1400). Data were corrected for drift and background effects.  
264 Major elements were reduced for matrix effects according to Franzini et al. (1972). Trace elements  
265 were reduced for matrix effects using the method of fundamental parameters according to Criss and  
266 Birks (1968). Thirty reference rock standards were used for calibration. Analytical accuracy is within  
267 ±1% for SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO, K<sub>2</sub>O and MnO, and ± 4% for MgO, Na<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub>. The  
268 accuracy of trace element analyses is ± 2 to 3% at 1000 ppm, ± 5 to 10% at 100 ppm, and ± 10 to  
269 20% at 10 ppm level. Rh and W *X*-ray tubes were used, and detection limits were around 3 ppm for  
270 most trace elements. Data are reported in Supplementary Material Table 2.

271 Eleven selected samples, representing all the Sàrrabus lithologies were analyzed for Sr and Nd  
272 isotopic compositions at the laboratories of Dipartimento Scienze della Terra (Università degli Studi  
273 di Firenze, Italy). Sr and Nd measurements were obtained by a Thermofisher Triton Plus multi-  
274 collector mass-spectrometer, running in a static mode, following separation of Sr and Nd using  
275 conventional ion-exchange procedures as reported in Avanzinelli et al. (2005). Measured <sup>87</sup>Sr/<sup>86</sup>Sr  
276 ratios were normalized to <sup>88</sup>Sr/<sup>86</sup>Sr = 8.375209, <sup>143</sup>Nd/<sup>144</sup>Nd ratios to <sup>146</sup>Nd/<sup>144</sup>Nd = 0.7219. During  
277 collection of isotopic data, replicate analyses of the Sr NIST SRM 987 (SrCO<sub>3</sub>) isotopic standards  
278 gave an average <sup>87</sup>Sr/<sup>86</sup>Sr value of 0.710251 ± 20 (2σ<sub>m</sub>, N = 100) well in agreement with the reference  
279 value of Thirwall, (1991). The in-house Nd isotopic standard NdFi (Nd oxide) was used to test  
280 reproducibility. Data are reported in Supplementary Material Table 3.

281 Lu–Hf analyses were performed on the same zircon crystals previously U–Pb dated by Secchi et  
282 al. (2021) on SSP2 sample from Cala Regina granodiorite (Capo Carbonara, Fig. 2). Analyses were  
283 done in the same dated domains and were carried out using a double focusing MC–ICP–MS with a  
284 forward Nier–Johnson geometry (Thermo Fisher Scientific, Neptune™), coupled to a 213 nm  
285 Nd:YAG laser ablation system (New Wave Research™) at the laboratory of Centro  
286 Interdipartimentale Grandi Strumenti of the Università di Modena e Reggio Emilia. Isotopic ratios  
287 were acquired in static mode with a block of 250 cycles (including laser warm-up, ~50–80 cycles of  
288 analysis and washout), an integration time of 0.5 s, a laser spot of 55 μm and a fluence of ~10 J/cm<sup>2</sup>.

289 A low laser frequency (~10 Hz) was used to achieve better signal stability with a He flux of ~0.5  
290 L/min. Details of the method are reported in Giovanardi et al. (2018). Data reduction was performed  
291 using the Hf-INATOR software (Giovanardi and Lugli, 2017). During the analytical session,  
292 reference material zircon TEMORA-2 was used to check accuracy and precision. TEMORA-2  
293 provides  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios of  $0.282686 \pm 0.000075$  ( $2\sigma$ ,  $n=6$ ), identical within error to the reference  
294 value of 0.282686 (Woodhead and Hergt, 2005). Data are reported in Supplementary Material Table  
295 4.

296

297

## 298 **Results**

299 Representative samples from the intrusive units of Sàrrabus pluton have been analyzed for major,  
300 trace elements and Sr and Nd systematics to integrate whole-rock data available in the literature for  
301 gabbroic rocks and granodiorites (Poli and Tommasini, 1999; Franciosi et al., 2019), granitic units  
302 (Conte et al., 2017), as well as for mafic and acidic dikes (Ronca et al., 1999).

303 Overall, this expanded dataset supports a new and broader petrological and evolutionary picture  
304 of the pluton.

305 According to Miller (1985), in this paper granites with  $\text{ASI} > 1$  ( $\text{ASI} = (\text{mol. Al}/(\text{Ca}+\text{Na}+\text{K}-$   
306  $1.67*\text{P})) < 1.0$ ) coupled with the occurrence of a more aluminous mineral phase than dark mica will be  
307 classified as peraluminous.

308

### 309 *Essential petrographic features*

310 The main petrographic and mineralogical features of Sàrrabus igneous units are outlined in Conte  
311 et al. (2017; 2018a; b and reference therein) and summarized in Fig. 4 and Tab. 1. Rocks were  
312 classified according to IUGS's recommendations, using modal compositions obtained by mass  
313 balance calculations (Stormer and Nicholls, 1978). In this paragraph we will briefly describe the  
314 principal features of the different lithotypes, summarizing information from D'Angelo (1998), Poli  
315 and Tommasini (1999), Conte et al. (2017) and Franciosi et al. (2019).

316 Petrographic differences observed in the Cala Regina granodiorites mainly consist of an increase  
317 southward in (a) size and amount of dark enclaves, which compositionally range from tonalites to  
318 hornblende quartz-gabbros, (b) color index (from 14% to 20%), as well as (c) abundance of primary  
319 Fe-hornblende (1%-4%;  $\text{Mg}\#_{0.40-0.36}$ ), respectively. Typical plagioclase feldspar is a light-coloured,  
320 slightly zoned andesine ( $\text{An}_{45-41}$ ), even if patchy zoned plagioclases with relic of calcic cores ( $\text{An}_{63-}$   
321  $39$ ; Fig. 4f) are locally observed especially in biotite granodiorites. Common accessory phases are  
322 well-developed euhedral allanite, associated with mafic minerals, zircon, monazite, and minor apatite  
323 + ilmenite as inclusion on brownish dark mica.

324 Dismembered mafic masses in granodiorites (Solanas Complex of Cala Regina Group  
325 granodiorites) are hornblende gabbroic rocks with relics of ortho- and clinopyroxene, grading to  
326 hornblende quartz gabbros. These latter represent the typical composition of dark enclaves (Fig. 4a),  
327 and usually show panidiomorphic and fluidal textures characterized by calcic plagioclase ( $An_{84-45}$ )  
328 with cotectic relationships with Fe-hornblende ( $Mg\#_{0.55-0.48}$ ), dark mica ( $Mg\#_{0.48-0.45}$ ) and interstitial  
329 quartz (Fig. 4b). The mafic masses also include olivine-bearing gabbroic rocks and leuco-gabbros with  
330 cumulate textures (Conte et al., 2018b; Secchi et al., 2021), which document a dismembered formerly  
331 stratified sequence. Cumulitic rocks show commonly poikilitic textures; the dominant mineral  
332 assemblage is homogeneous olivine ( $For_{74}$ ) with peritectic relationships with orthopyroxene  
333 ( $Wo_{2}En_{77}Fs_{21}$ ) followed by calcic plagioclase ( $An_{89-92}$ ) and clinopyroxene ( $Wo_{47-42}En_{45-49}Fs_{8-9}$ ) set in  
334 a dominant mass of amphibole of pargasitic composition (Fig. 4c).

335 Strong petrographic variations are observed within felsic rock-types in terms of mafic mineralogy,  
336 feldspar composition as well as typical accessory phases. In detail, granites at the core of Sàrrabus  
337 pluton (i.e., Bruncu Nicola Bove Unit -BNB in Fig. 2) range from biotite monzogranite to  
338 leucogranite with normal oligo-albitic plagioclase ( $An_{30-15}$ ). Conversely, the San Priamo granite is  
339 made up of coarse-grained pinkish biotite leucogranite showing a slightly less sodic plagioclase  
340 feldspar ( $An_{40-26}$ ), large allanite grains and magnetite as typical accessory phases; additional  
341 interstitial dark or, less frequently, white micas are often observed (Fig. 4g).

342 The Monte Maria granite is a garnet-bearing ( $Alm_{65-69}Sp_{22-27}Py_5Gr_3$ ) two-mica variety, locally  
343 containing altered cordierite (Fig. 4h), whereas the Monte Sette Fratelli Unit consist of leucogranite  
344 grading to monzogranite containing oligo-albitic plagioclase ( $An_{20-15}$ ), large euhedral Fe-hastingsite  
345 and red-brown dark micas as early crystallized phases. Main accessory phases are large allanite +  
346 magnetite + ilmenite, mostly included in amphiboles, abundant zircons included in quartz and K-  
347 feldspars and anhedral fluorite grains as interstitial phases. In these rocks, dark mica of annitic  
348 composition, also occurs as interstitial phase, or as discontinuous coronas on interstitial and altered  
349 fayalite grains (Conte et al., 2017).

350 Main petrographic information on mafic and felsic rocks in dike swarms is outlined by Ronca et  
351 al. (1999). Overall, dike swarms recorded similar features observed for compositionally-equivalent  
352 intrusive rocks. Generally, the NE trending peraluminous felsic dikes, which predate the other dike  
353 swarms, resemble the Monte Maria peraluminous granites: they are characterized by oligo-albitic  
354 plagioclase and perthitic orthoclase with minor amounts of dark and white mica and/or spessartine-  
355 rich garnet. Remarkably, rare corroded andalusite with continuous coronas of white mica are  
356 occasionally observed. Apatite, zircon, monazite, magnetite and locally tourmaline are the typical  
357 accessory phases.

358 Mafic dikes include rocks of dominant basaltic andesite to andesite composition, with minor  
359 amounts of basalts. Overall, an orthopyroxene + clinopyroxene succession replaced by amphibole, is  
360 frequently observed in the spessartitic mafic dikes (Fig. 4d); when observed, olivine occurs as  
361 completely altered phenocrysts. Locally basaltic rock-types display glomero-porphyritic which may  
362 be evidence of cumulitic character.

363 The final generation of basaltic dikes (tholeiitic basalt *sensu* Ronca et al., 1999) are commonly  
364 characterized by labradoritic plagioclase feldspar, altered olivine and augite set in a fine-grained  
365 matrix of augite, plagioclase, and minor amount of amphibole.

366

#### 367 *Whole rock chemistry*

368 Major and trace-element chemical compositions of selected samples are reported in  
369 Supplementary material Tables 1 and 2. Supplementary material Table 1 reports ICP-MS data for 9  
370 specimens from main intrusive units and 3 representative samples from mafic dikes emplaced in  
371 granodiorites. Supplementary Material Table 2 refers to additional unpublished *XRF* data while  
372 Supplementary Material Table 5 reports average *XRF* analyses of intrusive units calculated on both  
373 our analyses and literature data (Pirinu 1994, D'Angelo. 1998).

