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## Temporal source evolution and crustal contamination at Lopevi Volcano, Vanuatu Island Arc

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### Abstract:

Here we present a new geochemical study of Lopevi volcano, one the most active volcanoes in the Vanuatu island arc. We focus on the temporally well-defined sequence of lava flows emitted since 1960, and for the first time, on pre-1960 volcanic products, including high-MgO basalts and felsic andesites, the most evolved lavas sampled so far on this island. This work reports the first Pb and Hf isotopic study of lavas from Lopevi island. These lavas display correlations between differentiation indexes such as SiO<sub>2</sub> content and isotopic ratios. The felsic andesites extend the known correlations with both the least (Sr–Pb) and the most (Nd–Hf) radiogenic isotopic compositions on the island. Our results confirm that the rising magma interacted with the sub-arc crust. Assimilation–Fractional Crystallization (AFC) quantitative modeling of trace element ratios and isotopic compositions requires 1% and 10% of assimilated partial melts of a mafic oceanic crust to account for the pre- and post-1960 lavas, respectively. The post-1960 lavas differ from the former lavas emitted ~ 20 years earlier by enrichments in fluid mobile elements (K, Ba, Rb...), Th, and Light Rare Earth Elements (LREE). We ascribe these features to slight variations in the metasomatic agent added to the sub-arc mantle and ultimately derived from the subducted lithosphere. However, the contrasting time scales involved in subducted lithosphere dehydration and magma genesis, relative to the time elapsed between eruptions of the two lava series, suggest that two different portions of mantle which have undergone slightly different metasomatism, gave birth to the Lopevi lavas. These distinct magmas are still present beneath the volcano.

### Highlights

► New geochemical study with Hf–Pb isotopes of Lopevi, including recent and old lavas ► Evidences for interactions between ascending magmas and sub-arc crust ► Evidence for short time scale mantle source variations (~ 20 years) ► Involvement of a different metasomatic agent in the pre- and post-1960 lavas

**Keywords:** Lopevi ; Vanuatu ; Geochemistry ; Isotopes ; Subduction ; Mantle source

## 1. Introduction

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Intra-oceanic arcs are a privileged target for understanding the subduction process and for investigating the mantle source(s) of associated magmatism, because in this context the crustal contamination of mantle derived magmas is limited compared to the active continental margins setting, where the crust is thicker and chemically heterogeneous (e. g., [Hildreth and Moorbath, 1988](#) and [Woodhead, 1989](#)). However the magnitude of this contamination process remains poorly constrained in these intra-oceanic arcs and is not easy to identify due to potentially similar chemical and isotopic compositions between the contaminant (the oceanic crust) and the rising magmas.

The Vanuatu island arc is an intra-oceanic arc where near-primitive magmas such as picrites, ankaramites or high MgO basalts are commonly erupted at several volcanic centers, giving the opportunity to observe a straightforward geochemical mantle source signature.

According to along-arc geochemical studies, the Vanuatu lava compositions vary from low K tholeiite to shoshonite series, with some high Mg andesites emitted in the southernmost seamounts ([Monzier et al., 1997](#)). Isotopic studies suggest that Indian and Pacific mantle reservoirs coexist beneath the Vanuatu island arc ([Crawford et al., 1995](#)). The high inter- and

54 intra-islands geochemical variability observed is mainly related to elemental and isotopic  
55 heterogeneities in the sub-arc mantle wedge (Greene et al., 1994) and to variable addition of  
56 the subduction component along the arc (Peate et al., 1997). A few detailed studies have been  
57 focused on the origin of the primitive magmas and/or the geochemical evolution of a single  
58 volcanic system, on the scale of one island. Such studies include Merelava (Barsdell, 1988),  
59 Epi (Barsdell and Berry, 1990), Aoba (Eggins, 1993; Sorbadere et al., 2011), Efate (Raos and  
60 Crawford, 2004), Tanna (Métrich et al., 2011) and Lopevi (Handley et al., 2008).  
61 We present a new geochemical study of the Lopevi volcano (Figure 1), based on the  
62 temporally well-defined sequence of lava flows emitted since 1960, and on older lavas which  
63 include high MgO basalts as well as andesites, the most evolved rocks found on the island.  
64 This study reports for the first time geochemical data on pre-1960 samples and the first Pb  
65 and Hf isotopic compositions from Lopevi Island.

66  
67

## 68 **2. Geological setting and previous work**

69

70 The Vanuatu arc is made up of three parallel chains of volcanic islands located along the  
71 boundary of the SW Pacific plate: the western belt, the eastern belt, and the presently active  
72 central chain (Fig. 1). The aerial part of the Vanuatu central arc stretches along 1200 km from  
73 Ureparapara in the north to Hunter in the south. It is the surface expression of the fast  
74 subduction of the Australia plate beneath the North Fiji Basin which reaches  $118 \text{ mm.a}^{-1}$  at  
75 Tanna (Taylor et al., 1995; Calmant et al., 2003).

76 Tectonics of the SW Pacific is marked by the confrontation between the two large Australia  
77 and Pacific plates. The present convergence is characterized by a large deformed area of more  
78 than 1000 km, the North Fiji Basin and is expressed by two opposite subductions: the

79 westward Tonga-Kermadec and the eastward Solomon-Vanuatu. This is the result of a 25  
80 m.y. long and complex tectonic history (MacFarlane et al., 1988; Greene et al., 1994). Ancient  
81 westward subduction of the Pacific plate beneath the Australia plate has given birth to the  
82 Vitiaz volcanic arc (25-14 Ma) from the Solomon to the Tonga islands and corresponds to the  
83 Western Belt (Mitchell and Warden, 1971) as shown in figure 1a, b. This subduction probably  
84 stopped when the Ontong-Java plateau collided with the Solomon Islands in the north (Meffre  
85 and Crawford, 2001; Mann and Taira, 2004).

86 As convergence continued, the North Fiji Basin began to open ~12 Ma ago (Auzende et al.,  
87 1995). This convergence is marked 7 million years ago by the eastward diving of the  
88 Australia plate beneath the North Fiji Basin at the present place of the Vanuatu trench, giving  
89 birth to the Eastern Belt (Fig. 1a). At ~ 6 Ma, the active volcanic arc (Central Chain) moved  
90 closer to the trench, in response to the steepening of the slab diving angle to 70° (Pascal et al.,  
91 1978).

92 Between 3 and 1.5 Ma, the subduction-collision of the D'Entrecasteaux Ridge (an ancient  
93 Eocene arc) near Epi latitude (South of Lopevi) was a major tectonic event, producing a  
94 transverse fault system by compression in the central part of the arc (Collot et al., 1985;  
95 Greene et al., 1994). The collision zone shifted northward and is now located in front of Aoba  
96 (Fig. 1b), marked by the lack of trench and by the deceleration of the subducting plate to  
97 3.5 cm.a<sup>-1</sup>. A slab detachment between Ureparapara and Vanua Lava in the north and between  
98 Ambrym and Efate occurred within the last million years (Châtelain et al., 1992; Monzier et  
99 al., 1997). Further south, the Loyalty ridge still collides with the Vanuatu arc close to 22°S  
100 (Monzier et al., 1993). The North Loyalty basin, composed of a Middle Eocene oceanic crust  
101 overlain by ~ 650 m of mainly volcanoclastics sediments (Andrew et al., 1973), is currently  
102 subducting at 9 cm.a<sup>-1</sup> in front of Efate.

103 Strong geochemical variations along the Vanuatu arc have been well described by several  
104 groups based on major and trace element contents (Barsdell et al., 1982; Dupuy et al., 1982;  
105 Monzier et al., 1997; Peate et al., 1997) and Sr, Nd, Pb, and Hf isotopic compositions  
106 (Briqueu et al., 1994; Crawford et al., 1995; Peate et al., 1997; Laporte et al., 1998; Turner et  
107 al., 1999; Pearce et al., 2007; Heyworth et al., 2011). Low K arc-tholeiites erupted before 2-3  
108 Ma, are described as “normal suites” and show a Pacific-like mantle isotopic signature. Since  
109 the onset of the subduction-collision of the D’Entrecasteaux Ridge, lavas are characterized by  
110 a strong enrichment in K<sub>2</sub>O, large ion lithophile elements (LILE), and LREE and by an  
111 isotopic composition shifted toward an Indian-like mantle signature with radiogenic Sr and  
112 high <sup>207</sup>Pb/<sup>204</sup>Pb and <sup>208</sup>Pb/<sup>204</sup>Pb isotope ratios (Dupuy et al., 1982; Briqueu et al., 1994; Baker  
113 and Condliffe, 1996; Monzier et al., 1997; Peate et al., 1997; Laporte et al., 1998). The most  
114 recent studies argue for a westward upwelling of an enriched asthenospheric mantle from the  
115 back arc in front of the D’Entrecasteaux collision zone to explain the observed chemical  
116 differences (Monzier et al., 1997; Peate et al., 1997; Pearce et al., 2007; Heyworth et al.,  
117 2011).

118 Lopevi is one of the most active volcanoes of the archipelago. This small conical island, 7 km  
119 large and rising up to 1413 m, is composed of two distinct cones. The older one presents a  
120 summit crater with little fumarole activity. The most recent crater, 1150 m high, appeared  
121 during the 1963 eruptive phase (Williams and Curtis, 1964; Warden, 1967) and is breached to  
122 the NW. This strato-volcano has been active since historical time both at summit and flank  
123 vents, with different eruption styles, including explosive basaltic sub-plinian eruptions  
124 associated with pyroclastic flows (e.g. 1960 and 2003 eruptions) and effusive activities. The  
125 later produced lava flows that reached the coast and came mainly from the 1963 parasitic  
126 crater or from excentric vents opened on the western flank along a NW-SE-trending fissure  
127 system (Warden, 1967). Eruptive cycles of 15 to 20 years have been observed since the mid-

128 19<sup>th</sup> century. The last major eruptions occurred in 1939, 1960-1965, 1980, and 1998-2008.  
129 Lopevi shows a strong tectonic control, as the neighbouring island of Ambrym (Picard et al.,  
130 1995) since these volcanoes are constructed on transverse fractures (Greene et al., 1988)  
131 which are interpreted as major active transcurrent wrench faults related to the  
132 D'Entrecasteaux Ridge collision (Fig.1).

133

134

### 135 **3. Sampling and analytical techniques**

136

137 Thirty five samples from different lava flows were collected on the Lopevi island during  
138 fieldwork in September 2008 and 2009 (Fig. 2). Samples are more or less vesicular basalts  
139 and basaltic andesites with a porphyritic texture. Some samples belong to the well defined  
140 post-1960 activity while others pre-1960 samples were collected around the older summit  
141 crater and in deep gullies in the older part of the island. Some more differentiated samples  
142 such as andesitic pebbles are found along beaches south of the island, at the lower part of  
143 gullies. All samples are very fresh, with loss on ignition values (LOI) lower than 0.5 wt %.

144

#### 145 *3.1. Major and trace elements*

146

147 All samples were analysed for major and trace elements. Major element analyses of whole  
148 rock samples were performed on glass fusion beads by X-Ray Fluorescence spectrometry  
149 using a Philips PW 1404 (LGL, Lyon). Relative standard deviations are 1% for SiO<sub>2</sub> and 2%  
150 for the other major elements, except for low concentrations (< 0.50%) for which the absolute  
151 standard deviation is 0.01. Major element compositions for minerals (phenocrysts and  
152 microlites) of 12 samples were carried out on thin sections with a Cameca SX100 Electron

153 Probe Micro Analysis (Centre Microsonde Ouest - Plouzané). The operating conditions were  
154 15 kV accelerating voltage, 10 nA beam current, and 15-30 s counting time according to the  
155 element.

156 Trace element concentrations were determined in solution by HR-ICP-MS Thermo Fisher  
157 Element-II® (IUEM, Plouzané). Samples were measured according to the procedures  
158 described by Barrat et al. (1996) and by Chauvel et al. (2011). Trace element concentrations  
159 were calculated using a machine drift correction based on the 1-element (Tm) or 3-element  
160 (Be, In, Tm) spike with a mass-based interpolation. Precision for most elements is better than  
161 2 % RSD (3 % RSD for U and Th). Accuracy is better than 5 % for most elements relative to  
162 suggested values for international standards BCR-2 (Jochum and Brueckner, 2008) and JB-2  
163 (Peate et al., 2009) (Table 1).

164

### 165 *3.2. Isotopes*

166

167 Based on major and trace element concentrations, 15 samples were selected for Pb, Sr, Nd  
168 and Hf isotopic measurements. They are representative of the different volcanic phases of  
169 Lopevi and of the whole extent of magma differentiation. Chemical separation for isotopic  
170 measurements was carried out in a class 10000 clean room (Ifremer). From a single sample  
171 digestion, we used a combined procedure for separating Pb, Sr, Nd, and Hf in 5 steps  
172 chromatography. (1) About 700 mg of whole rock powder were dissolved for 72 h with a 3:1  
173 concentrated HF-HBr mixture in teflon Savillex® beakers at about 80°C and evaporated to  
174 dryness. (2) Pb was first separated from other elements using the classical HBr-anion-  
175 exchange resin technique (AG1-X8 100-200mesh) of Manhes et al. (1984). (3) The Pb-free  
176 fraction obtained was loaded onto a ~6.5 cm<sup>3</sup> cation-exchange resin BioRad® (AG50-8X 200-  
177 400 mesh) to separate from the major elements the High Field Strength Elements (HFSE)



178 with a mixed 0.5M HCl /0.15M HF, Sr with 3M HCl, and rare earth elements (REE) with  
179 3.6M HNO<sub>3</sub>. (4) Hf was further separated from Ti using a modified version of the method  
180 described by Yang et al. (2010). The HFSE fraction was loaded onto a column filled with 100  
181 mg of Eichrom® Ln-resin. Ti was removed with 15 mL of 6M HCl-H<sub>2</sub>O<sub>2</sub> mixture and the Hf-  
182 Zr fraction was eluted with 2 mL of 2M HF. (5) Finally Nd was isolated from the other REE  
183 using the Eichrom® Ln-resin technique adapted from Richard et al. (1976) with diluted HCl.  
184 Total procedural chemistry blanks during the course of this work were less than 58 pg for Hf,  
185 5 pg for Nd, 143 pg for Sr, and 50 pg for Pb. These values are totally negligible relative to the  
186 amounts of element present in the samples.

