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1 Multiple subduction imprints in the mantle below Italy  
2 detected in a single lava flow

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11

12 **Abstract**

13 Post-collisional magmatism reflects the regional subduction history prior to collision but the  
14 link between the two is complex and often poorly understood. The collision of continents along  
15 a convergent plate boundary commonly marks the onset of a variety of transitional  
16 geodynamic processes. Typical responses include delamination of subducting lithosphere,  
17 crustal thickening in the overriding plate, slab detachment and asthenospheric upwelling, or  
18 the complete termination of convergence. A prominent example is the Western-Central  
19 Mediterranean, where the ongoing slow convergence of Africa and Europe (Eurasia) has been  
20 accommodated by a variety of spreading and subduction systems that dispersed remnants of  
21 subducted lithosphere into the mantle, creating a compositionally wide spectrum of  
22 magmatism. Using lead isotope compositions of a set of melt inclusions in magmatic olivine  
23 crystals we detect exceptional heterogeneity in the mantle domain below Central Italy, which  
24 we attribute to the presence of continental material, introduced initially by Alpine and  
25 subsequently by Apennine subduction. We show that superimposed subduction imprints of a  
26 mantle source can be tapped during a melting episode millions of years later, and are recorded  
27 in a single lava flow.

28 **Keywords:** Melt inclusions, Pb isotopes, mantle heterogeneity, Italian magmatism,  
29 Mediterranean geodynamics, Latera volcano

30

31        **1. Introduction**

32                Despite its relative rarity, post-collisional potassium-rich magmatism provides  
33 important insight into the composition of the subcontinental lithospheric mantle along the  
34 Alpine-Himalayan belt, and highlights the role of recycled continental-crust (Guo et al., 2006;  
35 Lustrino et al., 2011; Miller et al., 1999; Prelević et al., 2013; Tommasini et al., 2011; Zhao et al.,  
36 2009). Extensive studies of Italian mainland volcanics have used Sr-Nd-Pb isotopes to argue for  
37 involvement of recycled crustal material (Conticelli et al., 2002; Lustrino et al., 2011; Peccerillo,  
38 1999), but in view of the complex subduction history of the Mediterranean region, the  
39 provenances are difficult to resolve using bulk-rock samples. Melt inclusions (MIs) provide  
40 direct information about primitive magma compositions in considerably more detail (Jackson  
41 and Hart, 2006; Kobayashi et al., 2004; Maclennan, 2008; Nikogosian and van Bergen, 2010;  
42 Rose-Koga et al., 2012; Saal et al., 2005; Sobolev et al., 2000; Sorbadere et al., 2012). We use  
43 olivine-hosted MIs from Latera, a strategically positioned volcano in Central Italy, to  
44 investigate the subcontinental mantle source beneath the Italian peninsula. We demonstrate  
45 that their Pb isotope compositions and trace-element signatures are diagnostic in tracing input  
46 from both Alpine and Apennine subduction.

47        **1.1. Magmatic and geodynamic setting**

48                Pliocene to present-day magmatism in peninsular Italy has developed in a post-collision  
49 setting associated with plate convergence involving continental Europe, the extending western  
50 Mediterranean realm and Adriatic-Ionian lithosphere (Fig. 1).  
51 The large compositional spectrum of predominantly potassic parental magmas has been  
52 attributed to (1) different subducted crustal components, (2) heterogeneous pre-

53 metasomatic mantle or (3) progressive melt-extraction processes (Conticelli et al., 2004; Foley,  
54 1992; Peccerillo, 2005).  
55 Further to this, systematic compositional variation in erupted products with geographic  
56 location could reflect lateral heterogeneity in mantle sources affected by distinct metasomatic  
57 events associated with multiple subduction systems (Peccerillo, 1999). Magmatism in and off  
58 the northern part of peninsular Italy (mostly in the Tuscany-Corsica region) has been linked to  
59 Cretaceous-Oligocene Alpine subduction (Peccerillo, 1999; Peccerillo and Martinotti, 2006)  
60 and is characterized by lamproite (LAM) - shoshonite (SHO) - calc-alkaline (CA) magmatic  
61 associations. In contrast, magma sources in Central-Southern Italy developed under the  
62 influence of the Miocene to Recent subduction of Adriatic-Ionian lithosphere and produced  
63 shoshonite and strongly silica-undersaturated leucite-bearing high-potassium (HKS) and minor  
64 subalkaline rock series (Conticelli et al., 2002; Peccerillo, 1999).

65         Seismic tomography has identified the presence of fossil and still actively subducting  
66 slabs below Italy, related to the south- to eastward subduction of Tethyan oceanic lithosphere  
67 in the north, and the southwest to westward subduction of Adriatic and Ionian lithosphere,  
68 with continental and oceanic affinities respectively, below the central and southern areas  
69 (Giacomuzzi et al., 2012; Spakman and Wortel, 2004). These two separate subduction  
70 processes are referred to as Alpine and Apennine subduction, respectively (see Fig. 1). The  
71 geodynamic influence on magmatism is further complicated by rollback, tearing, and  
72 detachment of slabs and lithospheric delamination that accompanied subduction of the  
73 Adriatic lithosphere in the Apennine subduction zone (Chiarabba and Chiodini, 2013; Faccenna  
74 et al., 2001; Giacomuzzi et al., 2012; Serri et al., 1993; Wortel and Spakman, 2000).

75            Latera stratovolcano represents the latest stage (0.28-0.15 Ma) of K-rich volcanism in  
76 the Vulsini volcanic complex (< 0.7 Ma), the northernmost sector of the Roman Magmatic  
77 Province (Roman MP) where HKS and SHO rock series prevail (Peccerillo, 2005). In this area,  
78 the Roman MP overlaps the neighboring Tuscan Magmatic Province (Tuscan MP) (Fig. 1)  
79 where mantle-derived magmas are represented by LAM-SHO-CA associations (Conticelli et al.,  
80 2010). Erupted products of Latera comprise SHO as well as HKS rock types (Conticelli et al.,  
81 1991). We focus on samples from various locations across a ca. 12 km long shoshonitic flow  
82 (Selva del Lamone, SdL) and from a representative HKS lava from nearby Monte Starnina  
83 (Conticelli et al., 1991). The SdL samples (4.8-5.8 wt.% MgO) contain olivine phenocrysts  
84 together with clinopyroxene, plagioclase, and rare sanidine. The Monte Starnina sample (4.8  
85 wt.% MgO) contains clinopyroxene leucite and olivine as phenocrysts (see Table B.1, Fig. A.1).