374 Gabbroic and mafic dikes rocks have medium-K character while medium- to high-K character is  
375 observed for quartz-gabbroic varieties (Fig. 5a). Gabbroic rocks and analyzed mafic dikes  
376 (Supplementary Material Table 1) may be defined as high alumina basalts (Fig. 5b) and show in  
377 addition the prevalence of Na<sub>2</sub>O over K<sub>2</sub>O as a common feature: Na<sub>2</sub>O/K<sub>2</sub>O ratio decreases from 2.45  
378 to 1.48 in olivine-bearing gabbros to quartz-gabbros, respectively, and from 2.95 to 1.90 in mafic  
379 dikes. In addition, gabbroic rocks show an abrupt increase of FeO/(FeO + MgO) and Na<sub>2</sub>O + K<sub>2</sub>O –  
380 CaO (modified alkali index) with SiO<sub>2</sub> from olivine-bearing gabbroic rocks to quartz gabbroic  
381 varieties (Fig. 5d).

382 Conversely, granodiorites and granites are plotted at the end of a high-K rock-series (Fig. 5a) and  
383 show a general increase of peraluminous character with SiO<sub>2</sub> evidenced by ASI in the range of 0.73  
384 ÷ 0.98 (in granodiorites) with a higher value of 1.05 in garnet-bearing granite (Supplementary  
385 Material Table 1). A prevalence of K with respect to Na is displayed in granodiorites and garnet-  
386 bearing granite in the restricted range of 0.72 ÷ 0.74 and 0.61, respectively (Supplementary Material  
387 Tables 1 and 5). In the Frost's and Frost (2001) discrimination diagrams, granodiorites display a  
388 magnesian/calc-alkalic signature while granites straddle along the ferroan/alkali-calcic fields (Fig.  
389 5c; d).

390 REE normalized contents of different rock-lithotypes show a similar LREE enriched pattern and  
391 are poorly fractionated in MREE and HREE (Supplementary Material Table 1; Fig. 6). However,  
392 some differences could be noticed. Rocks from gabbroic association show a slight decrease of the Eu

negative anomalies from two pyroxene-bearing gabbros ( $\text{Eu}/\text{Eu}^* 0.79 \div 0.81$ ) to quartz gabbros ( $\text{Eu}/\text{Eu}^* 0.63 \div 0.74$ , Supplementary Material Figure 1). Quartz gabbros and two-pyroxenes gabbros display less LREE fractionation ( $\text{La}_\text{N}/\text{Sm}_\text{N}$  ( $1.42 \div 2.00$  in quartz gabbros and  $1.6\text{-}2.2$  in two pyroxene bearing-gabbros) with respect to other gabbroic rocks (Fig. 6). Generally, a direct correlation is found between the Eu anomaly and the  $\text{La}_\text{N}/\text{Yb}_\text{N}$  ratio, while this latter is inversely correlated to the  $\text{Gd}_\text{N}/\text{Yb}_\text{N}$  (Supplementary Material Figure 1). Cumulate rocks show  $\text{Eu}/\text{Eu}^*$  values around 1 and  $\text{La}_\text{N}/\text{Sm}_\text{N}$  in the range of  $1.9 \div 2.9$ .

Trace elements normalized patterns for gabbroic rocks show negative anomalies for Nb, Ta, P, Ti and Sr and enrichments in more incompatible elements (i.e., Rb, Ba, Th and U; Fig. 7a).

Granodioritic rocks show fractionated LREE ( $\text{La}_\text{N}/\text{Sm}_\text{N}$  between 2.90 and 4.33) and higher  $\text{La}_\text{N}/\text{Yb}_\text{N}$  (between 8.02 and 13.53) than mafic rocks, with slightly more pronounced Eu anomalies ( $\text{Eu}/\text{Eu}^*$  average of 0.67) (Fig. 6b). In addition, trace elements show depletion for Nb, Ta, Sr and P, and high fractionation for the more incompatible elements (Rb, Ba, Th and U), along with peaks in Sr (Fig. 7b).

Granitic rocks display fractionated LREE, relatively flat HREE patterns with  $\text{Gd}_\text{N}/\text{Yb}_\text{N}$  values range from 0.95 to 1.45 (Supplementary Material Table 1).  $\text{Eu}/\text{Eu}^*$  decrease from 0.33 in Monte Sette Fratelli and San Priamo metaluminous/subaluminous granites to 0.18 in Monte Maria Unit peraluminous granite (Fig. 6b). In detail, granites from Monte Sette Fratelli Unit are more enriched in REE and show a slight fractionation in HREE. Conversely, granites from San Priamo Unit are less enriched in REE and show a convex pattern for M-HREE (Fig. 6d). The picture is complicated by the peraluminous granite (Monte Maria), which shows fractionated enrichment for LREE from La to Nd and almost flat trend from Sm to Lu (except for the Eu negative anomaly), showing LREE contents lower than other granites but HREE almost comparable with those observed for Monte Sette Fratelli granites (Fig. 6d). It is also the only lithology displaying Ba depletion while it also shows Nb, Sr and P negative anomalies (Fig. 7b).

Mafic dykes (basalts to andesite-basalt in composition) show fractionated REE patterns with LREE enrichments ( $\text{La}_\text{N}/\text{Yb}_\text{N}$  between 5.94 and 8.35) and weak or none Eu anomaly ( $\text{Eu}/\text{Eu}^*$  between 1.05 and 0.83). Trace elements are depleted in Nb, Ta and P, and the more primitive dykes have a positive Sr anomaly which became negative in the more evolved ones (Fig. 7a).

With respect to the studied samples, the late felsic dykes show the most heterogeneous REE contents (Fig. 6d). Different REE compositions, which basically overlap both metaluminous and peraluminous granites, point out to several different sources of the parent melts.

425

426 *Isotope data*



427 Sr and Nd isotopic ratios (Supplementary Material Table 3) have been calculated back to 286 Ma  
428 the likely age for intrusive rocks and mafic to felsic dykes (Secchi et al., 2021) assuming a  
429 substantially rapid emplacement of magmatic pulses based on the field evidence on the intrusion  
430 sequence, as well as on geochronological data.

431 When schematizing the Sàrrabus pluton as composed by an older *stage 1* and by a younger *stage*  
432 2, the isotope composition may be discussed as follows.

433 Granodiorites and associated gabbroic rocks show no correlation between  $1/\text{Nd}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$   
434 initial values (Supplementary Material Figure 2), as well as between  $\text{SiO}_2$  and  $^{87}\text{Sr}/^{86}\text{Sr}_t$  and  $\epsilon\text{Nd}_{(t)}$   
435 (not shown). In addition, in the  $^{87}\text{Sr}/^{86}\text{Sr}_t$  vs.  $\epsilon\text{Nd}_{(t)}$  diagram (Fig. 8) granodiorites plot in a restricted  
436 field, ranging from 0.7088 to 0.7097 and from  $-5.5$  to  $-6.3$ , respectively. Remarkably, gabbroic rocks  
437 commonly show more radiogenic values for Nd and range in composition from 0.7081/ $-5.9$  to  
438 0.7099/ $-6.8$ ; overall, a similar behavior is observed in the  $1000/\text{Sr}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}_t$  diagram  
439 (Supplementary Material Figure 2). A partial overlap in isotopic data between these groups of rocks  
440 is represented by tonalites, confirming field observations of mingling relationships with gabbroic  
441 rocks.

442 In the Rb-Sr and Nd-Sm isochron plot (Supplementary Material Figure 3), only the granodioritic  
443 rocks and microgranular quartz-gabbros cluster on a 286 Ma reference line (according to published  
444 Pb/Pb chronological data: Secchi et al., 2021), whereas gabbroic rocks show scattered values.

445 Peraluminous granites belonging to Monte Maria and peraluminous rhyolitic dikes show constant  
446  $\epsilon\text{Nd}_{(t)}$  ( $-7.5$ ) and extremely high  $^{87}\text{Sr}/^{86}\text{Sr}_t$  in the range of  $0.7154 \div 0.724$ , respectively, which approach  
447 to a supracrustal endmember.

448 Metaluminous to sub-aluminous granite rock-types belonging to *stage 2* (i.e., Monte Sette Fratelli  
449 and San Priamo), which occupy the northern side of the pluton, form an independent group showing  
450 a flat trend in the Sr–Nd diagram (barred symbols in Fig. 8; Conte et al., 2017). They exhibit a wide  
451 Sr isotopic composition, from 0.703 to 0.7095 and, conversely, a quite homogeneous  $\epsilon\text{Nd}_{(t)}$  value of  
452 about  $-7.5$  that does not differ from the field of metaluminous felsic dikes reported in Ronca et al.  
453 (1999).

454 In general, in the  $^{87}\text{Sr}/^{86}\text{Sr}_t$  vs.  $\epsilon\text{Nd}_{(t)}$  diagram (Fig. 8), mafic dikes overlap the trend described by  
455 the entire *stage 1* ranging from 0.7068/ $-2.9$  to 0.7097/ $-6.2$ . Is to be noticed that lesser and roughly  
456 constant radiogenic compositions ( $0.7053/-1.35$ ) are recorded for late mafic (tholeiitic) dikes hosted  
457 in leucogranites.

458 Further petrogenetic information may be provided by the Nd crustal residence ages for granites  
459 and basaltic dikes, on account of a crustal origin proposed in literature (Ronca et al., 1999; Conte et  
460 al., 2017) and of mafic/felsic magma interactions described in the previous geological section,

461 respectively. Given the observed linear correlation between Sm/Nd and two-stage Nd crustal  
462 residence age, a two-stage model is here preferred. Overall, calculated model ages are in the 1.4 – 1.6  
463 Ga range reported for European Variscan chain (Janoušek et al., 1995; Downes et al., 1997; Villaseca  
464 et al., 1998). In detail, two-stage Nd crustal residence ages calculated for basaltic dikes are in the  
465 range of 1.25 – 1.61 Ga and decrease to 1.11 in olivin-phyric tholeiitic basalts.  
466 Metaluminous/subaluminous granites and dikes are in the range of 1.44 ÷ 1.50 Ga; higher values  
467 clustered to 1.59 Ga have been obtained for peraluminous granites and dikes.

468 On the granodiorite sample dated by U-Pb zircon ages by Secchi et al. (2021), Lu-Hf analyses on  
469 dated zircons were performed (Supplementary Material Table 4 and Figure 4).  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios for  
470 Cala Regina granodiorite (sample SPP2) are between 0.282441 and 0.282621.  $\varepsilon\text{Hf}(t)$  recalculated back  
471 at 286 Ma (Secchi et al. 2021) provided negative values, between -5.6 and -1.0, but a single positive  
472 value was also found at 0.5.

473

474

## 475 Discussion

476

### 477 *Geological constraints for Sàrrabus magmatism*

478 The emplacement of Sàrrabus pluton occurred in a crustal segment likely made up of an ancient  
479 (Proterozoic) basement belonging to northern Gondwana margin overthrust by Paleozoic nappes  
480 dominated by Cambro-Ordovician anchimetamorphic sedimentary rocks (Carmignani et al., 1994;  
481 Edel et al., 2014).

482 Field (Secchi et al., 2021) and geochronological data discussed in the previous geological section  
483 provide evidence of rapid emplacement at shallow crustal levels (1-2 kb: Conte et al., 2017; Secchi  
484 et al., 2021) of a wide variety of compositionally different magma pulses: (a) mafic/granodiorite  
485 mingling relationships, the lack of contact metamorphic aureole and syn-magmatic deformation ; (b)  
486 granitic pulses that unconformably crosscut granodiorite flat intrusions with steep contacts; (c)  
487 undistinguishable ages, clustered at 286 Ma, based on several isotopic systematics on *stage 1* and  
488 *stage 2* units (Nicoletti et al., 1982; Di Vincenzo et al., 2005; Dack, 2009; Secchi et al., 2021); (d)  
489 occurrence of substantially coeval bimodal basaltic/rhyolitic dikes.