187 Sr and Nd isotope ratios were measured in static mode using a solid source Thermo Fisher®  
188 Triton TI-MS (Thermo Ionization – Mass Spectrometer) at IUEM (Plouzané, France) and a  
189 MAT26X TI-MS (MAT261 upgraded by Spectromat) at Ifremer (Plouzané, France). All  
190 measured ratios were fractionation corrected using  $^{88}\text{Sr}/^{86}\text{Sr} = 8.3752$  and  $^{146}\text{Nd}/^{144}\text{Nd} =$   
191  $0.7219$ . The average  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio measured for the NBS 987 standard was  $0.710271 \pm 14$   
192 (2SD, for 12 runs) on the Triton, and  $0.710244 \pm 18$  (2SD, for 5 runs) on the MAT26X. No  
193 correction was applied. The average  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio measured for the JNdi-1 standard was  
194  $0.512105 \pm 12$  (2SD, for 13 runs) and  $0.511846 \pm 7$  (2SD, for 6 runs) for the La Jolla standard.  
195 Pb and Hf isotopic ratios were measured using a Thermo Fisher® Neptune MC-ICP-MS  
196 (Multi Collector - Inductively Coupled Plasma – Mass Spectrometer) at IUEM. The Hf mass  
197 bias was corrected using an exponential law and assuming a  $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ . The average  
198  $^{176}\text{Hf}/^{177}\text{Hf}$  ratio measured for the JMC475 was  $0.282152 \pm 11$  (2SD, for 58 runs). Pb isotopic  
199 ratios were measured using the thallium addition technique in order to correct the mass bias  
200 (White et al., 2000). The NIST981 standard was run every two or three samples to correct all  
201 Pb isotopic ratios by standard bracketing with the value recommended by Galer and

202 Abouchami (1998). The average  $^{206}\text{Pb}/^{204}\text{Pb}$ ,  $^{207}\text{Pb}/^{204}\text{Pb}$ ,  $^{208}\text{Pb}/^{204}\text{Pb}$  ratios measured for the  
203 NIST981 were respectively  $16.930\pm 3$ ,  $15.483\pm 4$ , and  $36.670\pm 12$  (2SD, for 29 runs).

204

205

## 206 **4. Results**

207

### 208 *4.1. Major and trace element results*

209

210 Lopevi lavas display a medium-K calc-alkaline series (Fig. 3) and are mostly basalts and  
211 basaltic andesites ranging from 49.5 to 56 wt %  $\text{SiO}_2$ , except for two acid andesite pebbles at  
212  $\sim 61$  wt %  $\text{SiO}_2$  (only one data point visible in Fig. 3 because of their very similar chemical  
213 composition). Post-1960 lavas are slightly more enriched in  $\text{K}_2\text{O}$  than the older ones (Fig. 3).  
214 Basalts and basaltic andesites are composed of abundant euhedral to subeuhedral phenocrysts  
215 of clinopyroxene ( $\text{Wo}_{35-45}$ ,  $\text{Fs}_{6-17}$ ,  $\text{En}_{41-48}$ ), plagioclase ( $\text{An}_{78-92}$ ) and olivine ( $\text{Fo}_{70-90}$ ),  
216 surrounded by a glassy to fine grained matrix composed of microcrysts of clinopyroxene  
217 ( $\text{Wo}_{7-37}$ ,  $\text{Fs}_{14-36}$ ,  $\text{En}_{26-66}$ ), plagioclase ( $\text{An}_{30-89}$ ), olivine ( $\text{Fo}_{60-78}$ ) and Fe-Ti oxides. Phenocrysts  
218 from the basaltic-andesite LO14 show more evolved compositions with clinopyroxene ( $\text{Wo}_{8-}$   
219  $_{37}$ ,  $\text{Fs}_{33-66}$ ,  $\text{En}_{42-61}$ ), plagioclase ( $\text{An}_{55-85}$ ) and olivine ( $\text{Fo}_{74}$ ). Common tendency to aggregation  
220 of phenocrysts is observed. Andesites are composed of abundant tabular, sometimes zoned,  
221 plagioclases ( $\text{An}_{56-68}$ ) and less abundant clinopyroxene phenocrysts ( $\text{Wo}_{36-39}$ ,  $\text{Fs}_{15-20}$ ,  $\text{En}_{40-46}$ ).  
222 Olivine is absent and some scarce orthopyroxene phenocrysts ( $\text{Wo}_{2-3}$ ,  $\text{Fs}_{31-52}$ ,  $\text{En}_{44-65}$ ) are  
223 found. Those phenocrysts are set in a fine grained matrix composed of microcrysts of  
224 plagioclase ( $\text{An}_{23-60}$ ), clinopyroxene ( $\text{Wo}_{8-47}$ ,  $\text{Fs}_{25-44}$ ,  $\text{En}_{29-52}$ ) and Fe-Ti oxide. Overall,  
225 crystals set in the more evolved rocks are impoverished in Mg and in Ca, compared to others,  
226 as observed also in the microcrysts compared to the phenocrysts in one sample.

227 Major element variation diagrams (Fig. 4) show that some basalts have relatively high MgO  
228 content reaching 7.8 wt % and that the post-1960 lavas are also slightly more enriched in  
229 Al<sub>2</sub>O<sub>3</sub> than the older ones. MgO, Fe<sub>2</sub>O<sub>3</sub>, and CaO are negatively correlated with silica content,  
230 with a slope change at ~ 51 wt % SiO<sub>2</sub> for the post-1960 lavas and at ~ 52 wt % SiO<sub>2</sub> for the  
231 older ones, whereas Na<sub>2</sub>O and K<sub>2</sub>O show positive correlations (Figs. 3 and 4, Fe<sub>2</sub>O<sub>3</sub>, CaO, and  
232 Na<sub>2</sub>O are not shown). Al<sub>2</sub>O<sub>3</sub> is positively correlated with silica content for low SiO<sub>2</sub> values  
233 (< 51 - 52 wt %) and negatively correlated for higher values.

234 Chondrite-normalised rare earth element (REE) patterns (Fig. 5a) have slight to moderate  
235 enrichment in the Light REE (LREE ~ 20 to 30 times the chondritic values) relative to Heavy  
236 REE (HREE) which draw an almost flat pattern (~ 10 to 20 times the chondritic values). Pre-  
237 and post-1960 lavas show overall similar patterns, but the former display a larger range of  
238 compositions, in line with their higher Si content.

239 The extended trace element patterns (Fig. 5b) are typical of arc magmas with an enrichment in  
240 fluid mobile elements (Rb, Ba, U, K, Pb, Sr), and a depletion in high field strength elements  
241 (HFSE: Nb, Ta, Hf, Zr, Ti) relative to the REE. Overall post-1960 lavas are more  
242 homogeneous than the pre-1960 lavas. The high MgO basalt LO20 has the lowest trace  
243 element abundance, and its trace element pattern is slightly different from the others. Some  
244 lavas display negative Eu anomalies which are more developed in the most evolved lavas.  
245 Lopevi lavas display a moderate enrichment in fluid mobile elements, and relatively low  
246 La/Yb ratio (2-3) compared to other Vanuatu island lavas such as those facing the  
247 D'Entrecasteaux ridge collision which display La/Yb ratios reaching ~ 12 (Fig. 5). Highly  
248 incompatible elements (such as Nb and Th) content increases during magmatic differentiation  
249 (Fig. 6). Pre- and post-1960 lavas display two distinct positive trends with distinct Th/Nb  
250 ratios (~ 0.45 vs. 0.55, respectively), supporting the existence of two slightly distinct

251 magmatic series at Lopevi. However the felsic andesites, belonging to the pre-1960 group, are  
252 aligned on the post-1960 trend.

253

#### 254 4.2. *Isotopic results*

255

256 The Lopevi samples show a restricted isotopic range compared to the whole range reported  
257 from Vanuatu volcanic islands (Fig. 7). Their  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios vary from 0.70392 to 0.70409.  
258  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios show very small variations from 0.51296 to 0.51303 and  
259 from 0.28316 to 0.28318, respectively. Variations in Pb isotopic compositions are also  
260 limited, and range from 18.44 to 18.51 for  $^{206}\text{Pb}/^{204}\text{Pb}$ , from 15.53 to 15.55 for  $^{207}\text{Pb}/^{204}\text{Pb}$ ,  
261 and from 38.38 to 38.44 for  $^{208}\text{Pb}/^{204}\text{Pb}$ . This limited isotopic variation does not bring out  
262 significant isotopic differences between the pre- and the post-1960 lavas. However the new  
263 Sr-Nd isotopic analyses extend the compositional range reported by Handley et al. (2008)  
264 toward lower  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios and higher  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios recorded in the more differentiated  
265 products (Fig. 7a).

266 Lopevi lavas have relatively high  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $^{207}\text{Pb}/^{204}\text{Pb}$  and  $^{208}\text{Pb}/^{204}\text{Pb}$  values, and  
267 intermediate  $^{143}\text{Nd}/^{144}\text{Nd}$ ,  $^{176}\text{Hf}/^{177}\text{Hf}$ , and  $^{206}\text{Pb}/^{204}\text{Pb}$  values compared to the isotopic  
268 composition range reported for the Vanuatu lavas (Peate et al., 1997; Laporte et al., 1998;  
269 Turner et al., 1999; Pearce et al., 2007). This isotopic signature is intermediate between the  
270 isotopic signatures of the lavas emitted in front of the collision zone and those emitted away  
271 in the northern and the southern part of the arc. Lopevi lavas fall broadly in the Indian MORB  
272 field in the Pb-Pb and Hf-Nd isotopic spaces, having high  $^{207}\text{Pb}/^{204}\text{Pb}$  and  $^{208}\text{Pb}/^{204}\text{Pb}$  values  
273 for a given  $^{206}\text{Pb}/^{204}\text{Pb}$  value, and low  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio for a given  $^{176}\text{Hf}/^{177}\text{Hf}$  value (Fig. 7).  
274 However, in the Sr-Nd space (Fig. 7a), Lopevi lavas plot outside the MORB fields, displaying

275 higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios as commonly described in island arc lavas, and fall within the field of  
276 the North Loyalty Basin sediments.

277

278

## 279 **5. Discussion**

280

### 281 *5.1. Fractional Crystallization*

282

283 Lopevi arc lavas include only a small proportion of differentiated materials. Lopevi lavas host  
284 “classical” mineral assemblage: olivine, clinopyroxene, plagioclase, and Fe-Ti oxides. In the  
285 more evolved lavas, olivine disappears while orthopyroxene is present. No hydrous minerals  
286 like amphibole are present.

287 Major element covariation diagrams (Fig. 4) suggest by their trends and their inflections a  
288 two- stage crystallization. The first stage is characterized by the removal of olivine and  
289 clinopyroxene as seen by the decrease of MgO content from 8 to 5 % (Fig. 4). The inflection  
290 of the MgO-SiO<sub>2</sub> trend at 51-52 wt. % SiO<sub>2</sub> is related to the onset of Al<sub>2</sub>O<sub>3</sub> decrease in the  
291 lavas and to plagioclase fractionation. This change is also recorded by the Eu negative  
292 anomaly (which is compatible in plagioclase) shown in the trace element patterns of the more  
293 evolved samples. Thereby the appearance of low-Ca orthopyroxene in the most evolved rocks  
294 is probably related to the abundance of plagioclase which integrates a large amount of CaO  
295 and the lack of elevated water pressure to stabilize amphibole.

296 Least square modelling of the major element data (Bryan et al., 1969) accounts successfully  
297 for the first stage of fractional crystallization in the most mafic rocks until 51 % SiO<sub>2</sub> and  
298 gives similar results to those of Handley et al. (2008), with a ~30 % degree of crystal  
299 fractionation. However the modelling fails to account for the second stage of crystallization,

300 suggesting that an additional process is involved during magmatic differentiation. This is also  
301 suggested also by the change of Nb/Th ratios during the differentiation of the pre-1960 lavas  
302 (Fig. 6).