## 86        **2. Methods**

### 87        **2.1. Analytical techniques**

88 Whole-rock compositions of the studied samples were determined by XRF (major elements)  
89 and ICP-MS (trace elements) at the Earth Science Department of the Free University  
90 (Amsterdam), using a Philips PW1404/10 and Thermo Electron X-series II ICP-MS, respectively.  
91 Each sample was crushed and sieved to separate the olivine phenocrysts. They were  
92 embedded in epoxy holders and polished on one side for electron microprobe analysis (EPMA).  
93 The most forsterite-rich olivine grains with noticeable melt inclusions were selected to  
94 determine compositions and crystallization conditions of the parental melts. Melt inclusion re-  
95 homogenization and quenching experiments were performed with a high-T heating/quenching  
96 stage (design of Sobolev et al., 1980) at the Free University (Amsterdam), following the

97 experimental procedure described in Nikogosian and van Bergen (2010). Details of melt  
98 inclusions homogenization experiments can be found in Appendix A. After quenching, host-  
99 olivine grains were polished until the melt inclusions were exposed at the surface for major,  
100 trace, and volatile element analysis by EPMA, Secondary Ion Mass Spectrometry (SIMS), and  
101 Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).  
102 EPMA analyses were carried out using a JEOL JXA8600 Superprobe at Utrecht University,  
103 operated in WDS (wavelength dispersive) mode following the procedure described in De Hoog  
104 et al. (2001). Natural minerals, metals, and synthetic oxides were used as calibration standards.  
105 Daughter mineral phases in un-homogenized melt inclusions exposed at the surface were  
106 identified using semi-qualitative energy dispersive spectrometry (EDS) analysis.  
107 Low-temperature microthermometry on fluid phases was performed on a Linkam TP/91-THMS  
108 600 stage at the Free University (Amsterdam) following a routine as outlined in Nikogosian et  
109 al. (2002).  
110 Concentrations of trace elements in most of the quenched melt inclusions were determined by  
111 SIMS using a CAMECA IMS4f at the Institute of Microelectronics (Yaroslavl', Russia), following  
112 techniques and procedures reported by Danyushevsky and Sobolev (1996) and Portnyagin et  
113 al. (2007). Polished, gold-coated olivine mounts were initially sputtered with a 70  $\mu\text{m}$  diameter  
114 primary  $^{16}\text{O}_2^-$  beam for 3 minutes to remove the coating. Data were obtained using a  $^{16}\text{O}_2^-$   
115 primary ion beam of 15-20 nA accelerated to 50 kV resulting in a spot size of ca. 10-20  $\mu\text{m}$ .  
116 Each MI was analyzed near its center, with 5 data points taken over a 10–15  $\mu\text{m}$  deep vertical  
117 profile with an integration time of 40 to 60 minutes. A calibration curve for glass standards  
118 ATHO-Ga (Jochum et al., 2006) and NIST SRM 610(Jochum et al., 2011) was used to calculate

119 element concentrations based on the ratio of the respective isotopes to  $^{30}\text{Si}$ . Glass standards  
120 were analyzed after each 3-6 MI analyses. Data reproducibility is given in Table B.5.

121 Some of the additional quenched melt inclusions were analyzed for trace element contents by  
122 LA-ICP-MS using a GeoLas 200Q Excimer laser ablation system (193 nm wavelength) coupled  
123 to a Thermo Finnigan Element 2 sector field ICP-MS instrument at Utrecht University following  
124 the techniques of Mason et al. (2008). Data were obtained using a constant fluence of 5-10 J  
125  $\text{cm}^{-2}$  and pulse repetition rate of 10 Hz with 20-60  $\mu\text{m}$  diameter craters. Each MI was ablated  
126 for ca. 25-30s, and background count rates were measured prior to and after the ablation of MI.

127 Calcium determined by EPMA was used as an internal standard, with NIST 612 as the  
128 calibration standard.

129 Lead isotope compositions of MI were acquired by SIMS with a large geometry Cameca-1270  
130 ion microprobe at the NORDSIM Facility, Swedish Museum of Natural History, Stockholm  
131 closely following the methods described by Whitehouse et al. (2005). The samples (polished  
132 grain mounts) were gold coated to avoid charging during the sputtering process. Data were  
133 obtained using a  $^{16}\text{O}_2^-$  primary ion beam of 20 nA accelerated to 22.5 kV, resulting in a spot size  
134 of ca. 20  $\mu\text{m}$ . Following an initial pre-sputter with a rastered beam to remove the gold coating,  
135 the secondary ion beam was automatically centered in the 4000  $\mu\text{m}$  field aperture. An energy  
136 window of 45 eV was used without applying an energy offset. The instrument was operated in  
137 multi-collection mode with simultaneous determination of all four Pb isotopes in low noise ion-  
138 counting electron multipliers set on movable trolleys.  $^{204}\text{Pb}^+$  was measured in the electron  
139 multiplier (EM) set on the trolley position L2,  $^{206}\text{Pb}^+$  in C,  $^{207}\text{Pb}^+$  in H1, and  $^{208}\text{Pb}^+$  in H2. A mass  
140 resolution of 4860 (M/ $\Delta$ M) ensured adequate resolution from molecular interferences in the



141 melt inclusions and reference glasses. Mass calibration was performed at the beginning of each  
142 analysis based on the  $^{208}\text{Pb}$  signal. Each analysis consisted of 100 cycles with a total integration  
143 time of 1000 seconds for each isotope. Using the above setup, instrument sensitivity on  $^{208}\text{Pb}$   
144 was ca. 30 cps/ppm/nA.