490 *Stage 1* melt ascending is controlled by a dilatant roughly EW trending shear zone (the SSSZ) that  
491 acted as a feeder for magmas and records mingling relationships between granodiorites and gabbroic  
492 magmas. Indeed, the dilatant style of the SSSZ channelized the migration of large volumes of mantle-  
493 derived magmas up to upper crustal levels. Moreover, a close field association with peraluminous  
494 granites is observed (i.e., Monte Maria Unit; Fig. 2). Conversely, a succession of independent granitic  
495 magma pulses that share a common F-rich ferroan character marks the *stage 2* (Fig. 5d). In this stage,

mantle-derived magmas are only represented by few mafic dike swarms, representing a late generation of olivine-plagioclase phyric basalts with tholeiitic affinity (Ronca et al., 1999; Conte et al., 2017).

#### *Petrogenetic constraints for Sàrrabus magmatism*

Several lines of evidence support for the Sàrrabus pluton an early involvement of mantle-derived magmas and a progressive more relevant production of crustal-derived magmas. Overall, each rock-types shows distinctive petrographic and chemical characters which suggest independent evolution paths.

Petrographic data allow to constrain the evolution of different magma pulses to upper crustal levels. Evidence in favor of a general low-pressure evolution for mafic magmas hosted in Cala Regina Group (<5 kbar) is the early appearance of orthopyroxene followed by calcic plagioclase and clinopyroxene; in addition, olivine shows peritectic relationships with orthopyroxene (Conte et al., 2018a). The increase of water content in melts, testified by amphibole + dark mica segregation, characterizes the quartz gabbroic varieties; moreover, amphibole (Fe-hornblende) and dark mica of similar composition become the only mafic minerals within the assemblage of granodiorites.

Generation of different granitic magmas is constrained by the occurrence of garnet, muscovite and rare cordierite in Monte Maria Unit peraluminous rocks and, conversely, by the early appearance of hastingsite in metaluminous granites (Monte Sette Fratelli Unit). An upper limit of 5 kb for magma evolution (e.g., Green, 1977; Dahlquist et al., 2007 and references therein) is further confirmed for Monte Maria granite by homogeneous garnet compositions (spessartine contents > 10%), coexisting with cordierite.

Isotopic data constrain a general model for Sàrrabus magmatism. Sr–Nd systematics well document the contrasting behavior between two different groups of crustal-derived (peraluminous and metaluminous/subaluminous) granitic magmas and a small homogenous granodiorite field unrelated to the higher variation of the trend displayed by gabbroic magmas (Fig. 8). In addition, further evidence in favor of an independent origin between the mafic and granodioritic suites forming the Cala Regina Group is provided by serial affinity (Fig. 5c) and REE normalized patterns (Fig. 6a). In detail, the gabbroic rocks are generally LREE-enriched with respect to granodiorites; conversely, cumulitic varieties suggest that the segregation process for gabbroic parent melts produced a decrease in the LREE content. Granodiorites are more fractionated in LREE with respect to gabbroic rocks, but also show a more pronounced negative Eu anomaly, thus indicating that plagioclase fractionation in granodiorites has differently affected the REE compositions. The dual signature of gabbroic rocks pointing to none, or small segregation of plagioclase indicates different *P-T* conditions for the parental melts during fractionation, thus suggesting a vertically zoned magmatic reservoir.

531 In a general extensional setting, the ascent of gabbroic magmas at middle/upper crustal levels may  
532 provide the necessary heat input to cause dehydration melting of biotite and muscovite in  
533 metasedimentary rocks and promotes the generation of peraluminous granitic melts belonging to the  
534 *stage 1*. In this scheme, evidence in favour of a source located in the middle crust is the general low-  
535 pressure (<5 kbar) evolution indicated for gabbroic magmas by textural relationships. In addition,  
536 generally flat REE patterns lead to exclude a garnet-bearing source.

537 As expected by geological relationships and petrographic characters, mafic and felsic dike swarms  
538 overlap the trends observed for rocks belonging to *stage 1* and *stage 2*, respectively.

539 A genetic model involving contamination and crystal/liquid fractionation process has been already  
540 proposed to explain the magmatic evolution observed for gabbroic magmas of Scala Carbonara body  
541 (SC in Fig. 2) contaminated by granodioritic magma (Poli and Tommasini, 1999). The different  
542 behavior of gabbroic and granodioritic magmas point to different compositions and evolutions of the  
543 parent melts. Overall, an enriched mantle source is inferred from Ta/Yb–Th/Yb plot for gabbroic  
544 magmas and for selected mafic dikes from Sàrrabus pluton, in agreement with data reported by  
545 Gaggero et al. (2007) for lamprophyric dikes from northern Sardinia (Supplementary Material Figure  
546 5). In addition, mafic rocks of the Sàrrabus pluton shows several degrees of crustal assimilation as  
547 revealed by Rb, Ba, Th and U concentrations which are relatively high and negative  $\epsilon_{Nd}$  also in  
548 cumulate gabbroic rocks (Fig. 7). This implies consequences with regard to isotope ratios: Nd model  
549 ages for these rocks are actually meaningless, being calculated on mixed isotopic composition derived  
550 by several sources. Moreover, different isotopic trends displayed by gabbroic rocks and granodiorites  
551 suggest that the mantle-derived melts interacted with different crustal components and could be re-  
552 equilibrated at different crustal levels.

553 According to Conte et al. (2017), metaluminous to sub-aluminous granitic magmas require  
554 processes of partial melting involving lower crustal level of mostly intermediate/mafic composition,  
555 as confirmed by whole-rock initial Pb isotopic compositions of metaluminous to subaluminous  
556 granites (i. e., San Priamo and Monte Sette Fratelli units which plot in the lower crust field in the  
557  $^{206}Pb/^{204}Pb$ – $^{208}Pb/^{204}Pb$  plot in Conte et al., 2017).

558

#### 559 *Evaluating the involvement of crustal materials*

560 An essential assumption of our models of magma genesis and the relation to Nd isotopes is the  
561 involvement of pre-existing continental crustal material (with low  $\epsilon_{Nd}$  and relatively high Nd  
562 concentration) and/or contribution from sub-continental lithospheric mantle (SCLM) (with high  $\epsilon_{Nd}$   
563 and moderate Nd concentration) in the generation of mafic and granitic magmas. The  $^{147}Sm/^{144}Nd$   
564 ratio in a reservoir is expressed as the enrichment factor relative to CHUR as  $f_{Sm/Nd} =$

565  $(^{147}\text{Sm}/^{144}\text{Nd}_{\text{sample}})/(^{147}\text{Sm}/^{144}\text{Nd}_{\text{CHUR}}) - 1$  after De Paolo and Wasserburg (1976). According to De  
 566 Paolo et al. (1992) the fractional isotopic shift from mantle (MC) to crustal (CC)  $\epsilon\text{Nd}$  values can be  
 567 described by the Neodymium Crustal Index (NCI):  $\text{NCI} = [\epsilon\text{Nd}(\text{rock}) - \epsilon\text{Nd}(\text{MC})]/[\epsilon\text{Nd}(\text{CC}) -$   
 568  $\epsilon\text{Nd}(\text{MC})]$ . NCI thus describes the fraction of crustal Nd in a rock. NCI is 0 when the rock has no  
 569 crustal Nd (the  $\epsilon\text{Nd}$  value is equal to the mantle MC source value) and 1 when all Nd in a rock has a  
 570 crustal origin (the  $\epsilon\text{Nd}$  value is equal to the crustal CC value). Surveying local data, we have  
 571 considered MC = +8 and CC = -15 for NCI calculation, representing MC – an average composition  
 572 of the YMP mafic rocks from Sardinia (Gaggero et al., 2007), and CC – composition of the most  
 573 crustal metasedimentary schist from the Sardinia basement (Di Vincenzo et al., 1996). Nd isotopic  
 574 compositions of mafic/felsic rocks from Sàrrabus pluton and available data from entire Sardinia range  
 575 from near model mantle values to near model crustal values (Fig. 9a). Moreover, collected data show  
 576 slightly negative correlation in the  $f_{\text{Sm}/\text{Nd}}$  vs. NCI plot, and partial coincidence of mafic rocks with  
 577 granitic rocks. The abnormally high NCI = 0.62–0.75 for the mafic rocks was likely caused by fluid-  
 578 metasomatism of pre-existing SCLM or related to contamination with (amphibolitic) lower crust.  
 579 This enrichment is obvious from  $f_{\text{Sm}/\text{Nd}}$  vs.  $\epsilon\text{Nd}_{(286)}$  plot (Shirey and Hanson, 1986; Fig. 9b) where  
 580 both mafic and felsic rocks from Sàrrabus pluton lie in the quadrant characterized by crustal  
 581 enrichment (i. e. negative  $f_{\text{Sm}/\text{Nd}}$  and  $\epsilon\text{Nd}_{(i)}$  values; Fig. 9b).

582 Such mafic/felsic intrusions, that have initial Nd isotope ratios below to the chondritic value ( $\epsilon\text{Nd}$   
 583  $< 0$ ), indicate possible SCLM sources that are chemically enriched/metasomatized, and thus different  
 584 from the MORB or volcanic-arc basalt sources. Although the Sr–Nd isotopic characteristics of  
 585 particularly mafic components are quite atypical, nevertheless it is possible to model the mixing  
 586 between the mafic component (sample SSP6b from a mafic dike) and the crustal ones (sample SSP59,  
 587 from peraluminous granite; Fig. 10). Obviously, from the presented model, the crustal source is  
 588 dominant (80–85%) in the genesis of granodioritic magmas, as also supported by negative  $\epsilon\text{Hf}(t)$   
 589 values, while the concomitant mafic components with unusually high negative  $\epsilon\text{Nd}_{(286)}$  over -4 (Figs  
 590 8 and 10) show considerable crustal enrichment or fluid-metasomatism.

591 This large involvement of crustal materials is coherent with negative  $\epsilon\text{Hf}$  values of granodiorites  
 592 zircons and the large compositional gap emerging from Sr–Nd systematics for Corsica and northern  
 593 Sardinia granitoids with respect to Sàrrabus pluton (Fig. 8), that was inherited from deep sources of  
 594 granite magmas and related to the thermal structure of different lithospheric fragments assembled  
 595 during the Variscan collision in the Sardinia-Corsica massif. The more radiogenic signature and the  
 596 value of  $\delta^{18}\text{O}_{\text{SMOW}} = +8.4 \text{ ‰}$  (Brotzu et al., 1981) observed for mafic suites and associated  
 597 granodiorites from Sàrrabus pluton does not conflict with an earlier contamination stage and different  
 598 residence times at lower crustal levels with respect to the northern Sardinia/Corsica suites.