303

## 304 *5.2. Assimilation – Fractional Crystallization (AFC)*

305

### 306 *5.2.1. Isotopic evidence*

307

308 Classical long-lived radiogenic systems (Sr-Nd-Pb-Hf) are a powerful tool to spot magma  
309 contamination, provided that the isotopic composition of the contaminant is distinct from the  
310 composition of the magma. In spite of a rather restricted range in isotopic compositions, the  
311 Lopevi lavas display a negative Sr-Pb and a positive Nd-Hf correlation with the  
312 differentiation indexes (SiO<sub>2</sub>, MgO, Th, La), extending the correlations reported in Handley et  
313 al. (2008) towards lower <sup>87</sup>Sr/<sup>86</sup>Sr, higher <sup>143</sup>Nd/<sup>144</sup>Nd and higher SiO<sub>2</sub> values (Fig. 8, Hf  
314 isotopes not shown). It suggests that a contamination process occurred during the ascent of the  
315 magma toward the surface and that the contaminant is less (Sr and Pb) and more (Nd and Hf)  
316 radiogenic than the most evolved samples. This is in agreement with Handley et al. (2008)  
317 who identified contamination in the post-1960 lavas using Sr, Nd, Ra, and Th isotopes. These  
318 authors argued for the assimilation of a small degree of partial melt (2 – 10 %) of a >380 Ka  
319 old mafic oceanic crust, of MORB composition, rejecting the hypothesis of bulk assimilation  
320 of oceanic crust and magma mixing process.

321

### 322 *5.2.2. AFC model*

323

324 Contamination by the oceanic crust is investigated using an AFC model (DePaolo, 1981). The  
325 equation used is:  $C_m = C_m^0 F^{-z} + (r/r-1) (C_a/z) (1-F^{-z})$ , with  $z = (r + D-1)/(r-1)$ .  $C_a$  and  $C_m$  are  
326 the concentrations in the contaminant and in the magma respectively.  $D$  corresponds to the  
327 bulk partition coefficient,  $F$  is the fraction of remaining melt and  $r$  is the ratio of assimilation  
328 rate to fractional crystallization rate. The compositions of the parental magma as the starting  
329 end member are chosen among the basalts with the highest MgO content (LO03 and LO15 for  
330 post- and pre-1960 groups, respectively). The crust underneath Lopevi is a likely contaminant  
331 composed of oceanic crust and of some former magmatic intrusives. However its precise  
332 composition remains unknown. An N-MORB trace element composition from Sun and  
333 McDonough (1989) is taken as representative of this crust. Values for the isotopic  
334 composition of the contaminant are chosen to obtain the best fit with our data set. These  
335 values are included into the isotopic composition range reported for the North Loyalty Basin  
336 by Briquieu and Lancelot (1983), Briquieu et al. (1994), and Peate et al. (1997), except for the  
337 Hf isotopic value which is significantly different from the single value reported by Pearce et  
338 al. (2007) and for the low  $^{206}\text{Pb}/^{204}\text{Pb}$  value required for the recent contaminant. Assimilation  
339 of oceanic crust as partial melts (rather than bulk crust) is investigated. It has for main effect  
340 to increase the incompatible element concentration of the contaminant, while its Pb, Sr, Hf  
341 and Nd isotopic compositions remain unchanged. The trace element concentrations of the  
342 assimilated melts are calculated using a non-modal batch melting model (Shaw, 1970) of an  
343 N-MORB (Sun and McDonough, 1989) involving 1 and 10 % of melts, for the pre- and the  
344 post- 1960 contaminants, respectively.

345 Our model provides a good fit of the data in diagrams involving combined isotope ratios  
346 (insensitive to the fractional crystallization) or trace element and isotopic ratios (Fig. 9 and  
347 10). Notably, the two distinct sets of  $C_a$  (with 1% and 10% of assimilated partial melts for

348 pre- and post- 1960 lavas, respectively) and low ( $\leq 0.3$ )  $r$  parameters (Table 2) can account for  
349 the separate pre- and post- 1960 lava trends.

350 The pre-1960 lavas model requires a crustal partial melt contaminant with high U/Pb and  
351 Ba/Yb, associated with a low  $r$ , while the post-1960 model requires a contaminant with lower  
352 U/Pb, Ba/Yb ratios associated with a higher  $r$  value (Table 2). As seen in figures 9a and 9b,  
353 the post-1960 model requires a lower  $^{206}\text{Pb}/^{204}\text{Pb}$  than needed for the pre-1960 lavas.

354 Ratios such as U/Pb and Ba/Yb (U and Ba being respectively more incompatible than Pb and  
355 Yb) are very sensitive to the degree of partial melting, while Sr-Nd-Pb-Hf isotopic ratios are  
356 not affected by this process and remain constant. Two distinct partial melting degrees (1% for  
357 pre- and 10% for post-1960 lavas) of a single N-MORB contaminant generate consistent  $C_a$   
358 values for both series. Variable degrees of partial melting could be related to distinct  
359 conditions of pressure and temperature during assimilation or to a variable water content of  
360 the contaminant. The  $r$  values in the model for the post-1960 series are higher than those  
361 required for the older ones (0.3 versus 0.2), indicating a higher assimilation / fractional  
362 crystallization rate.

363 Many uncertainties remain in such models but our results are consistent with the model  
364 presented by Handley et al. (2008), with similar degrees of partial melting of the contaminant  
365 (1 and 10 % vs. 2-10 %), and  $r$  values (0.2 and 0.3 vs. 0.25). However we use a slightly more  
366 radiogenic Sr contaminant in our model (0.7033 vs. 0.7025) because a lower  $^{87}\text{Sr}/^{86}\text{Sr}$  value  
367 cannot explain the pre-1960 variations.

368

### 369 *5.3. Subduction component*

370

#### 371 *5.3.1. Chemical time evolution*

372



373 At the island arc scale, the Lopevi geochemical variations are limited (Monzier et al., 1997;  
374 Peate et al., 1997). Nevertheless at the scale of Lopevi volcano, differences appear between  
375 pre- and post-1960 lavas independently of the AFC process, especially when looking at trace  
376 element ratios such as Ba/Yb or Th/Nb (Figs. 6 and 10), as shown by the lack of overlap in  
377 Ba/Yb between both series (Fig. 10). The largest differences are observed in the most mafic  
378 (MgO rich) lavas, where the contamination effect is assumed to be the lowest and where the  
379 source signature is the most pronounced. Figure 11 shows the REE and trace element patterns  
380 of the basalts with MgO > 7 wt. %. Overall differences between both series are characterized  
381 by a higher enrichment in fluid mobile elements (Rb, Ba, U, K, Pb, Sr), in LREE (higher  
382 La/Yb) and in Th recorded in the post-1960 lavas. However the HFSE and HREE content are  
383 almost similar in the most mafic lavas (Fig. 11).

384 The isotopic signatures of Lopevi lavas are affected by the AFC process but the most mafic  
385 lavas from both series, which are supposed to be the least contaminated, have almost identical  
386 Nd, Pb and Hf isotopic compositions (Fig. 9). Only the Sr isotopes show a slight difference  
387 with more radiogenic ratios in the recent lavas.

388

### 389 *5.3.2. Mantle source composition*

390

391 Trace element variations in mafic lavas can reflect a change of 1) their mantle source  
392 mineralogy, 2) variable degrees of partial melting, or 3) different mantle sources. The most  
393 mafic post-1960 lavas have higher La/Yb ratios (~ 2.8 vs. 2.4) than the older ones (Fig. 11).  
394 As garnet incorporates some Yb amount in its structure, elevated La/Yb ratios in lavas could  
395 result from the melting of a garnet-bearing source at high pressure (Shimizu and Kushiro,  
396 1975; Langmuir et al., 1977). However the observed differences between both series are  
397 moderate and cannot be attributed to a significant change in the mantle source mineralogy.

398 Changes in the partial melting degree of a single mantle source can also produce various trace  
399 element compositions in mafic magmas, in particular a fractionation between the most and the  
400 least incompatible elements. For example, while Nb is more incompatible than Yb during  
401 partial melting processes, pre- and post-1960 Lopevi lavas have identical Nb/Yb ratios (~ 0.6  
402 for high-MgO basalts). Accordingly, partial melting cannot account for the chemical  
403 differences between the two series at Lopevi volcano.

404 In subduction zones, melting of the mantle wedge is triggered by the addition of a water-rich  
405 component released from the subducted oceanic lithosphere (e.g. Tatsumi, 1986; Peacock,  
406 1990; Grove et al., 2006). This water-rich component carries trace elements into the mantle  
407 wedge and gives the typical enriched signature of arc magmas compared to MORB  
408 (McCulloch and Gamble, 1991). However its exact nature (aqueous fluids or hydrous melt)  
409 and origin (altered oceanic crust or sediments) remains largely debated (Elliott et al., 1997;  
410 Hawkesworth et al., 1997; Eiler et al., 1998; Prouteau et al., 2001). Lopevi lavas show Nb/Yb  
411 ratios similar to those found in MORB, indicating that the mantle in the subduction area was  
412 as depleted as the MORB mantle before the subduction component addition. Other trace  
413 element ratios involving fluid/melt mobile elements are higher than in MORB and document  
414 the element flux derived from the subducted plate. Among these elements, Ba and Pb are  
415 often used to indicate low T dehydration of the subducted lithosphere because they are highly  
416 mobile in hydrous fluids (Brenan et al., 1995; Stalder et al., 1998; Kessel et al., 2005) whereas  
417 Th is used as an indicator of sediment melting because Th/REE fractionation increases at high  
418 T when sediments melt (Johnson and Plank, 1999; Kessel et al., 2005; Plank, 2005; Hermann  
419 and Spandler, 2008).

420 Lopevi lavas are weakly enriched in incompatible elements compared to MORB which is  
421 consistent with a moderate modification of their mantle source by a subduction component.  
422 Th/La ratio is slightly higher than in MORB but the main enrichments affect Ba, Sr and Pb.

423 Even if the participation of a sediment melt cannot be ruled out, it is clear that low T  
424 dehydration fluids carried LILE into the Lopevi mantle source, in agreement with the high  
425 Ba/Yb and Pb/Ce ratios of the Lopevi lavas.  
426 Post-1960 lavas are enriched in Ba and K while the less differentiated samples, which are also  
427 the less (or not at all) contaminated, have no significant differences in their Sr-Nd-Pb-Hf  
428 isotopic compositions. From these observations, one can argue that pre- and post-1960 lavas  
429 come from two different mantle sources beneath Lopevi. Both mantle portions have been  
430 metasomatised with fluids from a same origin, consistent with their identical isotopic  
431 composition, but the element flux was more elevated in the post-1960 mantle source, in  
432 agreement with the higher K and Ba enrichment observed in these more recent lavas.

433

#### 434 *5.4. Volcanological implications*

435

436 Several eruptions have been recorded at Lopevi volcano between 1864 and 1939, before the  
437 volcano entered a period of quiescence for more than 20 years (Williams and Curtis, 1964).  
438 Volcanic activity resumed in 1960 by a large basaltic plinian eruption which forced a  
439 definitive evacuation of the people living on the island. This eruption marked the beginning of  
440 a new eruptive cycle of the volcano, with the production of mafic olivine-bearing magmas and  
441 the opening of the new lateral crater on the NW flank (Warden, 1967). During the following  
442 years the main crater was only active at the beginning of the eruptions while the main activity  
443 was concentrated in the new lateral cone or occurred along adjacent NW trending fissures.  
444 The onset of this new activity cycle in 1960 was accompanied by a shift in the trace element  
445 composition of the erupted magmas, as shown previously. The change occurred within a very  
446 short time scale (~ 20 years) while the deep processes of magma formation and evolution  
447 have been shown to appear on a larger time scale. Using the fractionation of Ra and Th in

448 metasomatic fluids recorded by Ra-Th isotopes, Handley et al. (2008) estimated the  
449 metasomatism of the mantle wedge beneath Lopevi to have happened less than 8000 years  
450 ago, while the magmatic differentiation from basalt to basaltic andesite and the associated  
451 contamination was accomplished in less than 1000 years.

452 Taking these constraints all together indicates that fluid transfer from the subducted  
453 lithosphere into the mantle wedge creates mantle portions with different trace element  
454 compositions, probably in response to variable fluid flux in the mantle. Melting of at least two  
455 different mantle regions beneath Lopevi created magmas with slight differences in their trace  
456 element contents. These magmas followed different pathways from their source to the Lopevi  
457 volcano through the crust in which they were differentiated and contaminated in separate  
458 magma chambers beneath the volcano. The more enriched magma initiated the last volcanic  
459 cycle at Lopevi, and, following different pathways to the surface, created a new emission  
460 centre on the flank of the volcano.

461 The very short time scale of this shift indicates that the “older” and less enriched magma is  
462 still present beneath the volcano and can erupt again from the summit crater in the years or  
463 decades to come.

464

## 465 **6. Conclusions**

466

467 - New sampling of the Lopevi island increases the previous data set (mainly post-1960) of  
468 Handley et al. (2008), providing insight into the older history of the volcano. Notably, the pre-  
469 1960 data set contains more differentiated rocks, up to 61 wt % SiO<sub>2</sub>.

470 - Chemical and isotopic data on pre- and post-1960 lavas confirm the contamination of the  
471 ascending magmas by partial melts derived from the oceanic crust beneath the volcano. AFC

472 modelling requires 1% and 10% of assimilated crustal melts to account for the pre- and post-  
473 1960 lavas, respectively.

474 - Pre- and post-1960 lavas show different trace element compositions but very similar isotopic  
475 ratios. These differences, unrelated to the contamination process, are ascribed to the partial  
476 melting of different portions of the mantle, which have undergone slightly different  
477 metasomatic fluid flux from the subducted oceanic lithosphere.

478 - The renewal of volcanic activity in 1960, after more than 20 years of quiescence, marks the  
479 involvement of a new batch of magma coming from a different mantle source. However, the  
480 contrasted time scales involved in the magma genesis at depth and the volcanological  
481 evolution at the surface imply that the old magma is still present beneath the volcano but so  
482 far unable to mix with the younger one.