145 The USGS glass BCR-2G was used as the primary standard to correct for variations in detector  
146 efficiency and instrumental mass fractionation. Glasses GSE1-G, BHVO2-G, and BIR1-G were  
147 used as secondary standards to monitor the accuracy of the calibration, based on preferred  
148 values listed by Georem (Table B.6). Results for the secondary standards were within error of  
149 published values for all  $^{204}\text{Pb}$ -based ratios. As expected from counting statistics, a strong  
150 correlation between Pb concentrations of MI and analytical uncertainty in Pb isotope ratios  
151 was observed. Lead concentrations in melt inclusions were sufficiently high so that  $^{204}\text{Pb}$ -  
152 based ratios could be used for distinction of geochemical sources. Our in run precision ranged  
153 from 0.03 to 0.40 ( $2\sigma$ ) for  $^{206}\text{Pb}/^{204}\text{Pb}$ , from 0.03 to 0.35 ( $2\sigma$ ) for  $^{207}\text{Pb}/^{204}\text{Pb}$  and from 0.07 to  
154 0.85 ( $2\sigma$ ) for  $^{208}\text{Pb}/^{204}\text{Pb}$ . A total of 19 melt inclusions were analyzed for Pb isotope  
155 compositions, two of which were discarded based on high analytical uncertainties ( $>0.5$  for  
156  $^{206}\text{Pb}/^{204}\text{Pb}$ ) due to primary beam instability during the analysis of these two particular  
157 inclusions. Lead concentrations, isotopic ratios, and precision data are provided in Table A.3 for  
158 the complete dataset.

159

### 160 3. Results

161 The SdL flow contains two different magmatic olivine populations (Group-1 and Group-  
162 2) that we distinguish by their morphology, chemistry and compositions of trapped melt and

163 spinel inclusions (Tables B.2-B.4, Figs A.1-A.3), as well as rare mantle olivine xenocrysts.  
164 Group-1 olivines are characterized by the highest forsterite ( $\text{Fo}_{85}\text{-Fo}_{91}$ ), and by relatively low  
165 CaO (0.20-0.33 wt.%) and high NiO (0.15-0.40 wt.%) contents that tend to increase with  
166 increasing Fo. These euhedral phenocrysts host partially crystallized primary MIs in the 10-80  
167  $\mu\text{m}$  diameter range. Group-2 olivines have overlapping forsterite ( $\text{Fo}_{80}\text{-Fo}_{90}$ ), somewhat higher  
168 CaO (0.27-0.35 wt.%), and similar NiO contents relative to Group-1. They host large, fully  
169 crystallized primary MIs (>100  $\mu\text{m}$  in diameter) with large fluid bubbles, whereas smaller-sized  
170 MIs (10-20  $\mu\text{m}$ ) are also present.

171         The chemistry of the MIs corroborates the distinction between the two groups.  
172 Although all contain 7-11 wt.% MgO, have a SHO composition, and an overlapping range in  
173 potassium (1.7-4.8 wt.%  $\text{K}_2\text{O}$ ), Group-1 MIs have lower  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ , FeO and higher CaO,  
174  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$  and volatile contents than Group-2 MIs. In addition, the MIs show opposite  $\text{K}_2\text{O}$ -  
175 CaO relationships (Fig. 2). In both cases, trace element patterns of MIs (Fig. A.4) are overall  
176 similar and typical for subduction-related imprints of the mantle sources below peninsular Italy  
177 (e.g., Peccerillo, 2005). Group-2 melts are relatively enriched in Zr, Hf, and Pb and depleted in  
178 Sr, features that they share with Tuscan lamproites (Fig. A.4; cf., Conticelli et al., 1991;  
179 Conticelli et al., 2010; Peccerillo, 2005). Compositions of SdL Group-1 melt inclusions are  
180 typical for the shoshonite series ( $\text{SiO}_2=46.9\text{-}50.4$ ,  $\text{MgO}=7.1\text{-}9.5$ ,  $\text{K}_2\text{O}=1.7\text{-}3.5$  wt.%). Decreasing  
181  $\text{K}_2\text{O}$  is accompanied by a strong increase in CaO (9.3-14.6 wt.%, Fig. 2) and modest decreases  
182 in  $\text{Na}_2\text{O}$  (3-1.8 wt.%) and  $\text{Al}_2\text{O}_3$  (17.6-15.1 wt.%), while there are no systematic relations with  
183 MgO,  $\text{SiO}_2$ ,  $\text{TiO}_2$  (Fig.A.5) or volatile elements (Cl, S, F). Trace element patterns, normalized to  
184 depleted MORB mantle (Fig. A.4), display depletion in HFSE relative to LILE and LREE, and

185 enrichments in LREE relative to HREE. These characteristics are typical for all potassic rocks of  
186 Central-Southern Italy and are taken to reflect subduction-related enrichments of their mantle  
187 sources (Peccerillo, 2005).

188 Compositions of SdL Group-2 MIs are also predominantly shoshonitic ( $\text{SiO}_2 = 48.3\text{-}55.4$ ,  
189  $\text{MgO} = 7.7\text{-}13$ ,  $\text{K}_2\text{O} = 2.3\text{-}4.7$  wt.%) but cover a wider  $\text{K}_2\text{O}$  range and have significantly lower  $\text{CaO}$   
190 contents (1.9-6.9 wt.%) than those of Group-1. The Group-2 MIs have also higher  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  
191  $\text{Na}_2\text{O}$ ,  $\text{FeO}$ , and lower  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$  and volatile contents (Fig2, Fig.A.5). Unlike Group-1,  
192 decreasing in  $\text{K}_2\text{O}$  is associated with decreasing  $\text{CaO}$  (Fig.2), as well as decreasing  $\text{Na}_2\text{O}$  (3.4-  
193 1.8 wt.%) and modest increases in  $\text{MgO}$  and  $\text{Al}_2\text{O}_3$  (14-22 wt. %), while there are no obvious  
194 relationships with  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$  or volatile elements. Trace elements patterns are marked  
195 by strong enrichments in Rb, Th, U, Pb, LREE and HFSE, higher La/Yb and Th/Nb, and lower  
196 Sm/Yb ratios in comparison to Group-1 MI (Fig. A.4). They also display a Sr depletion and Zr, Hf  
197 enrichments. The Group-2 MIs share these features with Tuscan lamproitic lavas (cf., Conticelli  
198 et al., 1991; Peccerillo, 2005; Conticelli et al., 2010), but they differ in terms of their overall  
199 lower incompatible trace-element contents and stronger Pb enrichment. Melt inclusions with  
200 mixed Group-1 and Group-2 compositions were occasionally observed in the rims of Group-2  
201 olivines but are rare in Group-1 olivines.