600 *Mantle-crust interactions and nature of involved crustal materials*

601 When considering the genesis and emplacement of Sàrrabus magmas, which belong to a reworked  
 602 crust of the northern Gondwana margin thinned during the collapse and exhumation of the Variscan  
 603 chain (Casini and Oggiano, 2008; Rossi et al., 2015), a complex petrological model can be depicted.  
 604 Schematically, in a commonly accepted regime of lithospheric mantle delamination (Edel et al., 2014;  
 605 Rossi et al., 2015), extensional shear zones, as the SSSZ, favoured the repeated ascents of mantle-  
 606 derived magmas which experienced crystal/liquid fractionation (Poli and Tommasini, 1999; Conte et  
 607 al., 2018; Franciosi et al., 2019) and likely served as a heat source for melting of metasedimentary  
 608 crustal levels, producing peraluminous granite magmas in *stage 1*.

609 Tommasini et al. (1995) pointed out that the main geochemical characters of the Sardinian high-  
 610 K and I-type calcalkaline granitoids suggest a dominant derivation from partial melting of  
 611 metagneous and igneous-derived materials belonging to a volcanic arc linked to an Ordovician  
 612 subduction. Remarkably, this group of granites and rhyolitic dikes overlaps the field of felsic  
 613 granulites belonging to the Central Spanish Variscan System (Villaseca et al., 1998); an overlap with  
 614 lower crustal sources was also inferred by Pb isotopic data obtained for SPU leucogranites. According  
 615 to Conte et al. (2017), granitic rocks like MSFU, which plot in the III quadrant of  $^{87}\text{Sr}/^{86}\text{Sr}_t$  vs.  $\epsilon\text{Nd}_{(t)}$   
 616 diagram, have isotopic values which are rather uncommon at the scale of entire European Variscides.

617 Accordingly, the two-stage  $T_{DM}$  crustal residence ages calculated for Sàrrabus granites overlap  
 618 those calculated for Cambro-Ordovician orthogneisses from northern Sardinia and central Iberia (Di  
 619 Vincenzo and Ghezzo, 1996; Villaseca et al., 1998). On the other hand, the geochemical/metallogenic  
 620 and lead isotopic signatures of the F-rich, ferroan granites indicates the derivation from meta-igneous  
 621 sources in the lower crust (Conte et al., 2017). This provenience from a deep source for the  
 622 metaluminous/subaluminous products of the Sàrrabus pluton *stage 2* may also assume the  
 623 significance of a possible derivation from an inferred and more ancient (Proterozoic) volcanic arc,  
 624 rooted in a crystalline basement under the cover of Paleozoic nappes.

625

626

627 **Conclusions**

628 The Sàrrabus pluton documents a sequence of magmatic events which record a repeated bimodal  
 629 character in which different mantle-derived and crustal-related magmas, whose ascent was controlled  
 630 by dilatant extensional faults, are recognized. Several lines of evidence suggest a complex frame of  
 631 mafic magmas promoting partial melting of continental crust, as well as continuous mafic/felsic  
 632 magma interactions decreasing in time at different crustal levels. In the general late orogenic context  
 633 of the frontal zone of the Variscan wedge, it is possible to hypothesize different scenarios capable of

634 explaining thermal anomalies and magma production. Radiogenic heating of previous thickened crust  
635 and shear heating are mechanisms that can account for the heat supply consistent with generation of  
636 large volume of crustal melts. LID delamination is a further mechanism that from syn- to post-  
637 collisional settings can transfer large amount of heat from the mantle into the crust of evolving  
638 orogenic belts. Delamination models may be applied to the Variscan granitic provinces even in  
639 absence or scarcity of mantle magmas. Indeed, mixing processes, assimilation and mingled zones are  
640 clues for mantle contributes to the building of the Variscan batholiths, including the Corsica-Sardinia  
641 Batholith. The Sàrrabus pluton intruded at 286 Ma in a slightly thickened frontal portion of the  
642 orogenic wedge, where low levels of radiogenic heating are expected and syn-intrusive shear heating  
643 is not documented. Therefore, these two heat sources can hardly account for the melting of the crust  
644 in this part of the Variscan chain. Conversely, the progressive migration of delamination away from  
645 the suture zone located in Northern Sardinia, down to Central-Southern Sardinia and Sàrrabus, could  
646 have heated the crust up to temperatures close to 1000 °C, which might lead to crustal melting at  
647 different crustal levels. A further hypothesis may consider the high heat flux produced by a possible  
648 lithosphere necking triggered by pre-existing weak zones in the mantle, determining astenospheric  
649 uplift to the crust base; the far field stress able to initiate necking in an already stiffed Variscan crust  
650 could be envisaged in the plate reorganization the led to the Pangaea.

651 Whatever was the actual large-scale heating mechanism, stretching conditions of Sàrrabus crust  
652 favored the partial melting of different crustal levels by a heat input from mantle-derived gabbroic  
653 magmas. In this context, a regime of decreasing temperature of the crust may account for the marked  
654 bimodality of diking activity, which inhibits the production of voluminous granodioritic magmas by  
655 mixing processes.

656

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## Figure Captions

Fig. 1: simplified geological map of Sardinia-Corsica batholith (after Casini et al., 2012). 1-4: metamorphic basement. (1) Pan-African schists. (2) Unmetamorphosed Foreland. (3) Low- to medium-grade metamorphic units (nappe zone). (4) High grade metamorphic complex. 5-6 Sardinia-Corsica batholith. (5) Syn-collisional Variscan magmatism (Mg-K rock-series). (6) Late-Variscan post-collisional magmatism. (7) Post-Variscan covers. Other symbols: main Variscan faults (8). From north to south, Arg, SM, Arz, Br, Gn, Gh, Arb and SV refer to localities cited in the text (Santa Maria Island, Arzachena, Barrabisa, Gennargentu, Grighini, Arburèse and San Vito, respectively).

Fig. 2: Geological sketch map of late-Variscan Sàrrabus pluton (SE Sardinia, Italy). (1) Undifferentiated epimetamorphic complex: metasandstones, metapelites and metalimestones (Cambrian-early Carboniferous). (2-8) Late-Variscan igneous units of Sàrrabus pluton: (2) Two-pyroxene biotite gabbro tonalites (Burchi Unit). (3) biotite to biotite hornblende granodiorites (Cala Regina Group) with syn-plutonic stocks and dismembered dikes of two pyroxene-bearing hornblende gabbroic varieties (Solànas complex; SO). (4) Garnet-bearing two mica granites (Monte Maria Unit). (5) biotite monzogranites grading to leucogranites (Bruncu Nicola Bove Unit). (6) F-rich biotite leucogranite (San Priamo Unit). (7) F-rich hastingsite granite stocks (Monte Sette Fratelli Unit). (8) Mafic and acidic dike swarms. (9) Post-Mesozoic sedimentary and volcanic covers and recent continental and transitional sedimentary deposits. Other symbols (10-12). Late-Variscan southern Sàrrabus shear zone (SSSZ) (10). Main extensional faults, certain (11) and inferred/buried (12). CR, Ge, TF, So, SC, Vs, Ca, S.P., Bu, S.G. and M. SF refer to Cala Regina, Geremèas, Torre de su Fenugu, Solànas, Scala Carbonara, Villasimius, Castiadas, San Priamo, Burchi, San Gregorio and Monte Sette Fratelli localities cited in the text, respectively.

Fig. 3: Field relationships of Sàrrabus igneous rocks. (a) Sub-horizontal magmatic foliation of hornblende granodiorites evidenced by dark and felsic enclaves (FE; Capo Carbonara). (b) strongly foliated quartz diorites with large mafic enclaves of quartz gabbroic composition (Porto Murròni); (c) densely interdigitation between gabbroic rocks and quartz diorites (western slope of Torre de su Fenugu); (d) disrupted large syn-magmatic mafic dikes into granodiorite (western slope of Torre de su Fenugu); (e) contact relationships between different dike generation: composite dikes predate metaluminous acidic dikes (Cala Regina); (f) fine-grained centimetric rounded dark enclaves in acidic dike (Porto Murròni).

Fig. 4: Petrographical characters of magmatic rocks from Sàrrabus igneous massif. (a) two pyroxene-bearing equigranular gabbroic rocks from inner part of Scala Carbonara body (crossed polars; Scala Carbonara, sample SSP16.); (b) panidiomorphic textures of quartz microgabbros (crossed polars; sample SSP17; Capo Carbonara); (c) cumuloptyric texture of olivine-bearing dark layers from stratified septa (crossed polars; Cabu Oi, sample SSP29); (d) clinopyroxene/brown amphibole relationships in equigranular varieties of mafic dike (crossed polars; north of Olia Speciosa, sample ESP10); (e) local plagioclase enriched zones in hornblende quartz diorites (crossed polars; sample

SSP8, Porto Murrone; (f) large patchy-zoned plagioclase lath on Cala Regina granodiorites (crossed polars; Monte Nai, sample ESP1); (g) interstitial white mica in San Priamo leucogranites of (plane polarized light; Monte Gruttas, sample SPP9); (h) Almandine garnet associated to pinitized cordierite in peraluminous granites of Monte Maria Unit (plane polarized light; Porto Carbonara, sample LPC).

Fig. 5: Discrimination diagrams for the igneous rocks from Sàrrabus pluton. (a) Boundaries according to Peccerillo and Taylor (1976); (b) discrimination diagram for basaltic rocks. HAB and HMB refer to high alumina and high Mg basalts, respectively; boundaries according to Miyashiro (1974). (c) and (d) Frost's and Frost (2001) discrimination diagrams. C, CA, AC and A refer calcic, calc-alkalic, alkali-calcic and alkaline rock-series, respectively. Pale and smaller symbols refer to literature data. Literature after Poli and Tommasini (1999) and Franciosi et al. (2019) is reported for comparison. Fields refer to mafic and acidic dike swarms (data after Ronca et al., 1999).