483

484

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486

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493

## 494 **Figure captions**

495

496 **Figure 1:** (a) Bathymetric map of the Vanuatu island arc. Inset: General map of the south-  
497 west Pacific. (b) Interpretative map of the Vanuatu islands showing the general tectonic  
498 setting adapted from Pelletier et al. (1998). The Back Arc Thrust Belt is the thrusting of the  
499 Eastern belt on the North Fiji Basin (Calmant et al., 2003). The Vanuatu active arc (central  
500 chain) is drawn in red, with small white triangles representing the active volcanoes. Inclined  
501 hatching is used for islands belonging to the Western belt and to the Eastern belt. Simple  
502 arrows indicate the convergent rate in  $\text{cm.a}^{-1}$  of the subducted plate from GPS data (Calmant  
503 et al., 2003). Double arrows represent the divergent rates in  $\text{cm.a}^{-1}$  in the back arc domain  
504 (Price and Kroenke, 1991; Auzende et al., 1994; Huchon et al., 1994; Pelletier et al., 1998).  
505 The associated thin lines show the active spreading axes. Brown areas represent ridges and  
506 plateaus (submarine relief) on the subducted plate. Dashed bold lines represent the major  
507 faults and the associated half arrows represent the movement of each block. The dotted line in  
508 the north represents the ancient Vitiaz trench lineament. The star indicates the location of the  
509 DSDP (Deep Sea Drilling Project) hole 286.

510

511 **Figure 2:** (a) Location map of Lopevi samples (circles), and the main recent lava flows,  
512 adapted from Handley et al. (2008). Circles represent the location of the samples from this  
513 work, whereas triangles represent those studied by Handley et al. (2008). (b) Regional  
514 bathymetric map of the central part of the Vanuatu arc, with the location of the Lopevi island.

515

516 **Figure 3:**  $\text{K}_2\text{O}$  versus  $\text{SiO}_2$  diagram (Peccerillo and Taylor, 1976) illustrating the  
517 compositional diversity of the Lopevi lavas emitted before and after 1960, and the overall  
518 dominance of basic compositions for the Vanuatu lavas (small circles: data from Georoc  
519 database and from our unpublished data. Triangles are used for data from Handley et al.

520 (2008). Lopevi lavas plot in the medium-K calc alkaline series with low  $K_2O$  content  
521 compared to other Vanuatu lavas.

522

523 **Figure 4:** Major element binary diagrams showing the effect of fractional crystallization with  
524 crystallization of olivine and clinopyroxene before plagioclase. (a) MgO and (b)  $Al_2O_3$  shown  
525 as a function of silica content.

526

527 **Figure 5:** (a) REE patterns of the Lopevi lavas normalized to the chondritic values from  
528 McDonough and Sun (1995). (b) Extended trace elements patterns of Lopevi lavas normalized  
529 to the N-MORB values from Sun and McDonough (1989). Only samples measured with the  
530 method described by Chauvel et al. (2011) are shown in the extended diagram. Shaded areas  
531 correspond to Vanuatu basalts reported by Peate et al. (1997) from islands facing the  
532 D'Entrecasteaux Ridge (DER) collision (e.g. Gaua, Aoba, Ambrym).

533

534 **Figure 6:** Nb versus Th diagram showing the behaviour of two highly incompatible elements  
535 with similar bulk D values. Pre- (gray line) and post-1960 (black line) lavas display different  
536 Th/Nb ratios.

537

538 **Figure 7:** Isotopic diagrams showing the very restricted range of variation of the Lopevi  
539 lavas. (a) Nd-Sr isotope diagram. The mantle array is from Hofmann and White (1982). (b)  
540 Hf-Nd isotope diagram. The global correlation is from Graham et al. (2006). (c)  $^{208}Pb/^{204}Pb$ -  
541  $^{206}Pb/^{204}Pb$  and (d)  $^{207}Pb/^{204}Pb$  -  $^{206}Pb/^{204}Pb$  diagrams. The Northern Hemisphere Reference  
542 Line is from Hart (1984). The discrimination line is from Pearce et al. (2007) in diagram (b)  
543 and from Kempton et al. (2002) in diagram (c). MORB data are from Meyzen et al. (2007),  
544 using the East Pacific Rise data for the Pacific MORB and the South East Indian Ridge data

545 for the Indian MORB (excluding the references from the Australia Antarctica Discordance).  
546 NLB AOC: Altered Oceanic Crust from the North Loyalty Basin. NLB Sediments: North  
547 Loyalty Basin sediments. NLB data correspond to samples coming from the DSDP Hole 286  
548 (Fig. 1) and are from Peate et al. (1997)(for Pb, samples leached), Briquieu et al. (1994)(for  
549 Sr-Nd-Pb) and from Pearce et al. (2007)(for Sr-Nd-Hf). Vanuatu data are from Peate et al.  
550 (1997), Laporte et al. (1998), Turner et al. (1999), Pearce et al. (2007), and from personal  
551 unpublished data.

552

553 **Figure 8:** (a)  $^{87}\text{Sr}/^{86}\text{Sr}$  (b)  $^{143}\text{Nd}/^{144}\text{Nd}$  (c)  $^{208}\text{Pb}/^{204}\text{Pb}$  ratios versus  $\text{SiO}_2$  wt % diagrams  
554 showing the decrease (Sr, Pb) and the increase (Nd) of the isotopic ratios during the magmatic  
555 differentiation ( $\text{SiO}_2$  as an index of differentiation) due to crustal contamination.  $2\sigma$  represents  
556 the mean of the individual analytical error.

557

558 **Figure 9:** (a)  $^{206}\text{Pb}/^{204}\text{Pb}$  vs. U/Pb (b)  $^{207}\text{Pb}/^{204}\text{Pb}$  vs.  $^{206}\text{Pb}/^{204}\text{Pb}$  (c)  $^{176}\text{Hf}/^{177}\text{Hf}$  vs.  $^{208}\text{Pb}/^{204}\text{Pb}$   
559 diagrams showing combined assimilation and fractional crystallization (AFC) models  
560 described in the text. The starting end-members are the high MgO basalts LO03 (post-1960)  
561 and LO15 (pre-1960). The fraction of melt remaining (F) is indicated on the AFC model  
562 curves by tick marks every 0.1 step. Parameters used in the models for the pre- 1960 (gray  
563 curve) and the post- 1960 (black curve) are reported in the Table 2.

564

565 **Figure 10:**  $^{87}\text{Sr}/^{86}\text{Sr}$  versus Ba/Yb diagram showing the geochemical differences between the  
566 pre- and the post-1960 lavas, especially for the less differentiated samples, and the effect of  
567 AFC processes (parameters of the model in Table 2).

568



569 **Figure 11:** Extended trace element patterns showing the major differences between the high  
570 MgO basalts LO03, LO04 (post-1960) and LO15 and LO20 (pre-1960). REE in bold  
571 characters. Inset: REE patterns normalized to the chondritic values from McDonough and Sun  
572 (1995). Boxes indicate elements showing significant difference between the two series.  
573

574 **Table 1:** Major elements are presented on a volatile-free basis to 100 % with total iron as  
575  $\text{Fe}_2\text{O}_3(\text{t})$ . Samples ticked with a “ § ” were measured using the protocole developed by Barrat  
576 et al. (1996), while the others were measured by the protocole described in Chauvel et al.  
577 (2011). LO04 was measured by both protocols and standard deviation (sd) values between the  
578 two measurements are given. Sr isotopic data measured on a Finnigan MAT26X for data  
579 ticked with a “\*”, and on a Thermo Fischer TRITON for others.

580  
581 **Table 2:** AFC model parameters and results of batch melting model. The trace element  
582 contents of the contaminant ( $C_a$ ) were calculated from the batch melting (1 % for the pre-  
583 1960 group and 10 % for the post- 1960 group) of a metabasalt (source mineralogy: 0.2  
584 orthopyroxene, 0.40 clinopyroxene, 0.25 plagioclase, 0.15 amphibole) having the trace  
585 element content of an N-MORB from Sun and McDonough (1989). The respective  
586 contributions to the melt are 0.4 clinopyroxene, 0.35 amphibole, 0.2 plagioclase, 0.05  
587 orthopyroxene. Partition coefficients used to calculate bulk D values are from Adam and  
588 Green (2006) and Aignertorres et al. (2007). Partition coefficient of Yb between  
589 clinopyroxene and melt is from Green et al. (2000). Partition coefficients of Pb are from Hauri  
590 et al. (1994), Bindeman et al. (1998), and McKenzie and O’Nions (1991). The isotopic ratios  
591 of the contaminant ( $R_a$ ) were chosen to fit correctly the data and are consistent with values  
592 found in MORB. “r” value used is 0.3 for the post-1960 lavas and 0.2 for the pre-1960 lavas.  
593 D, Ca, and r are assumed to be constant during the AFC process. The r value used is as low as

594 possible, because a small degree of contamination is easier to invoke. The starting end-  
595 members are the high MgO basalts LO03 (post-1960) and LO15 (pre-1960). Parameters used  
596 in the model are slightly different between the pre- and the post-1960 lavas.

597

598

## 599 **References**

600

601

602 Adam, J. and Green, T., 2006. Trace element partitioning between mica- and amphibole-  
603 bearing garnet lherzolite and hydrous basanitic melt: 1. Experimental results and the  
604 investigation of controls on partitioning behaviour. *Contributions to Mineralogy and*  
605 *Petrology*, 152(1): 1-17.

606 Aigner-Torres, M., Blundy, J., Ulmer, P. and Pettke, T., 2007. Laser Ablation ICPMS study  
607 of trace element partitioning between plagioclase and basaltic melts: an experimental  
608 approach. *Contributions to Mineralogy and Petrology*, 153(6): 647-667.

609 Andrew, J.E., Packham, G., Eade, J.V., Holdsworth, B.K., Jones, D.L., De Vriesklein, G.,  
610 Kroenke, L.W., Saito, T., Shafik, S., Stoesser, D.B. and Van Der Lingen, G.J., 1973.  
611 Site 285 and 286. In: Andrew, J.E. and Packham, G. (Eds.), *Initial reports of the Deep*  
612 *Sea Drilling Project*, Washington, DC, United States (USA), pp. 27-131.

613 Auzende, J.M., Pelletier, B. and Eissen, J.P., 1995. The North Fiji Basin: Geology, Structure  
614 and geodynamic evolution. In: Taylor, B. (Ed.), *Back-arc basin: tectonics and*  
615 *magmatism*, New York, pp. 139-175.

616 Auzende, J.M., Pelletier, B. and Lafoy, Y., 1994. Twin active spreading ridges in the North  
617 Fiji Basin (Southwest Pacific). *Geology*, 22(1): 63-66.

618 Baker, P.E. and Condliffe, E., 1996. Compositional variations in submarine volcanic ashes  
619 from the vicinity of the Vanuatu island arc: A response to ridge-arc collision? *Journal*  
620 *of Volcanology and Geothermal Research*, 72(3-4): 225-238.

621 Barrat, J.A., Keller, F., Amosse, J., Taylor, R.N., Nesbitt, R.W. and Hirata, T., 1996.  
622 Determination of rare earth elements in sixteen silicate reference samples by ICP-MS  
623 after Tm addition and ion exchange separation. *Geostandards Newsletter*, 20(1): 133-  
624 139.

625 Barsdell, M., 1988. Petrology and petrogenesis of clinopyroxene-rich tholeiitic lavas,  
626 Merelava volcano, Vanuatu. *Journal of Petrology*, 29(5): 927-964.

627 Barsdell, M. and Berry, R.F., 1990. Origin and evolution of primitive island-arc ankaramites  
628 from Western Epi, Vanuatu. *Journal of Petrology*, 31(3): 747-777.

629 Barsdell, M., Smith, I.E.M. and Spoerli, K.B., 1982. The origin of reversed geochemical  
630 zoning in the northern New Hebrides volcanic arc. *Contributions to Mineralogy and*  
631 *Petrology*, 81(2): 148-155.

632 Bindeman, I.N., Davis, A.M. and Drake, M.J., 1998. Ion microprobe study of plagioclase-  
633 basalt partition experiments at natural concentration levels of trace elements.  
634 *Geochimica et Cosmochimica Acta*, 62(7): 1175-1193.

635 Brenan, J.M., Shaw, H.F., Ryerson, F.J. and Phinney, D.L., 1995. Mineral-aqueous fluid  
636 partitioning of trace-elements at 900 degrees-C and 2.0 gpa - Constraints on the trace-  
637 element chemistry of mantle and deep-crustal fluids. *Geochimica et Cosmochimica*  
638 *Acta*, 59(16): 3331-3350.

639 Briquieu, L. and Lancelot, J.R., 1983. Sr isotopes and K, Rb, Sr balance in sediments and  
640 igneous rocks from the subducted plate of the Vanuatu (New Hebrides) active margin.  
641 *Geochimica et Cosmochimica Acta*, 47: 191-200.

642 Briquieu, L., Laporte, C., Crawford, A.J., Hasenaka, T., Baker, P.E. and Coltorti, M., 1994.  
643 Temporal magmatic evolution of the Aoba Basin, central New Hebrides island arc; Pb,  
644 Sr, and Nd isotopic evidence for the coexistence of two mantle components beneath  
645 the arc. In: Greene, H.G., Collot, J.-Y., Stokking, L.B. et al. (Eds.), Proceedings of the  
646 Ocean Drilling Program, Scientific Results, 134, College Station, TX, United States  
647 (USA), pp. 393-401.