202 The compositions of spinel inclusions also confirm the grouping of their olivine hosts.  
203 In Group-1 they have slightly lower Cr-numbers [ $\text{Cr}\# = \text{Cr}/(\text{Cr} + \text{Al})$ ] than in Group-2 (0.36-0.46  
204 and 0.45-0.55, respectively; see Fig. A.3), as well as lower  $\text{Cr}_2\text{O}_3$ ,  $\text{TiO}_2$  and  $\text{Fe}^{2+}/\text{Fe}^{3+}$ , and higher  
205  $\text{Mg}\#$ ,  $\text{Al}_2\text{O}_3$  and  $\text{MnO}$ . The major and trace element compositions of the HKS MIs closely  
206 resemble those of mafic HKS lavas from East Vulsini (Fig. 2, Fig. A.6) testifying that HKS lavas

207 of Latera and adjacent centers in the northernmost sector of the Roman MP are co-genetic  
208 (cf., Conticelli et al., 1991).

209 Of the 19 MIs analyzed for Pb isotopes, 17 had Pb concentrations allowing isotope ratio  
210 measurements, including  $^{204}\text{Pb}$ , with minimal error (Fig. A.7). Melt inclusions show extreme Pb  
211 isotopic diversity (Fig. 3) compared to the narrow range for the host lavas. Group-1 MIs display  
212 a remarkable range in isotope ratios between highly unradiogenic and highly radiogenic values  
213 for  $^{207}\text{Pb}/^{204}\text{Pb}$  (14.57-16.04) and  $^{208}\text{Pb}/^{204}\text{Pb}$  (36.16-40.44) at  $^{206}\text{Pb}/^{204}\text{Pb}$  values of 17.91-19.29.  
214 The Pb isotope ratios of Group-2 MIs are less variable and distinctive with higher  $^{207}\text{Pb}/^{204}\text{Pb}$   
215 and lower  $^{206}\text{Pb}/^{204}\text{Pb}$  relative to the Group-1 trend. The combination of low  $^{206}\text{Pb}/^{204}\text{Pb}$  (18.28-  
216 18.30) and  $^{208}\text{Pb}/^{204}\text{Pb}$  (38.02-38.79), and moderately high  $^{207}\text{Pb}/^{204}\text{Pb}$  (15.56-15.72) in Group-2  
217 MIs has not been observed previously in any of the Italian potassic lavas. Together with the two  
218 extremes in the Group-1 trend, Group-2 forms three end-member components that make up  
219 the bulk-lava composition in Pb isotope space. The Pb isotope compositions of MIs from the  
220 HKS lava also display considerable variation ( $^{206}\text{Pb}/^{204}\text{Pb}$ =18.51-19.16;  $^{207}\text{Pb}/^{204}\text{Pb}$ =15.46-15.80;  
221  $^{208}\text{Pb}/^{204}\text{Pb}$ =38.58-39.54), but cover a narrower span. They tend to fall in the Group-1 trend and  
222 are close to those of the Vulsini HKS lavas.

223

#### 224 4. Discussion

225 The populations of Fo-rich olivines and their MIs with a large variation in  $\text{K}_2\text{O}$  are difficult to  
226 reconcile with simple crystal fractionation (Fig. A.7) and point to mingling between partly  
227 crystallized (near-)primary magmas indicating that the SdL lava is a product of different  
228 parental melts (ca. 80% Group-1 and 20% Group-2, estimated from mass balance based on

229 trace element concentrations) (Fig. 2, Fig. A.5), derived from two distinctive and  
230 heterogeneous mantle sources. Further association with the Monte Starnina lava, a typical  
231 example of Roman HKS magmatism in Vulcini (Conticelli et al., 2004), underscores the  
232 exceptional compositional diversity of the subcontinental lithospheric mantle beneath Latera,  
233 and typifies its complexity on a regional scale.

#### 234 **4.1. Provenances of Subduction-Related Contaminants of the Mantle Source**

235 Mantle sources of the Roman MP have been affected by input of marl-rich sediments  
236 through subduction of the continental sector of the Adriatic-Ionian domain in Tertiary times  
237 (e.g., Serri et al., 1993). Tuscan MP sources, by contrast, have been influenced by other upper  
238 crustal materials associated with the earlier Alpine collision (Peccerillo, 1999; Peccerillo and  
239 Martinotti, 2006), and possibly by northward drifted, Gondwana-derived continental slivers  
240 piled up by even older collisional events (Tommasini et al., 2011). Pb isotopes measured in bulk  
241 mafic lavas from Tuscan MP as well as the northernmost Roman MP confirm this source  
242 contamination by upper continental crust (Conticelli et al., 2010; Peccerillo, 2005), but they  
243 show insufficient contrast to discriminate between possible provenances of input materials,  
244 particularly in the region of overlap between these provinces. The same limitation applies to  
245 the SdL lava having Pb isotope ratios close to those reported for the Roman HKS lavas (Fig. 3c).