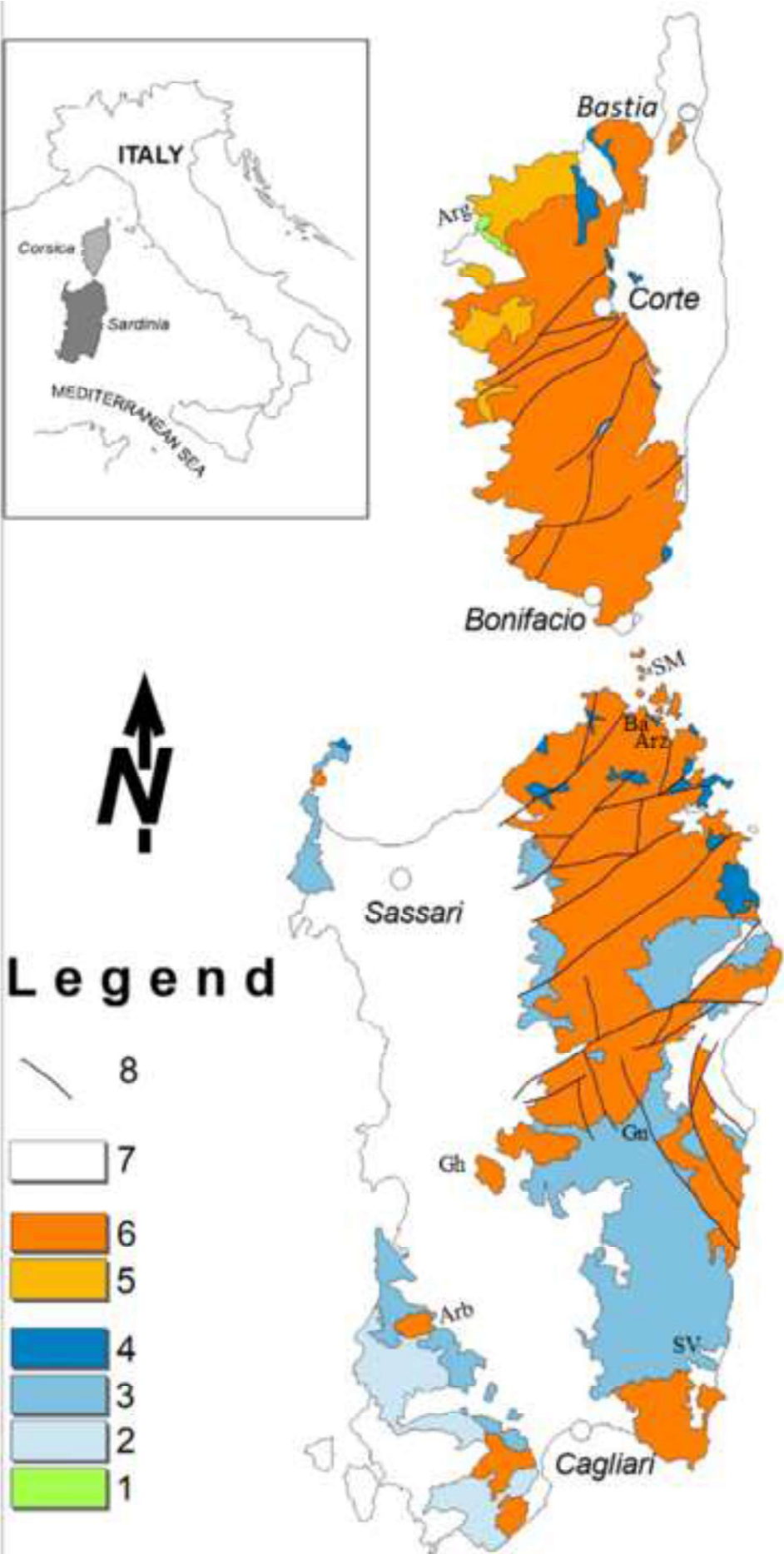
Fig. 6: REE normalized patterns for Sàrrabus magmatism: (a) syn-plutonic gabbroic suite; solid, double and dashed lines refer to olivine-bearing cumulate, two pyroxene-bearing gabbros and hornblende Qz-gabbros, respectively. Light and pale blue fields refer to data for olivine-bearing cumulates and hornblende Qz-gabbros (Franciosi et al., 2019), respectively. (b) Granodiorite rock-association; solid, double and dashed lines refer to Qz-diorite, tonalitic granodiorite and foliated granodiorite, respectively. The solid field refers to data for granodiorites after Franciosi et al. (2019); (c) mafic dikes; solid field refers to data for basalts from Ronca et al. (1999); (d) granites and felsic dikes; solid, dashed and dotted lines refer to peraluminous granite, metaluminous dikes and peraluminous dike (data after Ronca et al., 1999), respectively. Dark and pale yellow solid fields refer to San Priamo and Monte Sette Fratelli granites, respectively (data after Conte et al. (2017)). Data are normalized to CI (Mc Donough and Sun, 1995). Labels in (c) as in Supplementary Material Table 1.

Fig. 7: Spider diagrams for syn-plutonic mafic (a) and granodiorite (b) rock-associations from Sàrrabus pluton normalized to primitive mantle (McDonough and Sun, 1995). Peraluminous granite is reported for comparison.

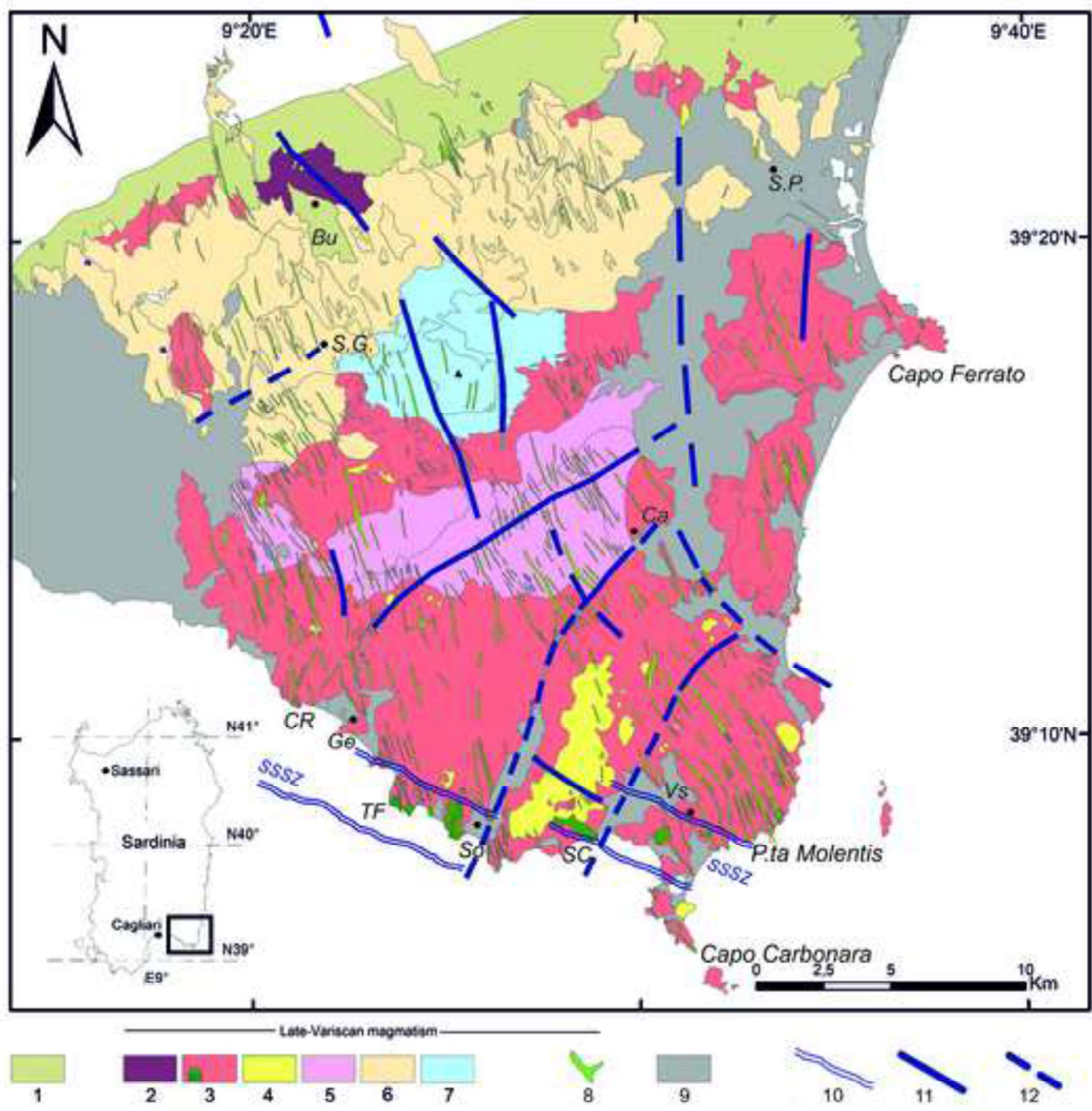
Fig. 8:  $\epsilon\text{Nd}_{(t)}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}_{(t)}$  for late-Variscan rocks from Sàrrabus pluton (south-eastern Sardinia, Italy) calculated for an age of 286 Ma (see text). Red, orange, and blue colors refer to Corsica, Gallura (northern Sardinia) and Sàrrabus pluton, respectively. Circle refer to peraluminous garnet-bearing granite from Monte Maria Unit. Barred circles refer to metaluminous to sub-aluminous granites of San Priamo and Monte Sette Fratelli units (data after Conte et al., 2017). Dike trend refers to mafic to intermediate dikes from Sàrrabus pluton (data after Ronca et al., 1999). Data for Corsica mafic suites after Cocherie et al. (1994); data for Gallura mafic suites after Tommasini et al., 1995 (Punta Falcone) and Casini (Bortigiadas and La Etica), still unpublished data; mafic (subalkaline and transitional) dikes after Gaggero et al., 2007). Dark blue arrow refers to gabbros to hornblende quartz micro gabbros evolutive line (with olivin-cumulites at left hand). Note the position of granodiorites outside of evolutive sequence and the intermediate position of tonalites for which a hybrid origin is required. Note also that less evolved granodiorites (i.e., Scala Carbonara and Capo Carbonara) show a more radiogenic character with respect of Solànas granodiorites (Porto Murrone).

Fig. 9: a)  $f(\text{Sm}/\text{Nd})$  vs. NCI plot for the Sàrrabus pluton and other available Sardinia samples.  $f(\text{Sm}/\text{Nd}) = (^{147}\text{Sm}/^{144}\text{Nd}_{\text{sample}})/(^{147}\text{Sm}/^{144}\text{Nd}_{\text{CHUR}}) - 1$  (DePaolo and Wasserburg, 1976);  $\text{NCI} = [\epsilon\text{Nd}(\text{rock}) - \epsilon\text{Nd}(\text{MC})] / [\epsilon\text{Nd}(\text{CC}) - \epsilon\text{Nd}(\text{MC})]$  according DePaolo et al. (1992). Field refer to metasediments from central-eastern Sardinia (data after Di Vincenzo et al., 1996). b)  $f(\text{Sm}/\text{Nd})$  vs.  $\epsilon\text{Nd}_{(286)}$  plot for the Sàrrabus pluton and other available Sardinia sample. DM, EM and CC are according to Hodkinson et al. (1995). Field refer to orthogneisses and migmatites from central-eastern Sardinia (data after Di Vincenzo et al., 1996). Other symbols as in Fig. 5.