648 Bryan, W.B., Finger, L.W. and Chayes, F., 1969. Estimating proportions in petrographic  
649 mixing equations by least-squares approximation. *Science*, 163(3870): 926-927.

650 Calmant, S., Pelletier, B., Lebellegard, P., Bevis, M., Taylor, F.W. and Phillips, D.A., 2003.  
651 New insights on the tectonics along the New Hebrides subduction zone based on GPS  
652 results. *Journal of Geophysical Research-Solid Earth*, 108(B6): 2319–2340.

653 Châtelain, J.L., Molnar, P., Prévot, R. and Isacks, B., 1992. Detachment of part of the  
654 downgoing slab and uplift of the New Hebrides (Vanuatu) islands. *Geophysical  
655 Research Letters*, 19(14): 1507-1510.

656 Chauvel, C., Bureau, S. and Poggi, C., 2011. Comprehensive Chemical and Isotopic Analyses  
657 of Basalt and Sediment Reference Materials. *Geostandards and Geoanalytical  
658 Research*, 35(1): 125-143.

659 Collot, J.Y., Daniel, J. and Burne, R.V., 1985. Recent tectonics associated with the subduction  
660 collision of the d'Entrecasteaux zone in the central New-Hebrides. *Tectonophysics*,  
661 112(1-4): 325-356.

662 Crawford, A.J., Briquieu, L., Laporte, C. and Hasenaka, T., 1995. Coexistence of Indian and  
663 Pacific oceanic upper mantle reservoirs beneath the central New Hebrides island arc.  
664 In: Taylor, B. and Natland, J. (Eds.), *Active margins and marginal basins of the  
665 western Pacific. Geophysical Monograph. American Geophysical Union, Washington,  
666 DC, United States (USA)*, pp. 199–217.

667 DePaolo, D.J., 1981. Trace-element and isotopic effects of combined wallrock assimilation  
668 and fractional crystallization. *Earth and Planetary Science Letters*, 53(2): 189-202.

669 Dupuy, C., Dostal, J., Marcelot, G., Bougault, H., Joron, J.L. and Treuil, M., 1982.  
670 Geochemistry of basalts from central and southern New Hebrides arc - Implication for  
671 their source rock composition. *Earth and Planetary Science Letters*, 60(2): 207-225.

672 Eggins, S.M., 1993. Origin and differentiation of picritic arc magmas, Ambae (Aoba),  
673 Vanuatu. *Contributions to Mineralogy and Petrology*, 114(1): 79-100.

674 Eiler, J.M., McInnes, B., Valley, J.W., Graham, C.M. and Stolper, E.M., 1998. Oxygen  
675 isotope evidence for slab-derived fluids in the sub-arc mantle. *Nature*, 393(6687): 777-  
676 781.

677 Elliott, T., Plank, T., Zindler, A., White, W. and Bourdon, B., 1997. Element transport from  
678 slab to volcanic front at the Mariana arc. *Journal of Geophysical Research-Solid Earth*,  
679 102(B7): 14991-15019.

680 Galer, S.J.G. and Abouchami, W., 1998. Practical application of lead triple spiking for  
681 correction of instrumental mass discrimination, Goldschmidt conference, Toulouse,  
682 pp. 491-492.

683 Graham, D.W., Blichert-Toft, J., Russo, C.J., Ruben, K.H. and Albarède, F., 2006. Cryptic  
684 striations in the upper mantle revealed by hafnium isotopes in southeast Indian ridge  
685 basalts. *Nature*, 440(7081): 199-202.

686 Green, T.H., Blundy, J.D., Adam, J. and Yaxley, G.M., 2000. SIMS determination of trace  
687 element partition coefficients between garnet, clinopyroxene and hydrous basaltic  
688 liquids at 2-7.5 GPa and 1080-1200 degrees C. *Lithos*, 53(3-4): 165-187.

689 Greene, H.G., Collot, J.-Y., Fisher, M.A. and Crawford, A.J., 1994. Neogene tectonic  
690 evolution of the New Hebrides island arc; a review incorporating ODP drilling results.  
691 In: Greene, H.G., Collot, J.-Y., Stokking, L.B. and al., e. (Eds.), *Proceedings of the*

692 Ocean Drilling Program, Scientific Results, 134, College Station, TX, United States  
693 (USA), pp. 19-46.

694 Greene, H.G., MacFarlane, A., Johnson, D.P. and Crawford, A.J., 1988. Structure and  
695 tectonics of the central New Hebrides arc. In: Greene, H.G. and Wong, F.L. (Eds.),  
696 Geology and offshore resources of Pacific Island Arcs - Vanuatu region. Earth Science  
697 Series. Circum-Pacific Council for Energy and Mineral Resources, Houston, TX,  
698 United States (USA), pp. 377-412.

699 Grove, T.L., Chatterjee, N., Parman, S.W. and Medard, E., 2006. The influence of H<sub>2</sub>O on  
700 mantle wedge melting. *Earth and Planetary Science Letters*, 249(1-2): 74-89.

701 Handley, H.K., Turner, S.P., Smith, I.E.M., Stewart, R.B. and Cronin, S.J., 2008. Rapid  
702 timescales of differentiation and evidence for crustal contamination at intra-oceanic  
703 arcs: Geochemical and U-Th-Ra-Sr-Nd isotopic constraints from Lopevi Volcano,  
704 Vanuatu, SW Pacific. *Earth and Planetary Science Letters*, 273(1-2): 184-194.

705 Hart, S.R., 1984. A large-scale isotope anomaly in the Southern-Hemisphere mantle. *Nature*,  
706 309(5971): 753-757.

707 Hauri, E.H., Wagner, T.P. and Grove, T.L., 1994. Experimental and natural partitioning of  
708 Th, U, Pb and other trace-elements between garnet, clinopyroxene and basaltic melts.  
709 *Chemical Geology*, 117(1-4): 149-166.

710 Hawkesworth, C.J., Turner, S.P., McDermott, F., Peate, D.W. and vanCalsteren, P., 1997. U-  
711 Th isotopes in arc magmas: Implications for element transfer from the subducted crust.  
712 *Science*, 276(5312): 551-555.

713 Hermann, J. and Spandler, C.J., 2008. Sediment melts at sub-arc depths: An experimental  
714 study. *Journal of Petrology*, 49(4): 717-740.

715 Heyworth, Z., Knesel, K.M., Turner, S.P. and Arculus, R.J., 2011. Pb-isotopic evidence for  
716 rapid trench-parallel mantle flow beneath Vanuatu. *Journal of the Geological Society*,  
717 168(1): 265-271.

718 Hildreth, W. and Moorbath, S., 1988. Crustal contributions to arc magmatism in the Andes of  
719 Central Chile. *Contributions to Mineralogy and Petrology*, 98(4): 455-489.

720 Hofmann, A.W. and White, W.M., 1982. Mantle plume from ancient oceanic-crust. *Earth and*  
721 *Planetary Science Letters*, 57(2): 421-436.

722 Huchon, P., Gracia, E., Ruellan, E., Joshima, M. and Auzende, J.M., 1994. Kinematics of  
723 active spreading in the central North Fiji Basin (Southwest Pacific). *Marine Geology*,  
724 116(1-2): 69-87.

725 Jochum, K.P. and Brueckner, S.M., 2008. Reference Materials in Geoanalytical and  
726 Environmental Research - Review for 2006 and 2007. *Geostandards and Geoanalytical*  
727 *Research*, 32(4): 405-452.

728 Johnson, M.C. and Plank, T., 1999. Dehydration and melting experiments constrain the fate of  
729 subducted sediments. *Geochemistry Geophysics Geosystems*, 1.  
730 <http://dx.doi.org/10.1029/1999GC000014>

731 Kempton, P.D., Pearce, J.A., Barry, T.L., Fitton, J.G., Langmuir, C. and Christie, D.M., 2002.  
732 Sr-Nd-Pb-Hf isotope results from ODP Leg 187: Evidence for mantle dynamics of the  
733 Australian-Antarctic Discordance and origin of the Indian MORB source.  
734 *Geochemistry Geophysics Geosystems*, 3. <http://dx.doi.org/10.1029/2002GC000320>

735 Kessel, R., Schmidt, M.W., Ulmer, P. and Pettke, T., 2005. Trace element signature of  
736 subduction-zone fluids, melts and supercritical liquids at 120-180 km depth. *Nature*,  
737 437(7059): 724-727.

- 738 Langmuir, C.H., Bender, J.F., Bence, A.E., Hanson, G.N. and Taylor, S.R., 1977.  
739 Petrogenesis of basalts from Famous area - Mid-Atlantic Ridge. *Earth and Planetary*  
740 *Science Letters*, 36(1): 133-156.
- 741 Laporte, C., Briquieu, L., Cluzel, D. and Eissen, J.P., 1998. Isotopic gradient along the New  
742 Hebrides arc (Vanuatu, SW Pacific). Collision of the d'Entrecasteaux Zone and  
743 heterogeneity of mantle sources. *Comptes Rendus de l'Académie des Sciences Série*  
744 *IIA*, 326(2): 101-106.
- 745 MacFarlane, A., Carney, J.N., Crawford, A.J. and Greene, H.G., 1988. Vanuatu - A review of  
746 the onshore geology. In: Greene, H.G., Wong, F.L. (Ed.), *Geology and offshore*  
747 *resources of Pacific Island Arcs - Vanuatu region*. Earth Science Series. Circum-  
748 Pacific Council for Energy and Mineral Resources, Houston, TX, United States  
749 (USA), pp. 24-68.
- 750 Manhès, G., Allègre, C.J. and Provost, A., 1984. U-Th-Pb systematics of the eucrite Juvinas -  
751 Precise age-determination and evidence for exotic lead. *Geochimica et Cosmochimica*  
752 *Acta*, 48(11): 2247-2264.
- 753 Mann, P. and Taira, A., 2004. Global tectonic significance of the Solomon Islands and  
754 Ontong Java Plateau convergent zone. *Tectonophysics*, 389(3-4): 137-190.
- 755 McCulloch, M.T. and Gamble, J.A., 1991. Geochemical and geodynamical constraints on  
756 subduction zone magmatism. *Earth and Planetary Science Letters*, 102(3-4): 358-374.
- 757 McDonough, W.F. and Sun, S.S., 1995. The composition of the Earth. *Chemical Geology*,  
758 120(3-4): 223-253.
- 759 McKenzie, D. and O'Nions, R.K., 1991. Partial melt distributions from inversion of Rare-  
760 Earth Element concentrations. *Journal of Petrology*, 33(6): 1453-1453.
- 761 Meffre, S. and Crawford, A.J., 2001. Collision tectonics in the New Hebrides arc (Vanuatu).  
762 *Island Arc*, 10(1): 33-50.



763 Métrich, N., Allard, P., Aiuppa, A., Bani, P., Bertagnini, A., Shinohara, H., Parello, F., Di  
764 Muro, A., Garaebiti, E., Belhadj, O. and Massare, D., 2011. Magma and Volatile  
765 Supply to Post-collapse Volcanism and Block Resurgence in Siwi Caldera (Tanna  
766 Island, Vanuatu Arc). *Journal of Petrology*, 52(6): 1077-1105.

767 Meyzen, C.M., Blichert-Toft, J., Ludden, J.N., Humler, E., Mevel, C. and Albarède, F., 2007.  
768 Isotopic portrayal of the Earth's upper mantle flow field. *Nature*, 447(7148): 1069-  
769 1074.

770 Monzier, M., Danyushevsky, L.V., Crawford, A.J., Bellon, H. and Cotten, J., 1993. High-Mg  
771 andesites from the southern termination of the New-Hebrides island-arc (SW Pacific).  
772 *Journal of Volcanology and Geothermal Research*, 57(3-4): 193-217.

773 Monzier, M., Robin, C., Eissen, J.P. and Cotten, J., 1997. Geochemistry vs. seismo-tectonics  
774 along the volcanic New Hebrides Central Chain (Southwest Pacific). *Journal of*  
775 *Volcanology and Geothermal Research*, 78(1-2): 1-29.

776 Pascal, G., Isacks, B.L., Baranzangi, M. and Dubois, J., 1978. Precise relocalisations of  
777 earthquakes and seismotectonics of the New Hebrides island arc. *Journal of*  
778 *Geophysical Research*, 83: 4957-4973.

779 Peacock, S.M., 1990. Fluid processes in subduction zones. *Science*, 248(4953): 329-337.

780 Pearce, J.A., Kempton, P.D. and Gill, J.B., 2007. Hf-Nd evidence for the origin and  
781 distribution of mantle domains in the SW Pacific. *Earth and Planetary Science Letters*,  
782 260(1-2): p 98-114.

783 Peate, D.W., Baker, J.A., Jakobsson, S.P., Waight, T.E., Kent, A.J.R., Grassineau, N.V. and  
784 Skovgaard, A.C., 2009. Historic magmatism on the Reykjanes Peninsula, Iceland: a  
785 snap-shot of melt generation at a ridge segment. *Contributions to Mineralogy and*  
786 *Petrology*, 157(3): 359-382.

787 Peate, D.W., Pearce, J.A., Hawkesworth, C.J., Colley, H., Edwards, C.M.H. and Hirose, K.,  
788 1997. Geochemical variations in Vanuatu arc lavas: the role of subducted material and  
789 a variable mantle wedge composition. *Journal of Petrology*, 38(10): 1331-1358.