246 Our Pb isotope data in MIs from the SdL lava reveal two distinctive trends (Fig. 3), not  
247 visible in the bulk rock data. The Group-1 trend extends towards not previously seen extreme  
248  $^{207}\text{Pb}/^{204}\text{Pb}$  and  $^{208}\text{Pb}/^{204}\text{Pb}$  values. One end points towards a radiogenic end-member that  
249 could have been introduced through source contamination with upper continental crust. We  
250 explain the unradiogenic end-member of the Group-1 melt inclusions by involvement of

251 ancient lower continental crust as a mantle contaminant. Its comparatively high  $^{206}\text{Pb}/^{204}\text{Pb}$   
252 ratio relative to old lower crust (Kramers and Tolstikhin, 1997) implies that this signature must  
253 have been created in multiple stages. A plausible scenario is that this crustal contaminant  
254 derived from a source in which the Pb isotopic evolution had been retarded relative to single-  
255 stage model mantle reservoirs. Such an exotic composition requires an extensive amount of  
256 time for Pb ingrowth implying a time of separation in the early Archean, after which an  
257 increased U/Pb ratio through intracrustal differentiation ultimately produced the higher  
258  $^{206}\text{Pb}/^{204}\text{Pb}$  signature. The present-day Pb isotope composition of this Group-I endmember is  
259 exotic for modern mantle-derived igneous rocks, but it overlaps with Late Archean granitoids  
260 from West Greenland (Fig. 3a) that represent re-melting of a lower crustal mafic source or  
261 gneissic precursor (Moorbath et al., 1981; Næraa et al., 2014). We therefore surmise that  
262 material with an analogous history was introduced in the source of Latera volcano. This would  
263 be consistent with the inference that dismembered blocks of an Archean microcontinent in the  
264 central-western Mediterranean realm have been involved in collisions with passive margins  
265 and the development of subduction-related volcanic arcs during the Tertiary convergence of  
266 Africa and Europe (González-Jiménez et al., 2013). The associated mantle source  
267 contamination may have occurred through delamination of subducted continental lithosphere  
268 or subduction erosion of the overriding plate (cf., Kay and Kay, 1993; Lustrino et al., 2000;  
269 Lustrino, 2005). Contamination of mantle sources by ancient lower continental crust with  
270 multistage isotopic evolution has not been previously seen in the post-collisional magmatism  
271 of peninsular Italy but has been inferred from volcanics in Sardinia (Lustrino et al., 2007).

272 In terms of Pb isotopes, MIs of the Monte Starnina HKS lava are virtually  
273 indistinguishable from Group-1 MIs. The isotopic variability, whilst less than that in Group 1,  
274 remains considerable in comparison to bulk data, and overlaps the field of Roman MP HKS  
275 lavas (Fig. 3c). Since there is a broad consensus that Roman MP HKS sources were affected by  
276 subducted components from Adriatic lithosphere (Peccerillo, 2005), we infer that upper  
277 continental metasomatic imprints in the mantle below Latera were predominantly derived  
278 from this input. We suggest that the lower continental crust input seen in the Group-1 MIs was  
279 introduced by delamination of Adriatic lithosphere as observed in recent seismic tomographic  
280 studies (e.g., Giacomuzzi et al., 2012). A similar case where Pb isotopic signatures of magma  
281 sources were determined by different portions of a subducted continental margin has been  
282 inferred for the arc-continent collision sector in the Sunda-Banda arc (Elburg et al., 2004).

283 Group-2 MIs (Fig. 3c) are distinctive and point to the presence of a metasomatic  
284 component in the Latera mantle source with a separate origin. Ratios for trace elements of  
285 comparable incompatibility confirm the compositional dissimilarity of the post-metasomatic  
286 mantle source (Fig. 2d). The Pb-isotope compositions (unradiogenic  $^{206}\text{Pb}$ , moderately  
287 radiogenic  $^{207}\text{Pb}$  and  $^{208}\text{Pb}$ ) are similar to lower continental crust found in the Variscan and  
288 older basement of Sardinia and Calabria. They are also close to the composition of Permian  
289 sandstones in the Southern and Eastern Alps, representing erosion products of the Variscan  
290 orogeny. These similarities strongly suggest that the Group-2 mantle component has an  
291 isotopic affinity to ancient lithologies with a paleogeographic position that allowed their  
292 involvement in the early-Tertiary Alpine subduction as: (1) erosion products of exhumed  
293 basement on top of Ligurian-Provençal oceanic lithosphere (Malavieille et al., 1998), (2)

294 subducted continental lithosphere (Handy et al., 2010) or (3) via subduction erosion of the  
295 overriding continental crust (Peccerillo and Martinotti, 2006). The near-vertical trend in Group-  
296 2 (Fig. 3c) might indicate mixing between this component and the unradiogenic end-member  
297 of Group-1 in Latera's mantle source.

298 An "Alpine" origin has also been proposed for the Tuscan MP lamproites where melts  
299 were derived from mantle sources with a crustal metasomatic imprint obtained during the  
300 southeastwards Alpine subduction of Tethyan lithosphere under northern Italy (Peccerillo and  
301 Martinotti, 2006). This hypothesis fits with the inference that western Mediterranean  
302 lamproites inherited their isotopic variations largely from the provenance and age of  
303 continent-derived magma source components that were recycled into the mantle by the  
304 Alpine subduction, with Hercynian Europe acting as a passive margin (Prelević et al., 2008). In  
305 keeping with this, the unradiogenic  $^{206}\text{Pb}$  signature detected at Latera in Group-2 and its  
306 correspondence to the fields for Sardinian/Calabrian basement and Alpine sandstones suggest  
307 that the earliest introduced source component was subducted erosion products of Variscan or  
308 older lithologies. We therefore infer that, relative to the Group-1 MI trend, minor shifts  
309 towards lower  $^{206}\text{Pb}/^{204}\text{Pb}$  values in lavas from the northern Roman MP and the Tuscan MP  
310 (Fig. 3c) reflect relict components in sub-Apennine mantle sources that were subducted during  
311 the Alpine event, in addition to the prevailing components supplied later by the Apennine  
312 subduction. Our findings reveal that bulk-lava data should be regarded as mixtures of  
313 isotopically contrasting components, and that Pb isotope signatures of MIs can depict the  
314 provenance of metasomatic components in the mantle below Central Italy in greater detail.

#### 315 4.2. Geodynamic Framework



316 To further explore the connection between post-collisional magmatism and  
317 geodynamics we combine our provenance results with independent geophysical evidence  
318 concerning the mantle structure and geodynamic evolution of the region. Figure 1b shows that  
319 the Latera site is located just above a tear in the subducted slab as inferred from seismic  
320 tomography using P-wave delay times (Spakman and Wortel, 2004). Northwest of the tear, the  
321 Northern Apennines slab appears to be continuous, whereas to the southeast, the  
322 tomographic images indicate detachment of the subducted slab (cf., Wortel and Spakman,  
323 2000).