989 Fig. 10: Mixing binary plot of  $^{87}\text{Sr}/^{86}\text{Sr}_{(286)}$  vs.  $\epsilon\text{Nd}_{(286)}$  showing variability of rocks from Sàrrabus  
990 pluton. Symbols as in Fig. 5 and 10; numbers refer to SSP samples reported in Supplementary  
991 Material Table 3. Dashed lines refer to possible mixing hyperbolas obtained by reverse least-squares  
992 method (Janoušek et al., 2016) using SSP6b (mafic dike) and SSP59 (peraluminous granite) samples  
993 as mantle- and crustal-derived endmembers, respectively to model the observed granodiorite rock-  
994 association. Pale field refer to data for granodiorite rock-association after Poli and Tommasini (1999)  
995 and Franciosi et al. (2019).  
996  
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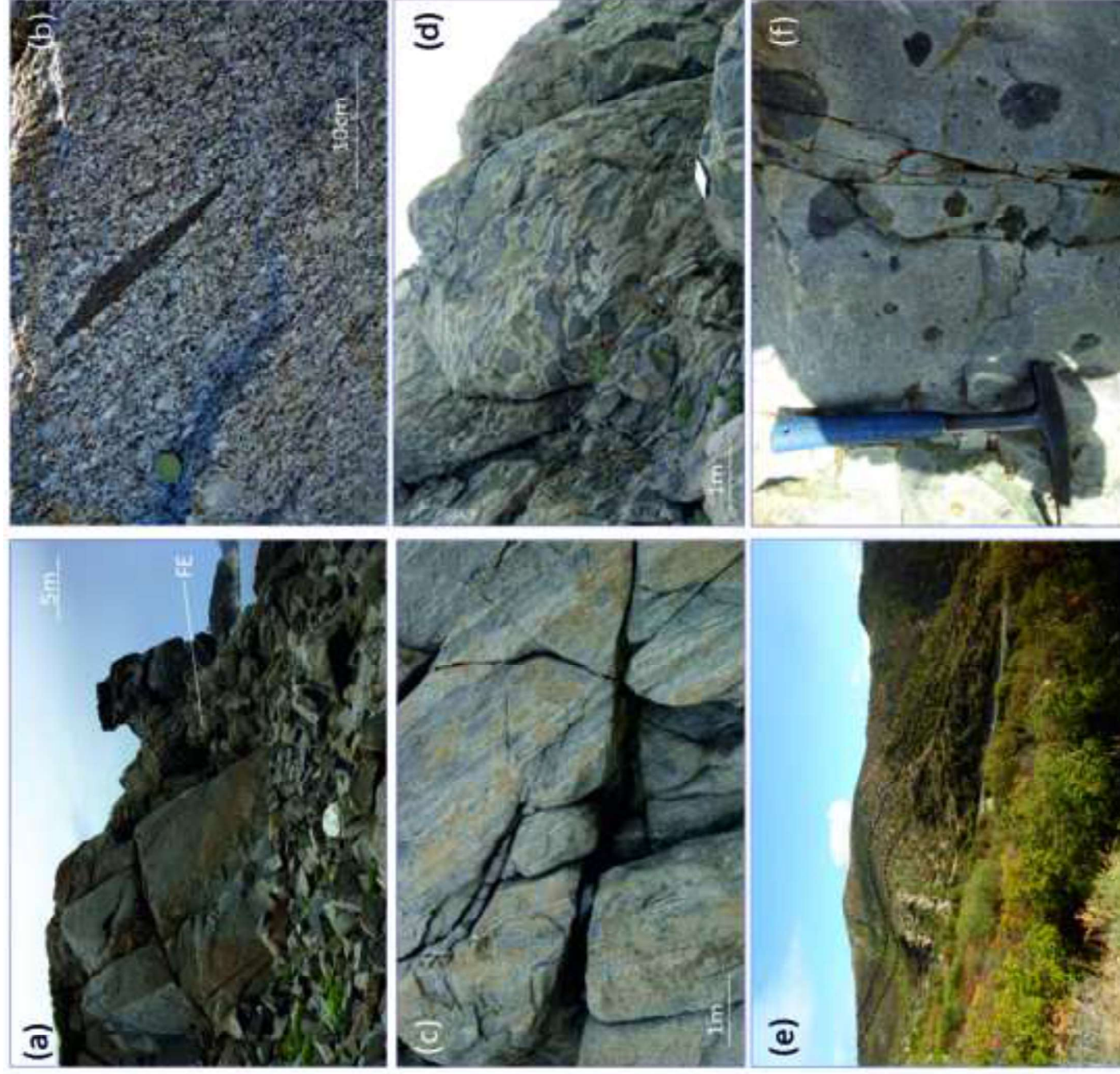
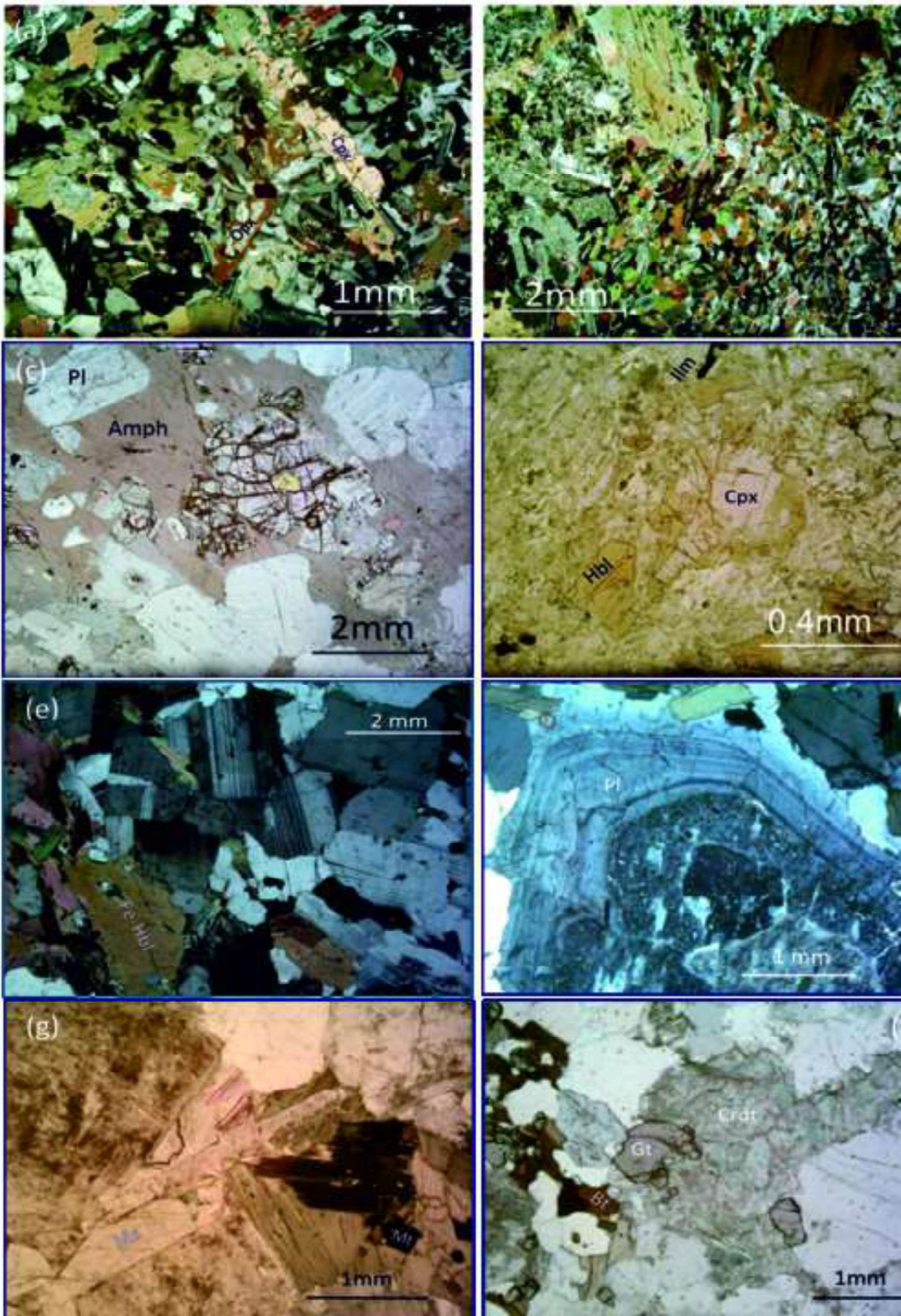




Figure 4

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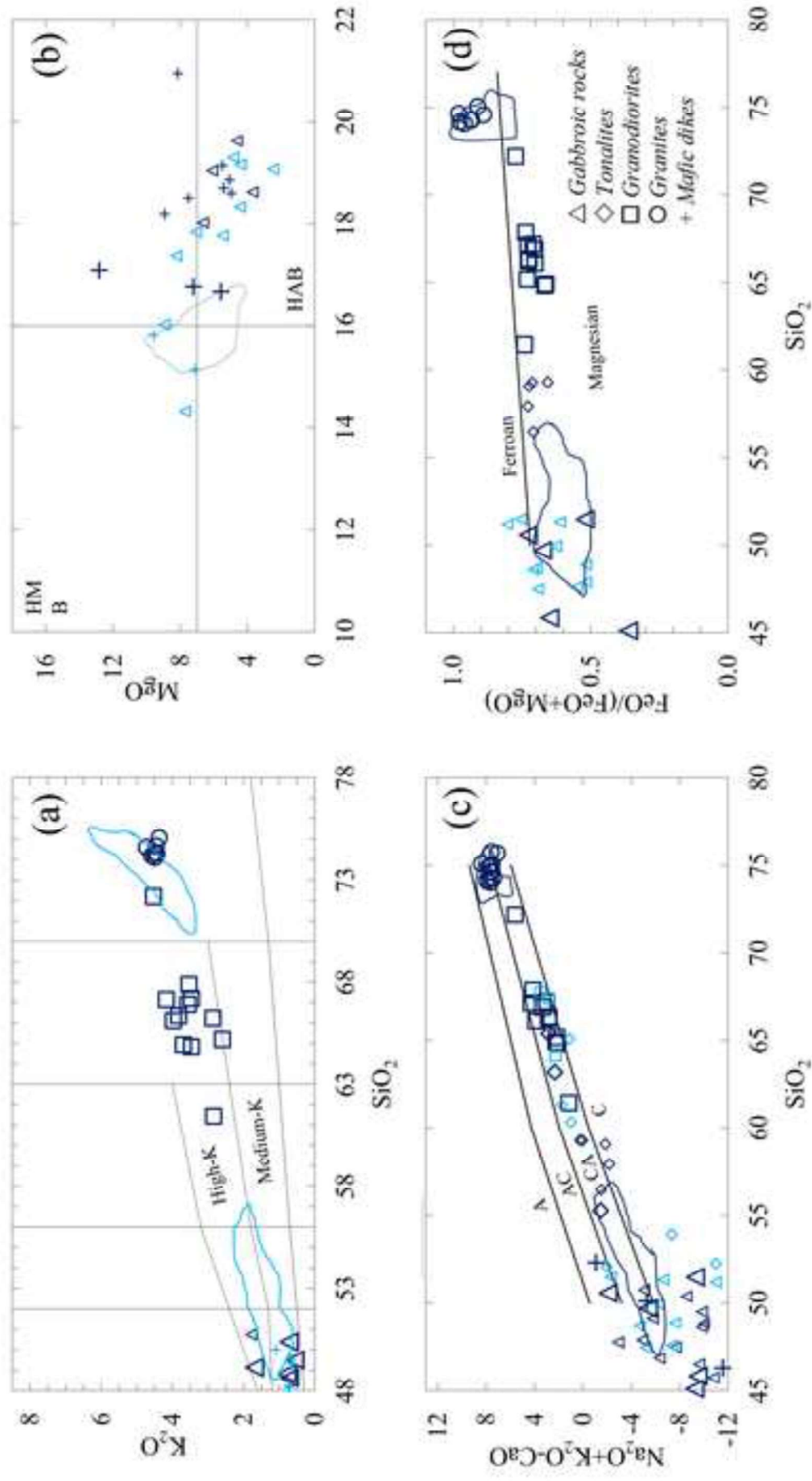
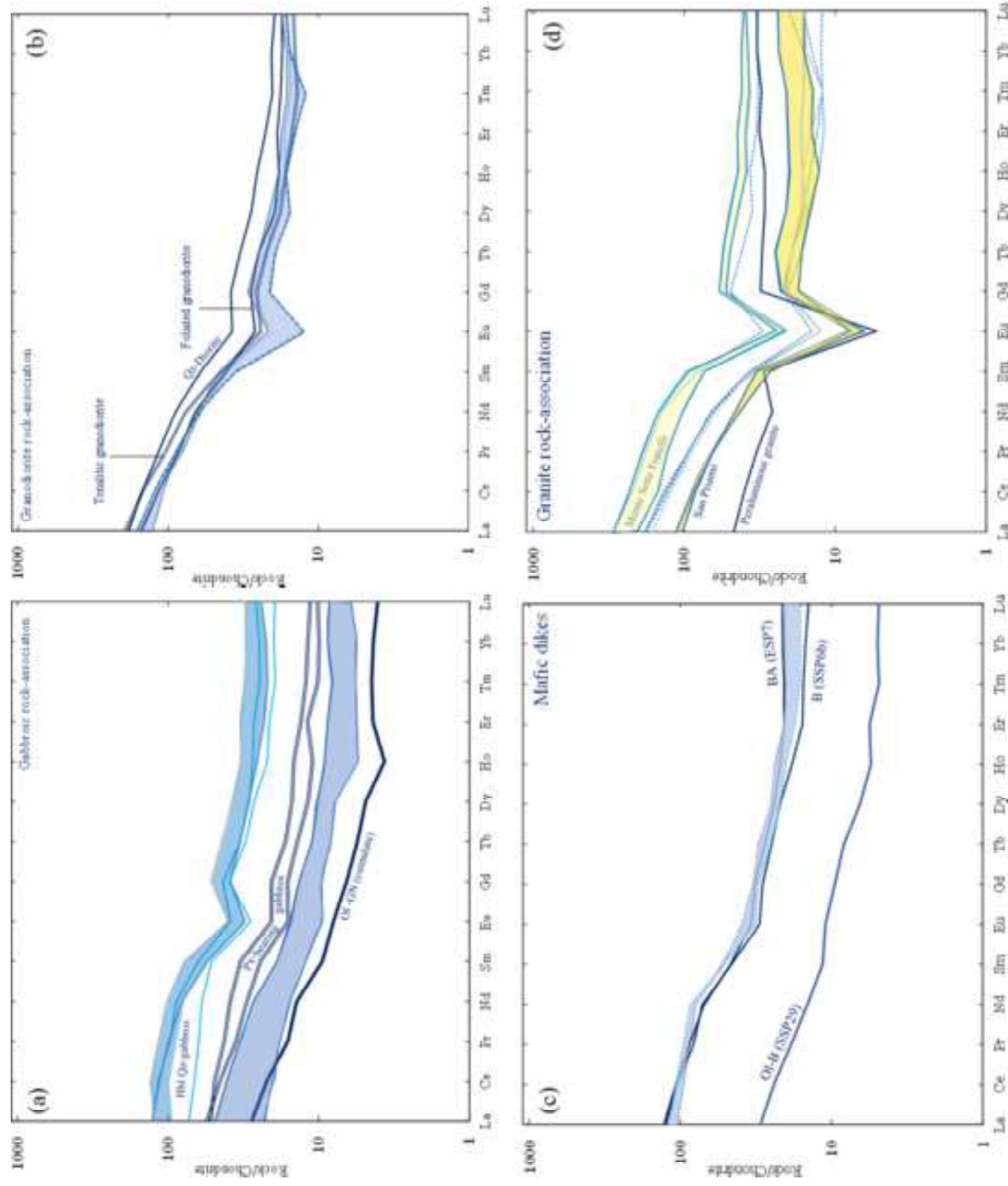