790 Peccerillo, A. and Taylor, S.R., 1976. Geochemistry of Eocene calc-alkaline volcanic-rocks  
791 from Kastamonu area, Northern Turkey. *Contributions to Mineralogy and Petrology*,  
792 58(1): 63-81.

793 Pelletier, B., Calmant, S. and Pillet, R., 1998. Current tectonics of the Tonga New Hebrides  
794 region. *Earth and Planetary Science Letters*, 164(1-2): 263-276.

795 Picard, C., Monzier, M., Eissen, J.-P. and Robin, C., 1995. Concomitant evolution of tectonic  
796 environment and magma geochemistry, Ambrym volcano (Vanuatu, New Hebrides  
797 arc). In: Smellie, J.L. (Ed.), *Volcanism associated with extension at consuming plate*  
798 *margin*. Geological Society of America, Special Publication, pp. 135-154.

799 Plank, T., 2005. Constraints from thorium/lanthanum on sediment recycling at subduction  
800 zones and the evolution of the continents. *Journal of Petrology*, 46(5): 921-944.

801 Price, R.C. and Kroenke, L.W., 1991. Tectonics and magma genesis in the northern North Fiji  
802 Basin. *Marine Geology*, 98(2-4): 241-258.

803 Prouteau, G., Scaillet, B., Pichavant, M. and Maury, R., 2001. Evidence for mantle  
804 metasomatism by hydrous silicic melts derived from subducted oceanic crust. *Nature*,  
805 410(6825): 197-200.

806 Raos, A.M. and Crawford, A.J., 2004. Basalts from the Efate Island Group, central section of  
807 the Vanuatu arc, SW Pacific: geochemistry and petrogenesis. *Journal of Volcanology*  
808 *and Geothermal Research*, 134(1-2): 35-56.

809 Richard, P., Shimizu, N. and Allègre, C.J., 1976. Nd<sup>143</sup>/Nd<sup>146</sup> A natural tracer - Application  
810 to oceanic basalt. *Earth and Planetary Science Letters*, 31(2): 269-278.

811 Shaw, D.M., 1970. Trace element fractionation during anatexis. *Geochimica et*  
812 *Cosmochimica Acta*, 34(2): 237-243.

813 Shimizu, N. and Kushiro, I., 1975. Partitioning of rare-earth elements between garnet and  
814 liquid at high-pressures - Preliminary experiments. *Geophysical Research Letters*,  
815 2(10): 413-416.

816 Sorbadere, F., Schiano, P., Métrich, N. and Garaebiti, E., 2011. Insights into the origin of  
817 primitive silica-undersaturated arc magmas of Aoba volcano (Vanuatu arc).  
818 *Contributions to Mineralogy and Petrology*, 162(5): 995-1009.

819 Stalder, R., Foley, S.F., Brey, G.P. and Horn, I., 1998. Mineral aqueous fluid partitioning of  
820 trace elements at 900-1200 degrees C and 3.0-5.7 GPa: New experimental data for  
821 garnet, clinopyroxene, and rutile, and implications for mantle metasomatism.  
822 *Geochimica et Cosmochimica Acta*, 62(10): 1781-1801.

823 Sun, S.S. and McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts:  
824 Implications for mantle composition and processes, *Chemical and isotopic systematics*  
825 *of oceanic basalts*. Geological Society, London, Special Publications., pp. 313-345.

826 Tatsumi, Y., 1986. Formation of the volcanic front in subduction zones. *Geophysical*  
827 *Research Letters*, 13(8): 717-720.

828 Taylor, F.W., Baevis, M.G., Schutz, B.E., Kuang, D., Recy, J., Calmant, S., Charley, D.,  
829 Regnier, M., Perin, B., Jackson, M. and Reichenfeld, C., 1995. Geodetic  
830 measurements of convergence at the New-Hebrides-island arc indicate arc  
831 fragmentation caused by an impinging aseismic ridge. *Geology*, 23(11): 1011-1014.

832 Turner, S.P., Peate, D.W., Hawkesworth, C.J., Eggins, S.M. and Crawford, A.J., 1999. Two  
833 mantle domains and the time scales of fluid transfer beneath the Vanuatu arc.  
834 *Geology*, 27(11): 963-966.

835 Warden, A.J., 1967. The 1963–65 eruption of Lopevi Volcano (New Hebrides). *Bulletin of*  
836 *volcanology*, 30: 277-306.

837 White, W.M., Albarède, F. and Telouk, P., 2000. High-precision analysis of Pb isotope ratios  
838 by multi-collector ICP-MS. *Chemical Geology*, 167(3-4): 257-270.

839 Williams, C.E. and Curtis, R., 1964. The eruption of Lopevi, New Hebrides, July 1960.  
840 *Bulletin of volcanology*, 27: 423-433.

841 Woodhead, J.D., 1989. Geochemistry of the mariana arc (Western Pacific) - Source  
842 composition and processes. *Chemical Geology*, 76(1-2): 1-24.

843 Yang, Y.H., Zhang, H.F., Chu, Z.Y., Xie, L.W. and Wu, F.Y., 2010. Combined chemical  
844 separation of Lu, Hf, Rb, Sr, Sm and Nd from a single rock digest and precise and  
845 accurate isotope determinations of Lu-Hf, Rb-Sr and Sm-Nd isotope systems using  
846 Multi-Collector ICP-MS and TIMS. *Int. J. Mass Spectrom.*, 290(2-3): 120-126.

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Table 1: Isotope ratios, major and trace element content for the Lopevi lavas

Rock type Age Latitude Longitude	Post-1960 lavas												Pre-1960 lavas							
	LO01	LO02	LO03	LO04	LO05	LO06	LO07	LO17	LO25	LO30	LO31	LO35	LO08	LO09	LO10 <sup>b</sup>	LO11 <sup>b</sup>	LO12 <sup>b</sup>	LO13	LO14 <sup>b</sup>	
	lava flow 2001	lava flow 1963	lava flow 2000	lava islet 1960 ?	lava flow 2003	bomb post-2003	scoria post-2003	lava flow 2004-2005	lava flow 2000	bomb ?	lava flow 2000	block 1968 ?	lava flow	lava flow	lava flow	pebble	pebble	pebble	pebble	pebble
	S 16° 30' 56.7" E 168° 18' 51.0"	S 16° 30' 51.3" E 168° 18' 50.8"	S 16° 31' 01.3" E 168° 18' 53.3"	S 16° 30' 38.0" E 168° 18' 46.7"	S 16° 29' 54.4" E 168° 18' 55.1"	S 16° 29' 57.9" E 168° 19' 11.6"	S 16° 29' 57.9" E 168° 19' 11.6"	S 16° 31' 53.7" E 168° 19' 55.3"	S 16° 30' 42.0" E 168° 19' 45.8"	S 16° 30' 30.6" E 168° 20' 23.2"	S 16° 30' 44.3" E 168° 19' 16.4"	S 16° 31' 05.8" E 168° 21' 00.6"	S 16° 31' 28.2" E 168° 19' 32.2"	S 16° 31' 29.2" E 168° 19' 39.7"	S 16° 31' 43.7" E 168° 19' 28.9"	S 16° 31' 43.7" E 168° 19' 28.9"	S 16° 31' 43.7" E 168° 19' 28.9"	S 16° 31' 43.7" E 168° 19' 28.9"	S 16° 31' 43.7" E 168° 19' 28.9"	
<b>wt %</b>																				
SiO <sub>2</sub>	52.01	50.71	49.57	49.56	50.60	50.68	50.65	51.15	51.03	51.95	52.45	53.62	50.25	50.56	50.73	52.10	51.86	61.37	54.26	
TiO <sub>2</sub>	0.79	0.73	0.69	0.70	0.73	0.72	0.72	0.75	0.76	0.76	0.82	0.84	0.77	0.69	0.69	0.82	0.78	0.75	0.87	
Al <sub>2</sub> O <sub>3</sub>	16.79	19.32	16.33	16.25	19.46	19.60	19.66	19.15	19.58	17.26	18.71	17.04	17.11	17.85	17.89	20.10	18.67	16.05	17.45	
Fe <sub>2</sub> O <sub>3</sub> (t)	9.51	9.56	10.48	10.62	9.54	9.49	9.41	9.52	9.46	9.97	9.44	9.87	11.07	9.74	9.66	9.35	9.49	7.53	9.91	
MnO	0.16	0.16	0.18	0.17	0.16	0.16	0.15	0.16	0.16	0.17	0.16	0.17	0.19	0.17	0.17	0.15	0.16	0.14	0.17	
MgO	4.38	4.67	7.68	7.77	4.66	4.56	4.49	4.58	4.41	5.79	4.34	4.90	6.16	6.38	6.29	3.24	4.51	2.46	3.93	
CaO	10.54	11.46	12.13	11.95	11.46	11.45	11.53	11.12	10.48	10.18	9.37	9.37	11.21	11.64	11.56	10.52	10.24	5.72	8.89	
Na <sub>2</sub> O	2.74	2.54	2.10	2.13	2.54	2.49	2.49	2.61	2.58	2.64	2.81	2.96	2.46	2.30	2.33	2.92	3.41	3.91	3.33	
K <sub>2</sub> O	0.89	0.70	0.69	0.69	0.70	0.70	0.75	0.80	0.74	0.80	0.92	1.02	0.64	0.55	0.55	0.66	0.71	1.82	1.00	
P <sub>2</sub> O <sub>5</sub>	0.18	0.15	0.15	0.15	0.15	0.15	0.15	0.17	0.16	0.17	0.19	0.21	0.15	0.12	0.13	0.15	0.16	0.24	0.20	
LOI	-0.42	-0.43	-0.49	-0.48	-0.48	-0.52	-0.39	-0.48	0.01	-0.39	-0.39	-0.35	-0.50	-0.43	-0.43	-0.29	-0.28	-0.32	0.26	
Total	100.73	100.94	101.05	100.92	100.97	100.7	100.59	100.95	100.07	100.69	100.54	100.68	100.72	100.57	100.84	100.51	101.04	100.68	99.49	
<b>ppm</b>																				
Sc	29	29	35	36	28	30	29	30	28	36	27	30	35	34	33	28	32	20	27	
V	256	265	277	274	269	262	266	277	274	269	267	259	279	246	257	272	271	149	265	
Cr	28	26	190	188	28	31	31	34	17	63	27	45	44	64	59	2	22	4	18	
Co	27	29	40	40	29	29	29	29	26	31	23	29	38	33	33	24	30	19	28	
Ni	17	17	56	61	19	19	19	20	17	27	16	20	29	36	34	8	16	6	13	
Cu	128	122	115	115	121	135	115	125	114	99	106	119	119	120	107	75	97	55	105	
Ga	18	19	16	17	17	19	18	18	18	15	18	19	18	16	15	19	19	17	18	
Rb	15.7	12.4	12.4	12.4	12.1	12.2	12.0	14.3	12.6	14.1	15.4	16.6	10.8	9.5	9.1	10.8	12.2	32.7	18.0	
Sr	340	366	359	360	365	368	365	363	374	311	331	304	304	266	255	280	280	228	263	
Y	23.6	19.9	17.4	17.2	19.7	19.2	19.2	19.2	21.9	23.6	25.1	20.0	21.0	19.3	20.0	24.3	25.6	37.3	31.1	
Zr	74	56	47	49	56	57	55	65	56	68	76	89	55	49	52	68	76	159	102	
Nb	1.81	1.38	1.11	1.18	1.38	1.38	1.35	1.55	1.69	1.85	1.69	1.85	1.29	1.30	1.30	1.28	1.33	3.68	3.68	
Cs	0.40	0.33	0.36	0.37	0.32	0.32	0.32	0.38	0.34	0.38	0.42	0.45	0.33	0.27	0.29	0.31	0.21	0.25	0.54	
Ba	164	140	135	138	141	139	138	155	141	159	165	178	126	102	103	114	133	251	169	
La	6.99	5.51	4.98	5.21	5.50	5.52	5.39	6.38	5.56	6.34	7.07	7.80	4.70	4.57	4.48	5.15	6.05	11.84	8.07	
Ce	16.0	12.9	11.7	12.2	12.9	12.8	12.4	14.6	12.8	14.9	16.2	18.4	11.3	10.9	10.6	12.6	14.2	27.8	18.9	
Pr	2.34	1.90	1.77	1.84	1.89	1.90	1.83	2.11	1.91	2.14	2.37	2.63	1.75	1.57	1.57	1.87	2.07	3.94	2.79	
Nd	10.9	9.1	8.7	8.9	9.0	9.0	8.8	10.0	9.1	10.2	11.2	12.4	8.6	7.7	7.7	9.0	10.1	17.8	13.0	
Sm	3.04	2.55	2.42	2.46	2.53	2.53	2.49	2.77	2.58	2.83	3.09	3.36	2.56	2.26	2.29	2.73	2.88	4.70	3.63	
Eu	0.99	0.88	0.83	0.85	0.87	0.88	0.86	0.93	0.87	0.94	1.00	1.06	0.90	0.81	0.79	0.94	0.97	1.23	1.10	
Gd	3.52	2.97	2.79	2.84	2.96	2.95	2.87	3.20	2.91	3.34	3.54	3.82	3.09	2.74	2.78	3.43	3.56	5.20	4.27	
Tb	0.58	0.50	0.46	0.46	0.49	0.49	0.48	0.53	0.49	0.56	0.60	0.63	0.52	0.47	0.49	0.58	0.61	0.88	0.74	
Dy	3.89	3.31	2.95	3.06	3.28	3.28	3.25	3.54	3.23	3.74	3.99	4.24	3.52	3.22	3.17	3.86	4.05	5.96	4.80	
Ho	0.83	0.70	0.63	0.65	0.70	0.70	0.69	0.75	0.70	0.79	0.84	0.91	0.75	0.69	0.70	0.85	0.89	1.28	1.06	
Er	2.50	2.10	1.86	1.89	2.09	2.10	2.06	2.25	2.08	2.25	2.54	2.71	2.21	2.07	2.08	2.35	2.62	3.90	3.17	
Yb	2.43	2.03	1.78	1.82	2.01	2.01	1.98	2.17	2.03	2.31	2.49	2.62	2.15	2.00	2.04	2.49	2.56	3.95	3.17	
Lu	0.36	0.31	0.27	0.27	0.30	0.30	0.30	0.33	0.31	0.35	0.37	0.40	0.32	0.30	0.30	0.36	0.38	0.60	0.47	
Hf	2.03	1.59	1.35	1.40	1.59	1.57	1.56	1.79	1.61	1.87	2.12	2.42	1.56	1.41	1.41	2.06	4.19	4.19	3.20	
Ta	0.113	0.085	0.071	0.074	0.087	0.087	0.085	0.098	0.090	0.108	0.120	0.141	0.084	0.081	0.081	1.48	2.68	5.23	3.20	
Pb	3.16	2.60	2.62	2.54	2.58	2.62	2.76	2.96	2.79	1.98	1.46	3.91	2.30	1.88	1.77	1.48	2.68	5.23	3.20	
Th	0.91	0.72	0.62	0.64	0.71	0.71	0.71	0.83	0.77	0.82	0.95	1.02	0.54	0.58	0.59	0.61	0.78	1.92	1.08	
U	0.38	0.29	0.26	0.26	0.29	0.29	0.29	0.34	0.32	0.35	0.39	0.45	0.24	0.22	0.23	0.27	0.33	0.88	0.49	
<b>Isotopes</b>																				
<sup>87</sup> Sr/ <sup>86</sup> Sr	0.703970 ± 11 *	0.703996 ± 8 *	0.704035 ± 9 *	0.704085 ± 8	0.703969 ± 9 *			0.704011 ± 10 *				0.704012 ± 8	0.703961 ± 8 *					0.703937 ± 8		
<sup>143</sup> Nd/ <sup>144</sup> Nd	0.51298 ± 6	0.512968 ± 6	0.512975 ± 6	0.512971 ± 6	0.512968 ± 6			0.512961 ± 10				0.512986 ± 8	0.512972 ± 8					0.512994 ± 8		
εNd	6.67	6.44	6.57	6.50	6.44			6.30				6.79	6.52					6.94		
<sup>206</sup> Pb/ <sup>204</sup> Pb	18.448 ± 1	18.444 ± 1	18.512 ± 1	18.508 ± 1	18.447 ± 1			18.453 ± 1				18.471 ± 1	18.475 ± 1					18.514 ± 1		
<sup>207</sup> Pb/ <sup>204</sup> Pb	15.538 ± 1	15.543 ± 1	15.549 ± 1	15.547 ± 1	15.542 ± 1			15.541 ± 1				15.543 ± 1	15.543 ± 1					15.542 ± 1		
<sup>208</sup> Pb/ <sup>204</sup> Pb	38.379 ± 3	38.396 ± 2	38.425 ± 3	38.422 ± 3	38.397 ± 2			38.392 ± 2				38.394 ± 2	38.402 ± 3					38.383 ± 2		
<sup>176</sup> Hf/ <sup>177</sup> Hf	0.283183 ± 3	0.283179 ± 4	0.283174 ± 4	0.28317 ± 3	0.283157 ± 10			0.283184 ± 4				0.283172 ± 3	0.283181 ± 4					0.283177 ± 3		
εHf	14.54	14.40	14.23	14.06	13.60			14.58				14.14	14.46					14.32		