324 Latera's peculiar location with respect to this underlying mantle structure implies that  
325 magma source components and melt generation should be considered in a true 3D context.  
326 Lateral contributions are to be expected from both sides of the tear, corresponding with the  
327 Northern and Central Apennines plate boundary segments, respectively. Moreover, the  
328 position close to approximately overlapping Adriatic and fossil Alpine lithosphere slabs (Fig.  
329 1b) corroborates the inferred magma derivation from sources affected by metasomatic  
330 contributions from both, either superimposed in the same mantle domain or stratigraphically  
331 separated. Our data provide no evidence for an asthenospheric contribution from below the  
332 Adriatic slab (cf., Rosenbaum et al., 2008).

333 The melting trigger at Latera was probably the same as that responsible for  
334 magmatism in the entire Roman MP. The more easterly advance of the Northern Apennines  
335 front relative to that of the Central-Southern Apennines has been suggested to indicate  
336 differential retreat of the corresponding slab segments in Late-Pliocene-Quaternary times  
337 (Scrocca, 2006). In this context we propose that a sudden and massive advection of heat,

338 associated with the upwelling of hot asthenospheric material in response (Faccenna et al.,  
339 2010; Levin et al., 2002) to the segmentation, breaking off and sinking of the central(-  
340 southern) Apennines slab (see Fig. 1b), was the magma generating process in the  
341 heterogeneous mantle column that produced Latera's SHO and HKS flows. Cooling of the  
342 asthenospheric material after upwelling and exhaustion of the metasomatized domains with  
343 relatively low melting temperature accounted for the short-lived nature of the Roman Province  
344 magmatism, including that of Latera volcano.

## 345 **5. Conclusions**

346 Multiple associations of olivine phenocrysts and inclusions of spinel and primitive melt  
347 within lavas of Latera volcano demonstrate a strong vertical heterogeneity in the mantle below  
348 the region of overlap between the Roman and Tuscan Magmatic Provinces (Central Italy). Co-  
349 existence of shoshonitic and lamproite-like assemblages in a single lava flow, and proximity to  
350 coeval silica-undersaturated ultrapotassic products point to simultaneous extraction of melts  
351 from mantle domains with different subduction-related metasomatic signatures.

352 Extremely variable Pb-isotope compositions of melt inclusions reveal multiple origins  
353 for metasomatic agents that remain unnoticed in data from bulk lava samples. We distinguish  
354 end-members that agree with subducted continental components with an Alpine inheritance  
355 and with derivation from Adriatic upper as well as ancient lower continental crust. Hence, in  
356 line with independent geodynamic evidence, our data from Latera volcano expose  
357 superimposed imprints from the fossil Alpine and the Apennines subduction systems in the  
358 subcontinental mantle of Central Italy. We propose that melting was caused by a thermal pulse  
359 associated with upwelling of hot asthenospheric material, triggered by opening of a slab

360 window after segmentation of the Apennines slab and detachment and sinking of the central  
361 Apennines slab segment.

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536 **Figure Captions**

537 **Figure 1. a:** Location of Latera volcano and other volcanic centers of central-southern Italy.

538 Map redrawn after Peccerillo (2005). RMP: Roman Magmatic Province, TMP: Tuscan Magmatic

539 Province, ERMP: Ernici-Roccamonfina Magmatic Province, CMP: Campanian Magmatic

540 province. Orange curve marks Alpine subduction and blue curve marks Apennine subduction,

541 including Calabrian subduction in the southern part. **b:** Schematic representation of

542 tomographic model for mantle structure with subducted slabs beneath Italy and Tyrrhenian

543 Sea, after Spakman and Wortel (2004), and approximate position of the mantle column below

544 Latera volcano.

545 **Figure 2.** Variation diagrams for lavas and melt inclusions (MIs) of Selva del Lamone and Mt.

546 Starnina of **a:** K<sub>2</sub>O vs. CaO, **b:** MgO vs. CaO, **c:** MgO vs. Pb, **d:** Th/Ba vs. Pb/Nd normalized to

547 depleted MORB mantle (DMM). Symbols refer to different groups of MIs in the Selva del

548 Lamone (SdL) and Monte Starnina lavas. Fields for shoshonite (SHO) and lamproite (LAM)

549 volcanic rocks from Latera and Tuscany, respectively, and for silica-undersaturated leucite-

550 bearing high-potassic series rocks (HKS) from Vulcini are based on data from Conticelli et al.

551 (1991) and Lustrino et al. (2011). Note that the measured compositions of Group-2 MIs were

552 not corrected for possible post-entrapment re-equilibration so that original MgO

553 concentrations might have been lower than shown in the plots. Arrows in **b** and **c** indicate

554 direction of melt evolution predicted by crystal fractionation of olivine and/or clinopyroxene.

555 Hence, crystal fractionation cannot have produced the difference between the MI groups from

556 SdL, whereas the bulk lava composition can be explained as a slightly evolved mixture of the

557 two. The trace element ratios in **d** represent pairs with comparable incompatibility and are

558 shown to illustrate that Group-2 melts were derived from a compositionally distinct mantle  
559 source.