Figure 6



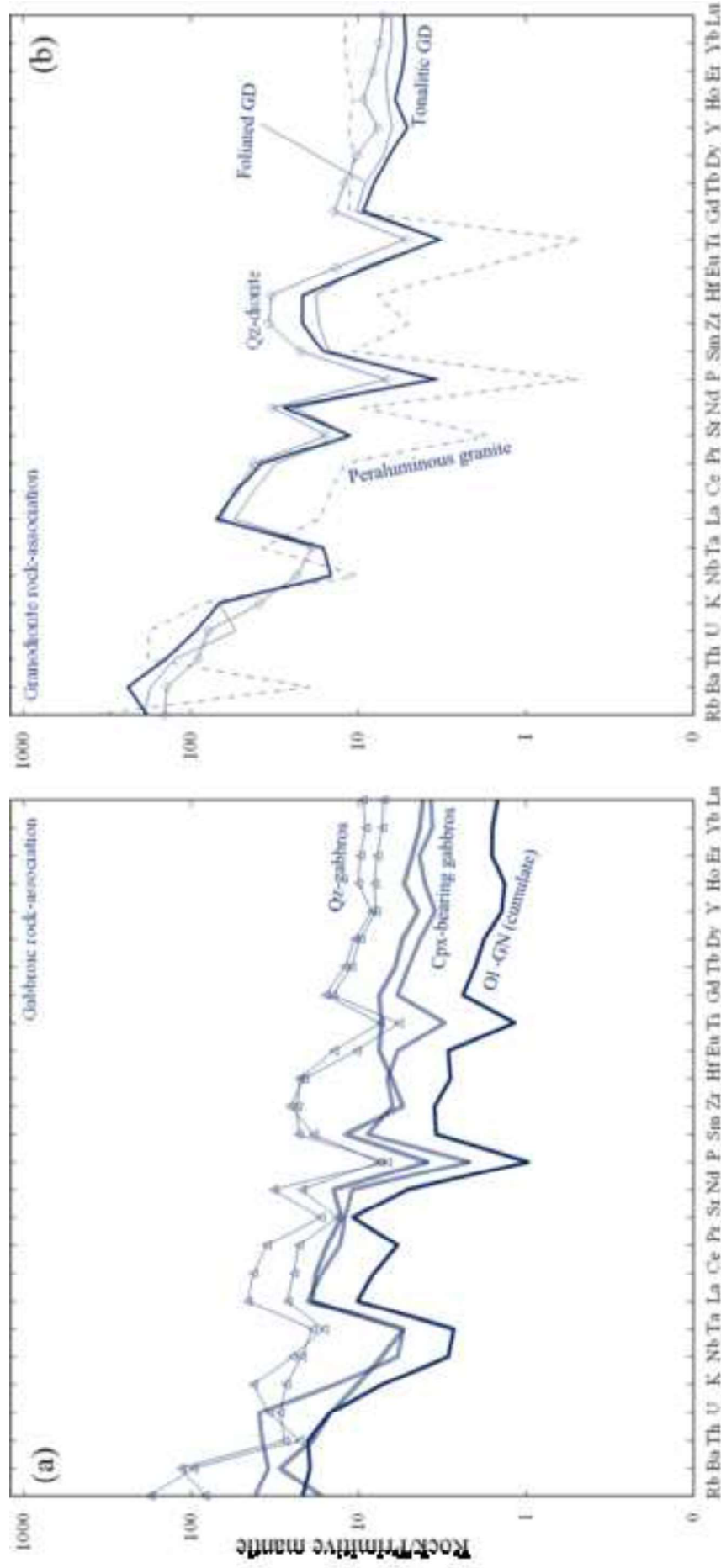


Figure 7

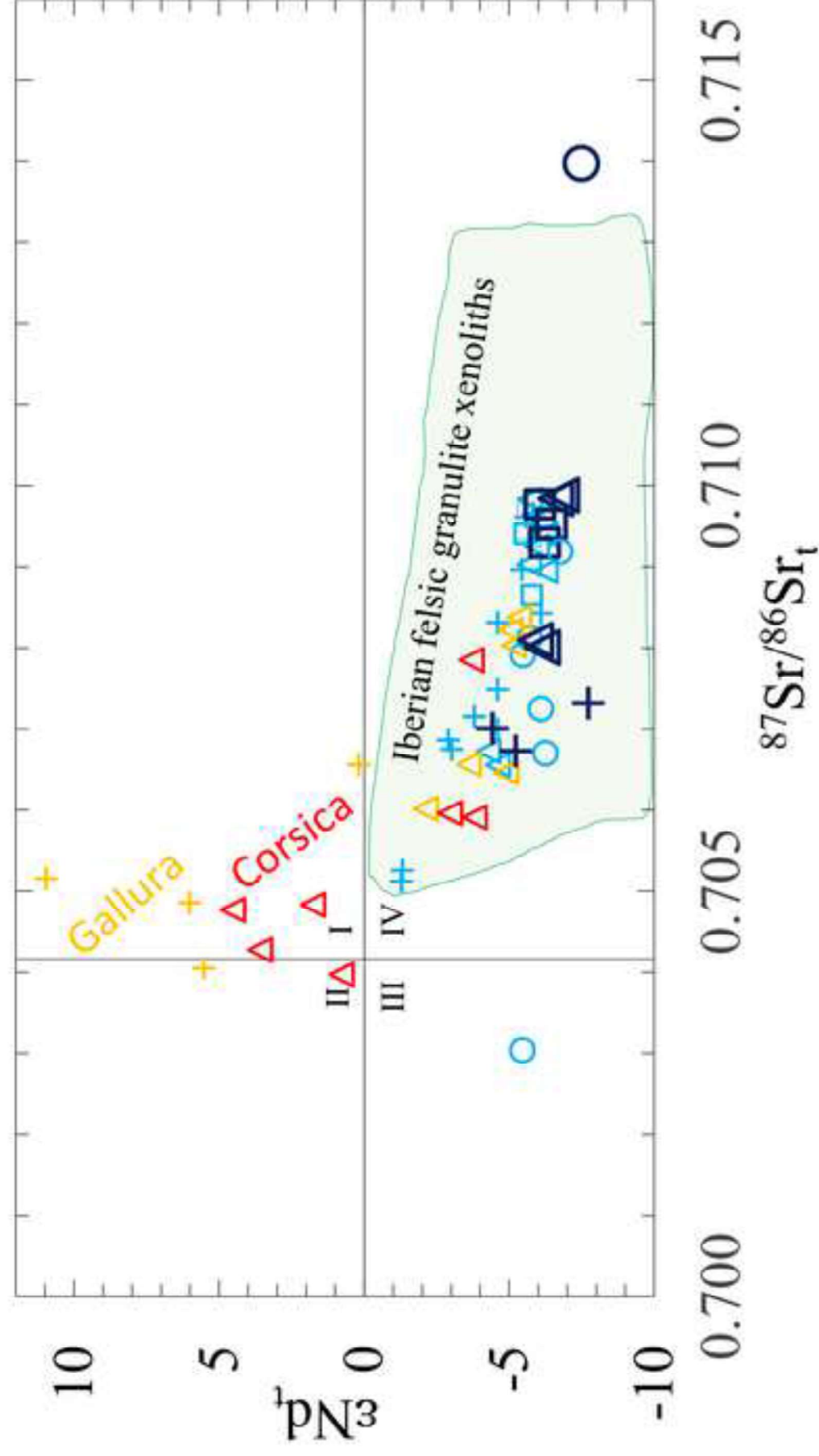
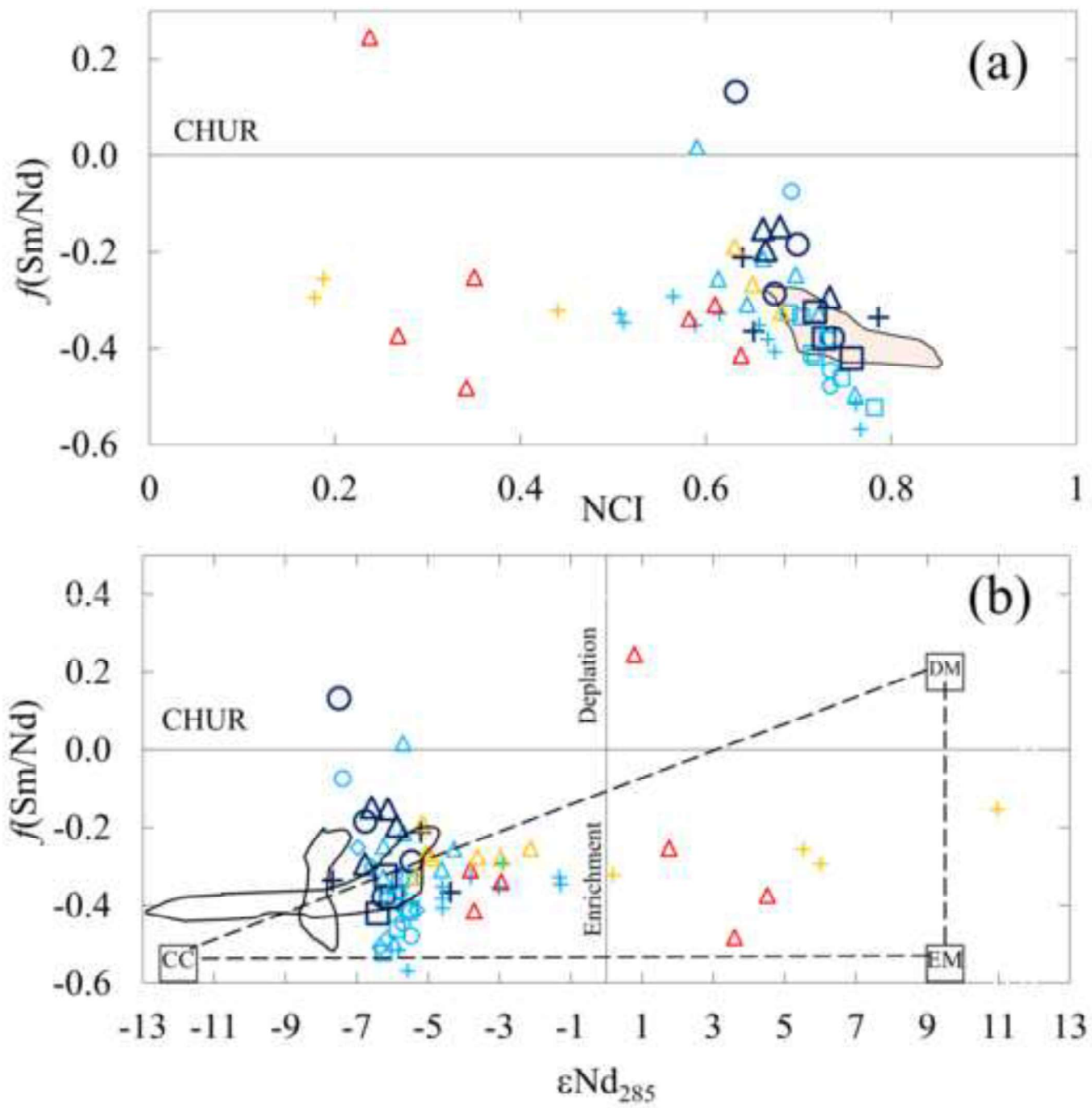