Table 1: continued

Rock type	Pre-1960 lavas															Standard				Duplicate		
	LO15	LO16	LO18	LO19 <sup>1</sup>	LO20	LO21 <sup>1</sup>	LO22	LO23 <sup>1</sup>	LO24 <sup>1</sup>	LO26 <sup>1</sup>	LO27 <sup>1</sup>	LO28	LO29 <sup>1</sup>	LO33 <sup>1</sup>	LO34 <sup>1</sup>	LO36	mean RGM1 (n=36)	BCR2 <sup>1</sup> (n=1)	mean JB-2 (n=3)	sd	LO04 <sup>1</sup>	sd
Age																						
Latitude	S 16° 31' 58.8"	S 16° 31' 58.8"	S 16° 31' 17.3"	S 16° 31' 17.3"	S 16° 32' 04.2"	S 16° 32' 04.3"	S 16° 32' 03.4"	S 16° 32' 01.6"	S 16° 31' 56.8"	S 16° 30' 25.2"	S 16° 30' 31.3"	S 16° 30' 32.5"	S 16° 31' 30.6"	S 16° 31' 17.3"	S 16° 31' 17.3"	S 16° 30' 30.6"						
Longitude	E 168° 20' 05.1"	E 168° 20' 05.1"	E 168° 19' 01.3"	E 168° 19' 01.3"	E 168° 20' 50.2"	E 168° 20' 40.7"	E 168° 20' 27.3"	E 168° 20' 23.9"	E 168° 20' 09.9"	E 168° 20' 26.7"	E 168° 20' 24.0"	E 168° 20' 27.9"	E 168° 20' 26.9"	E 168° 19' 01.3"	E 168° 19' 01.3"	E 168° 20' 23.2"						
wt %																						
SiO <sub>2</sub>	49.93	56.13	61.35	52.08	50.64	52.45	52.73	51.23	52.16	52.45	55.31	50.64	52.35	52.43	52.44	54.06	73.43					
TiO <sub>2</sub>	0.70	0.79	0.75	0.78	0.58	0.79	0.81	0.81	0.78	0.80	0.66	0.79	0.81	0.80	0.79	0.84	0.27					
Al <sub>2</sub> O <sub>3</sub>	16.65	17.61	16.06	18.79	16.97	19.75	19.45	17.37	20.36	19.00	16.96	17.30	18.70	18.73	20.09	18.48	13.76					
Fe <sub>2</sub> O <sub>3</sub> (t)	10.33	8.85	7.51	9.47	9.31	9.23	9.24	10.39	9.11	9.36	8.67	10.90	9.69	9.48	9.08	9.28	1.90					
MnO	0.18	0.16	0.14	0.16	0.16	0.16	0.16	0.18	0.15	0.16	0.16	0.19	0.17	0.16	0.16	0.16	0.04					
MgO	7.50	3.49	2.49	4.74	7.68	3.70	3.72	5.72	3.43	4.51	5.15	6.04	4.32	4.63	3.55	3.89	0.29					
CaO	11.86	8.27	5.72	10.40	12.08	10.26	10.16	10.99	10.43	10.09	9.02	10.85	10.16	10.09	10.19	9.03	1.19					
Na <sub>2</sub> O	2.18	3.32	3.92	2.77	2.05	2.79	2.81	2.49	2.79	2.85	2.49	2.80	2.81	2.89	3.14	4.10	4.10					
K <sub>2</sub> O	0.53	1.18	1.82	0.66	0.43	0.72	0.77	0.67	0.64	0.69	1.05	0.66	0.83	0.71	0.66	0.92	4.35					
P <sub>2</sub> O <sub>5</sub>	0.13	0.20	0.24	0.15	0.11	0.16	0.16	0.15	0.15	0.16	0.16	0.15	0.18	0.16	0.15	0.19	0.05					
loi	-0.44	-0.24	-0.34	-0.28	-0.25	-0.29	-0.24	-0.40	-0.30	-0.10	-0.28	-0.32	-0.12	-0.17	-0.44	-0.37	0.93					
Total	101.16	100.75	100.8	100.63	100.79	100.63	100.61	100.75	100.8	100.49	99.95	100.38	100.02	100.37	101.07	100.92	100.31					
ppm																						
Sc	34	27	18	30	39	29	28	32	28	28	33	35	29	29	29	27	3.8					
V	271	216	146	267	243	255	262	276	265	269	209	257	267	265	280	261	15					
Cr	144	9	5	32	131	8	9	42	2	25	87	41	14	23	0.2	7	2.7					
Co	41	24	19	30	40	26	26	35	24	27	35	28	28	25	24	24	1.2					
Ni	49	11	7	19	51	10	9	26	8	14	32	30	12	16	8	9	3.2					
Cu	119	91	46	100	92	96	105	101	74	81	92	82	104	61	91	84	15					
Ga	16	18	18	18	15	18	18	17	19	18	16	16	17	17	19	18	16					
Rb	9.5	20.9	32.2	8.4	7.6	12.4	12.9	11.5	11.3	11.8	13.7	10.4	13.5	11.3	10.7	16.3		48.0	6.2	0.18	12.3	0.1
Sr	288	254	225	262	240	299	290	299	298	275	244	307	315	271	289	300		359	180	1	353	5
Y	18.6	29.2	36.9	23.8	15.4	24.4	22.9	23.8	23.6	24.3	27.2	21.6	24.0	24.1	25.8	25.8		40.0	24.0	0.2	18.4	0.6
Zr	48	106	157	68	41	67	66	65	65	68	91	55	74	62	62	83		183	47	0.3	52	2.2
Nb	1.17	2.46	3.65	1.01	1.01	1.74	1.74	1.74	1.74	1.74	1.31	1.31	1.31	1.31	1.31	2.02			0.48	0.01		
Cs	0.31	0.53	0.22	0.18	0.24	0.37	0.35	0.36	0.32	0.35	0.53	0.32	0.49	0.12	0.15	0.39		1.33	0.82	0.005	0.40	0.025
Ba	97	177	251	120	75	123	127	134	116	127	161	126	140	116	147	147		700	218	2	135	2
La	4.37	8.44	11.97	5.65	4.10	5.76	5.85	5.25	5.37	5.84	7.18	4.76	6.16	5.82	5.37	7.06		25.5	2.25	0.03	5.18	0.02
Ce	10.8	19.7	27.3	13.2	10.0	13.5	14.0	12.5	12.7	13.7	16.5	11.5	14.9	13.8	13.0	16.5		53.1	6.5	0.05	12.1	0.1
Pr	1.60	2.80	3.92	1.92	1.48	2.00	2.05	1.88	1.88	2.00	2.41	1.75	2.17	1.99	1.89	2.43		7.04	1.14	0.005	1.82	0.01
Nd	8.0	13.0	17.5	9.3	7.2	9.6	9.9	9.1	9.1	9.8	11.2	8.8	10.3	9.6	9.2	11.6		28.8	6.4	0.06	8.7	0.15
Sm	2.36	3.60	4.63	2.68	2.03	2.73	2.80	2.70	2.62	2.74	3.10	2.61	2.99	2.76	2.65	3.21		6.58	2.28	0.01	2.47	0.01
Eu	0.85	1.08	1.22	0.91	0.73	0.95	0.94	0.92	0.91	0.90	0.86	0.93	1.02	0.88	0.92	1.04		1.88	0.85	0.003	0.85	0.004
Gd	2.82	4.16	5.18	3.32	2.39	3.35	3.34	3.29	3.21	3.48	3.70	3.17	3.55	3.54	3.41	3.75		6.89	3.16	0.01	2.81	0.02
Tb	0.47	0.71	0.88	0.58	0.40	0.58	0.57	0.57	0.56	0.58	0.60	0.54	0.63	0.60	0.60	0.63		1.07	0.57	0.003	0.47	0.006
Dy	3.17	4.72	5.91	3.82	2.69	3.78	3.81	3.73	3.66	4.01	4.10	3.57	4.08	3.70	3.78	4.25		6.36	3.99	0.02	2.99	0.05
Ho	0.67	1.02	1.27	0.83	0.58	0.83	0.82	0.82	0.81	0.84	0.92	0.77	0.87	0.88	0.84	0.91		1.33	0.87	0.007	0.67	0.015
Er	2.01	3.10	3.86	2.44	1.73	2.43	2.47	2.36	2.35	2.47	2.70	2.29	2.53	2.51	2.47	2.74		3.75	2.60	0.02	1.94	0.03
Yb	1.91	3.06	3.92	2.42	1.66	2.37	2.40	2.29	2.33	2.48	2.80	2.19	2.43	2.55	2.45	2.69		3.48	2.54	0.02	1.83	0.005
Lu	0.29	0.46	0.60	0.36	0.25	0.36	0.37	0.34	0.35	0.37	0.42	0.33	0.39	0.38	0.38	0.41		0.49	0.38	0.003	0.27	0.004
Hf	1.39	2.85	4.12	1.24	0.88	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24						
Ta	0.074	0.160	0.241	0.064	0.064	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.132			0.039	0.0004		
Pb	2.29	3.68	4.49	2.00	1.96	2.32	2.62	2.32	2.12	2.24	3.26	2.13	2.53	1.41	2.21	3.07		9.84	5.18	0.04	2.41	0.09
Th	0.51	1.16	1.92	0.73	0.46	0.68	0.74	0.58	0.61	0.82	1.12	0.54	0.85	0.75	0.66	0.92		5.81	0.26	0.005	0.64	0.004
U	0.21	0.53	0.88	0.30	0.19	0.29	0.32	0.25	0.27	0.32	0.51	0.25	0.35	0.32	0.29	0.39		1.65	0.15	0.002	0.27	0.01
Isotopes																						
<sup>87</sup> Sr/ <sup>86</sup> Sr	0.704001 ± 9 *	0.703938 ± 6	0.703917 ± 10 *		0.703955 ± 8		0.703965 ± 8									0.703977 ± 8		0.703686 ± 6				
<sup>143</sup> Nd/ <sup>144</sup> Nd	0.512965 ± 10	0.512999 ± 6	0.512988 ± 6		0.512984 ± 4		0.512982 ± 10									0.512984 ± 10		0.513089 ± 8				
<sup>ε</sup> Nd	6.38	7.04	6.83		6.75		6.71									6.75		8.80				
<sup>206</sup> Pb/ <sup>204</sup> Pb	18.513 ± 1	18.505 ± 0	18.513 ± 1		18.519 ± 1		18.518 ± 1									18.519 ± 1		18.343 ± 1				
<sup>207</sup> Pb/ <sup>204</sup> Pb	15.554 ± 1	15.545 ± 1	15.543 ± 1		15.554 ± 1		15.55 ± 1									15.550 ± 1		15.557 ± 1				
<sup>208</sup> Pb/ <sup>204</sup> Pb	38.439 ± 3	38.395 ± 2	38.381 ± 2		38.435 ± 2		38.425 ± 2									38.423 ± 2		38.265 ± 2				
<sup>176</sup> Hf/ <sup>177</sup> Hf	0.283161 ± 6	0.283179 ± 4	0.283181 ± 9		0.283157 ± 11		0.283175 ± 5									0.283178 ± 5		0.283251 ± 4				
εHf	13.76	14.41	14.47		13.61		14.26									14.34		16.95				