560 **Figure 3.** Pb isotope data for melt inclusions from the SdL and Monte Starnina lavas. **a:**  
561  $^{207}\text{Pb}/^{204}\text{Pb}$  vs.  $^{206}\text{Pb}/^{204}\text{Pb}$  comparing compositions of MIs with data for Late Archean granitoids  
562 from West Greenland (orange stars) that were derived from a crustal source with (at least  
563 partly) an Eoarchean age (Moorbath et al., 1981; Næraa et al., 2014); note that the  
564 unradiogenic endmember of the Group-1 MIs overlaps with the radiogenic end of the granitoid  
565 array. **b:**  $^{207}\text{Pb}/^{204}\text{Pb}$  vs.  $^{206}\text{Pb}/^{204}\text{Pb}$  for MIs from the SdL and Monte Starnina lavas. **c:** Close up  
566 of b. together with fields for bulk lavas from the northern Roman Magmatic Province HKS,  
567 Latera SHO, and the Tuscan Magmatic Province (Lustrino et al., 2011) and for basement rocks  
568 in the region. The Calabrian basement is represented by granitoids (Rottura et al., 1991), the  
569 Sardinian basement by K-Feldspars from pre-Variscan sandstones and granites (Caron et al.,  
570 1997) and sulfides (Stos-Gale et al., 1995), and the Alpine sandstone by K-feldspars and  
571 galenites from the Permian Grödener sandstones, East Alps (Koppel and Schroll, 1985). The  
572 isotopic closeness of the Group-2 MIs to Sardinian and Calabrian basement rocks and the  
573 Permian sandstone suggests that these lithologies or their erosion products contaminated the  
574 mantle source below Latera via the Alpine subduction system. Conversely, the signatures of  
575 the Group-1 and Mt. Starnina MIs point to a superimposed imprint from the Apennine  
576 subduction. **d:**  $^{208}\text{Pb}/^{204}\text{Pb}$  vs.  $^{206}\text{Pb}/^{204}\text{Pb}$  for MIs from the SdL and Monte Starnina lavas. **e:**  
577  $^{208}\text{Pb}/^{206}\text{Pb}$  vs.  $^{207}\text{Pb}/^{206}\text{Pb}$  for MIs from the SdL and Monte Starnina lavas; Magmatic provinces:  
578 TMP=Tuscan, RMP=Roman, ERMP=Ernici-Roccamonfina, CMP=Campanian (Lustrino et al.,  
579 2011). Symbols as in Fig.2. Error bars, where larger than the symbol size, represent 2-sigma

580 uncertainties based on the standard error of the mean. The diagonal error bars in the isotope  
581 plots are due to the highly correlated errors of  $^{204}\text{Pb}$ -based ratios. Dashed line in each panel is  
582 the Northern Hemisphere Reference Line. UCC=upper continental crust, LCC=lower  
583 continental crust.

Figure 1  
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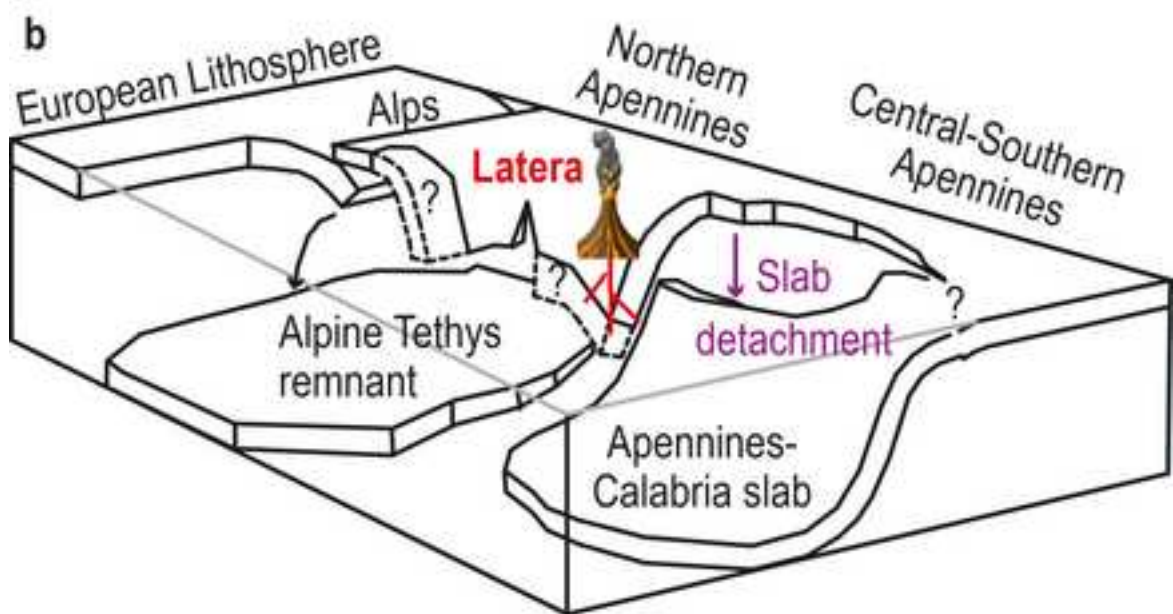
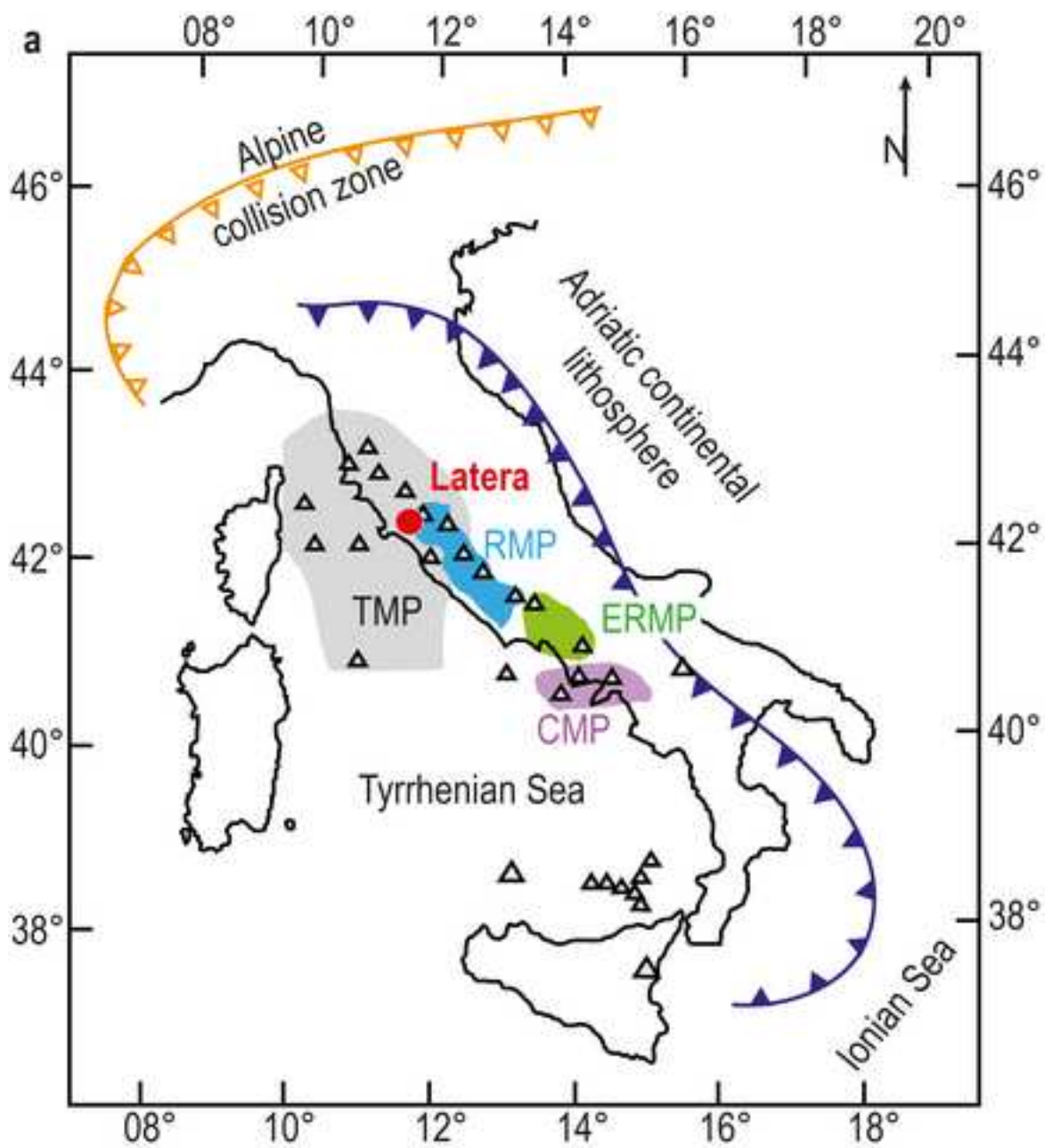