Figure 8



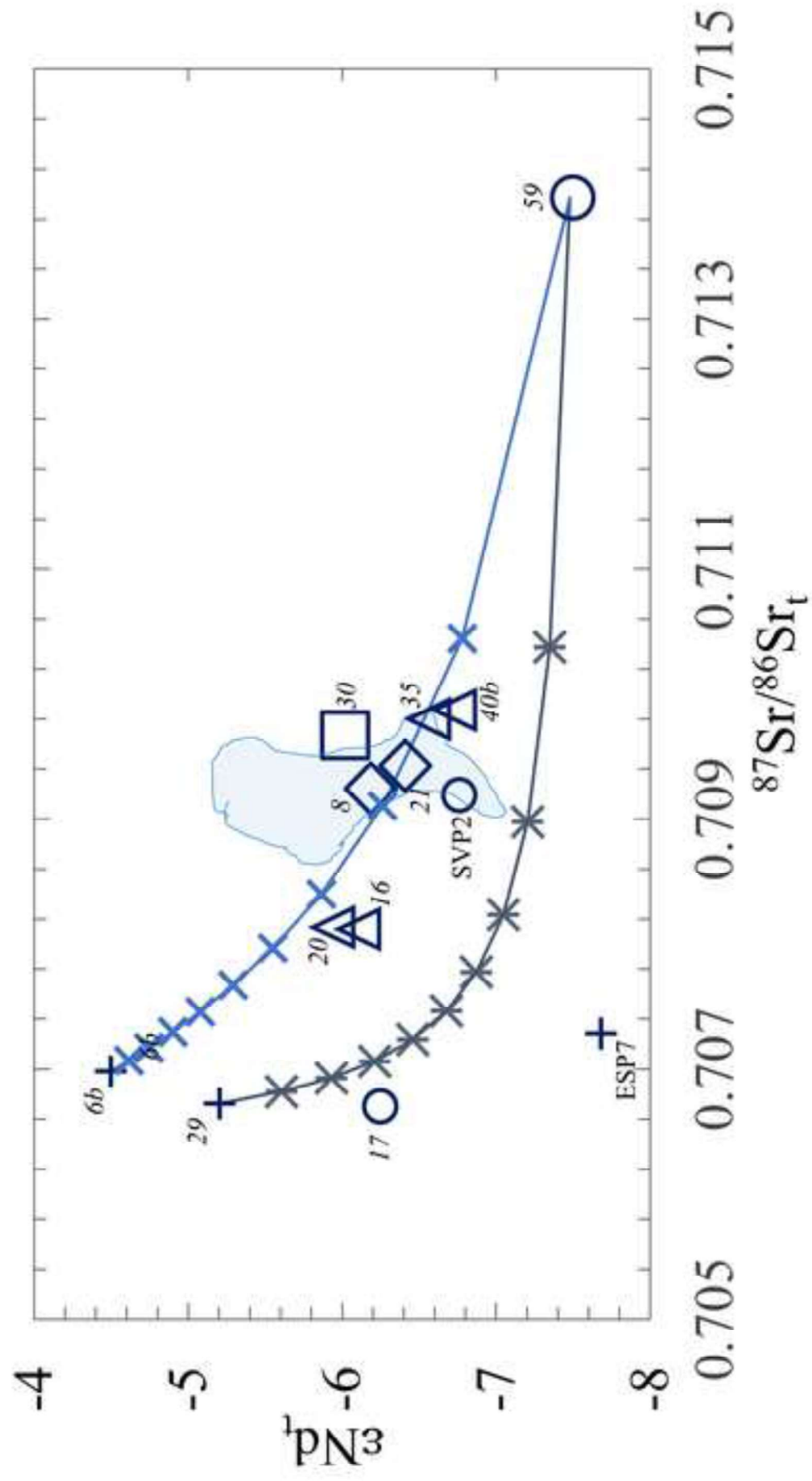


Figure 10



TABLES

Tab. 1 -Summary of petrographic features for late-Variscan intrusives and dikes from Sàrrabus igneous massif (south-eastern Sardinia, Italy)

Rock-types	Rock-textures	Fundamental phases	Accessory phases	Late-stage
Latest mafic dikes (tholeiitic basalts)	Porphyritic Sub ophitic	Ol + Pl → Cpx + Pl ± Hbl Pl + Cpx ± Ol + Qz	Ti-Mt + Ilm + Sulf + Ap	Tc + Cc
Mafic dikes (basalts to andesites)	Porphyritic to hypidiomorphic	Pl + Hbl + Qz ± Bt ± Opx ± Cpx	Ti-Mt + Ilm + Sulf + Ap ± All	
Felsic dikes	Microgranular to granophyric	Qz + Kfs + Pl + Bt  SF: Qz + Kfs + Pl + Hs + Ann SP: Qz + Kfs + Pl + Bt BNB: Qz + Kfs + Pl + Bt	Zrn + Ap + All + Mnz + Ilm + Mt  Aln + Mt + Zrn + Ap Aln + Mt + Zrn Ilm + Ap + Zir	Fl  Fl + Ann Bt + Ms + Fe-Chl
Peraluminous felsic dikes	Microgranular/porphyritic	Qz + Kfs + Pl + Bt ± Ms ± And	Ilm + Zrn + Ap ± Mnz	Tum
Peraluminous granite (MM)	Hypidiomorphic	Qz + Kfs + Pl + Bt + Gt + Ms ± Chrd	Ilm + Zrn + Ap ± Mnz	
Gabbroic rocks (CR)	Hypidiomorphic Panhydiomorphic/Hypidiomorphic Pecilophytic	Mg-Hbl + Pl + Bt + Qz ± Opx ± Cpx Pl + Mg-Hbl + Bt + Qz ± Kfs ± Opx Ol + Opx + Cpx + Pl + Qz	Tit + Mt+ Ap + Ilm Ilm+Tit+All+Zrn Mt + Ap	Actin+Cumm Cumm Actin+Prgs
Granodiorites (CR))	Hypidiomorphic	Pl + Kfs + Qz + Fe-Hbl + Bt	Ilm + Ap + Aln + Mon ± Tit	Turn
Gabbrotonalites (BU)	Hypidiomorphic Porphyritic	Qz + Kfs + Pl + Bt ± Fe-Hbl  Pl + Qz + Kfs + Bt + Opx + Cpx Pl + Opx + Cpx ± Hbl → Pl + Bt + Kfs + Qz	Ilm + Zrn + Ap  Ilm + Ap + Zrn + Sulf	Turn  Actin+Cumm

CR, BU, MM, BNB, SP and SF refer to, Cala Regina Group and Burcèi, Monte Maria, Bruncu Nicola Bove, San Priamo and Monte Sette Fratelli rock-units reported in Fig. 2. Abbreviations list for mineral phases: Pl = plagioclase; Qz = quartz; Kfs = K-feldspar; Bt = biotite; Hbl = hornblende; Opx = orthopyroxene; Cpx = clinopyroxene; Hs = hastingsite; Gt = garnet; Ms = white mica; And = andalusite; Chrd = cordierite; Ol = olivine; Ilm = ilmenite; Ap = apatite; Mon = monazite; Aln = allanite; Zrn = zircon; Sulf = sulphides; Mt = magnetite; Alb = albite; Fl = fluorite; Ann = annite; Actin = actinolite; Cumm = cummingtonite; Prgs = pargasite; Fe-Chl = Fe-chlorite; Tc = talc. Talc observed in mafic dikes formed at the expense of olivine phenocrysts. Ortho- and clinopyroxene observed in Burcèi gabbrotonalites and gabbroic rocks belonging to Stage 1 show commonly a hypersthene and augitic composition, respectively; they are often replaced by actinolite and cummingtonite.