Figure 2

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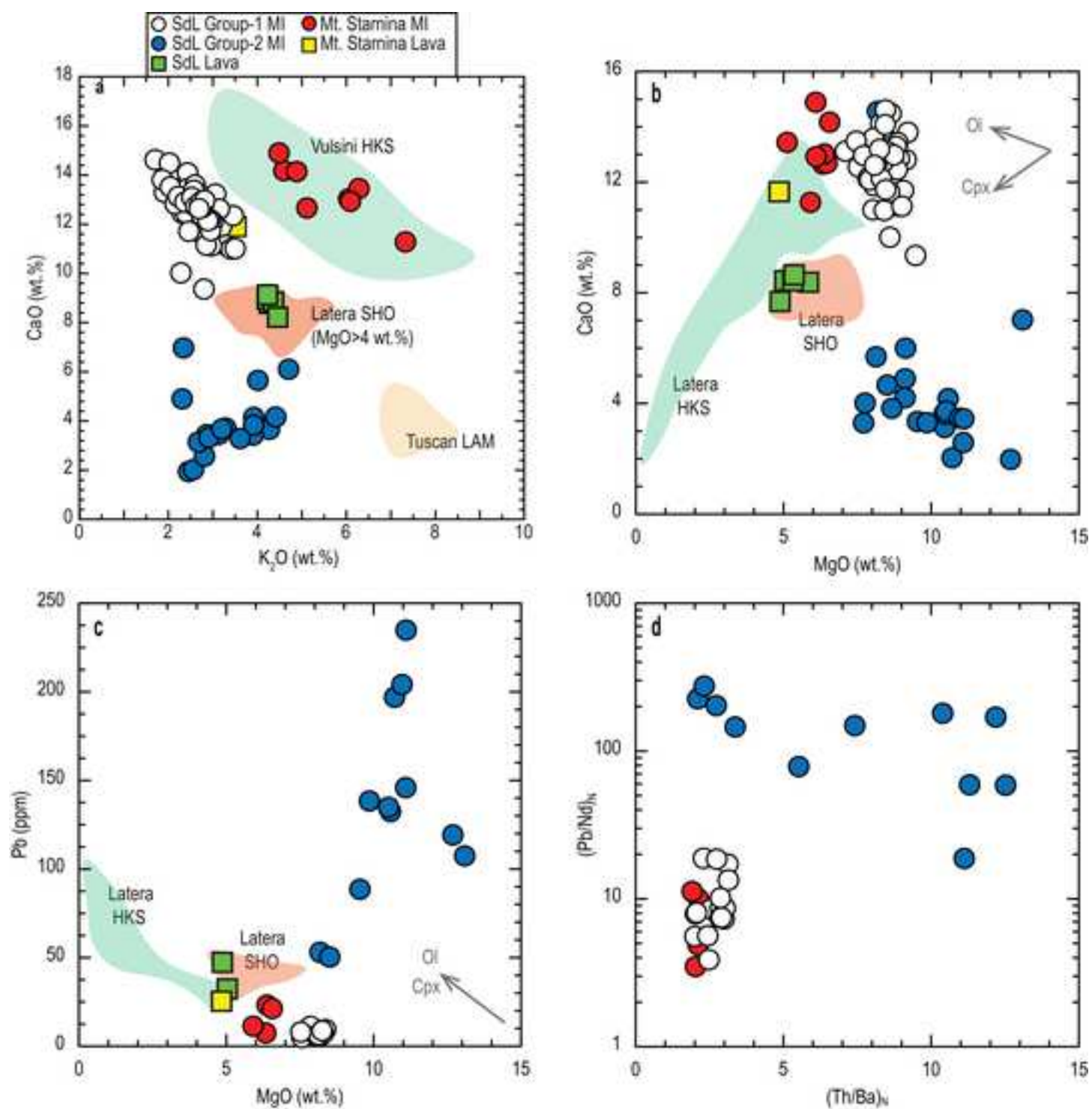


Figure 3  
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