**Table 2**

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Table 2: Bulk D values and end member composition (most basic magmas and contaminant) input in the AFC model

		U	Pb	Ba	Yb	Sr	Hf	<sup>206</sup> Pb/ <sup>204</sup> Pb	<sup>207</sup> Pb/ <sup>204</sup> Pb	<sup>208</sup> Pb/ <sup>204</sup> Pb	<sup>87</sup> Sr/ <sup>86</sup> Sr	<sup>176</sup> Hf/ <sup>177</sup> Hf	r
Most basic magma	<b>Bulk D</b>	0.03	0.13	0.11	0.58	0.52	0.11						
	<b>Pre-1960: LO15</b>	0.212	2.29	97	1.91	288	1.39	18.513	15.554	38.439	0.704001	0.283161	
	<b>Post-1960: LO03</b>	0.260	2.62	135	1.78	359	1.35	18.512	15.549	38.425	0.704035	0.283174	
Contaminant	<b>C<sub>a</sub> and R<sub>a</sub> pre-1960: 1% partial melt</b>	1.189	2.28	58.2	5.32	176	19.0	18.50	15.48	38.07	0.7033	0.28319	0.2
	<b>C<sub>a</sub> and R<sub>a</sub> post-1960: 10% partial melt</b>	0.369	1.41	32.7	4.93	159	10.7	17.90	15.48	38.07	0.7033	0.28319	0.3

Figure 1 Color

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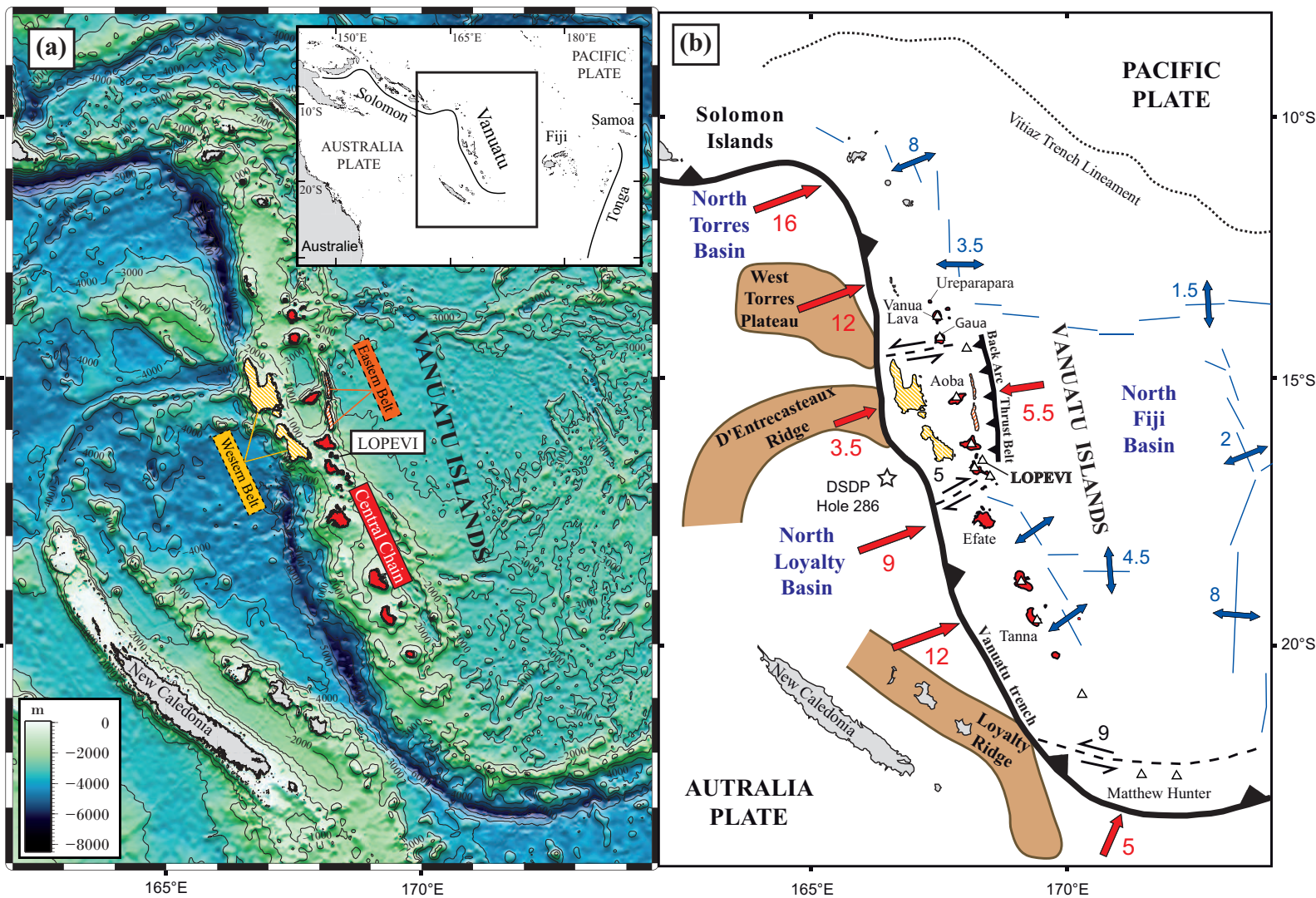


Figure 1



Figure 2 Color

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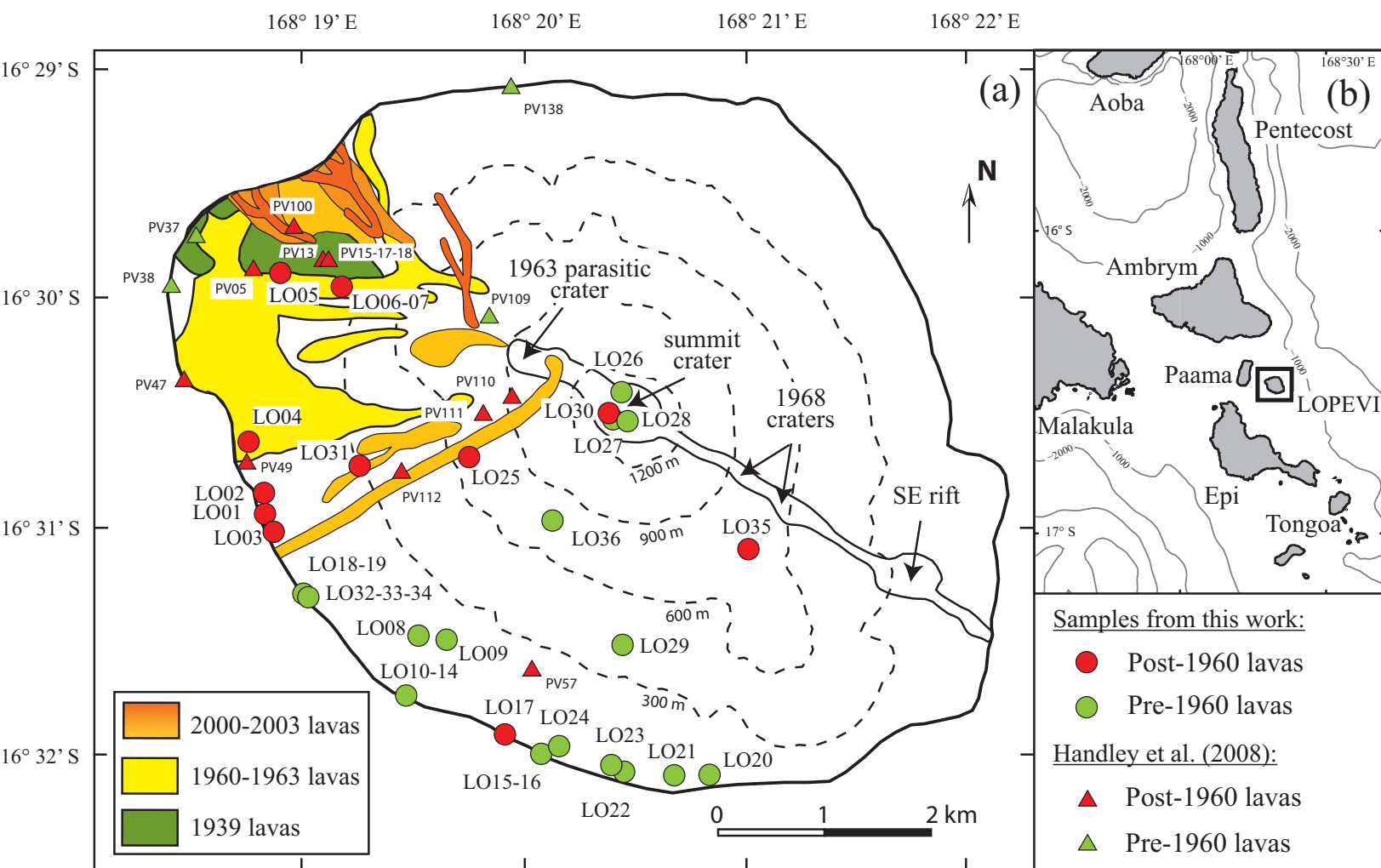


Figure 2

Figure 3 Color

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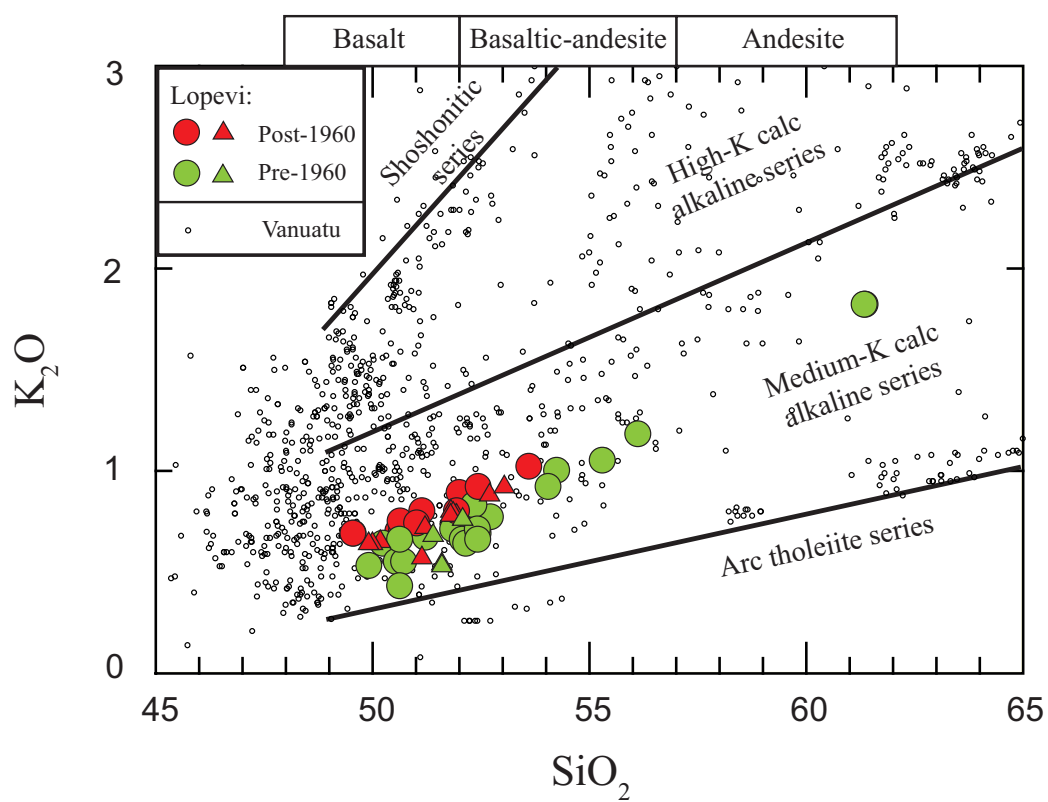


Figure 3

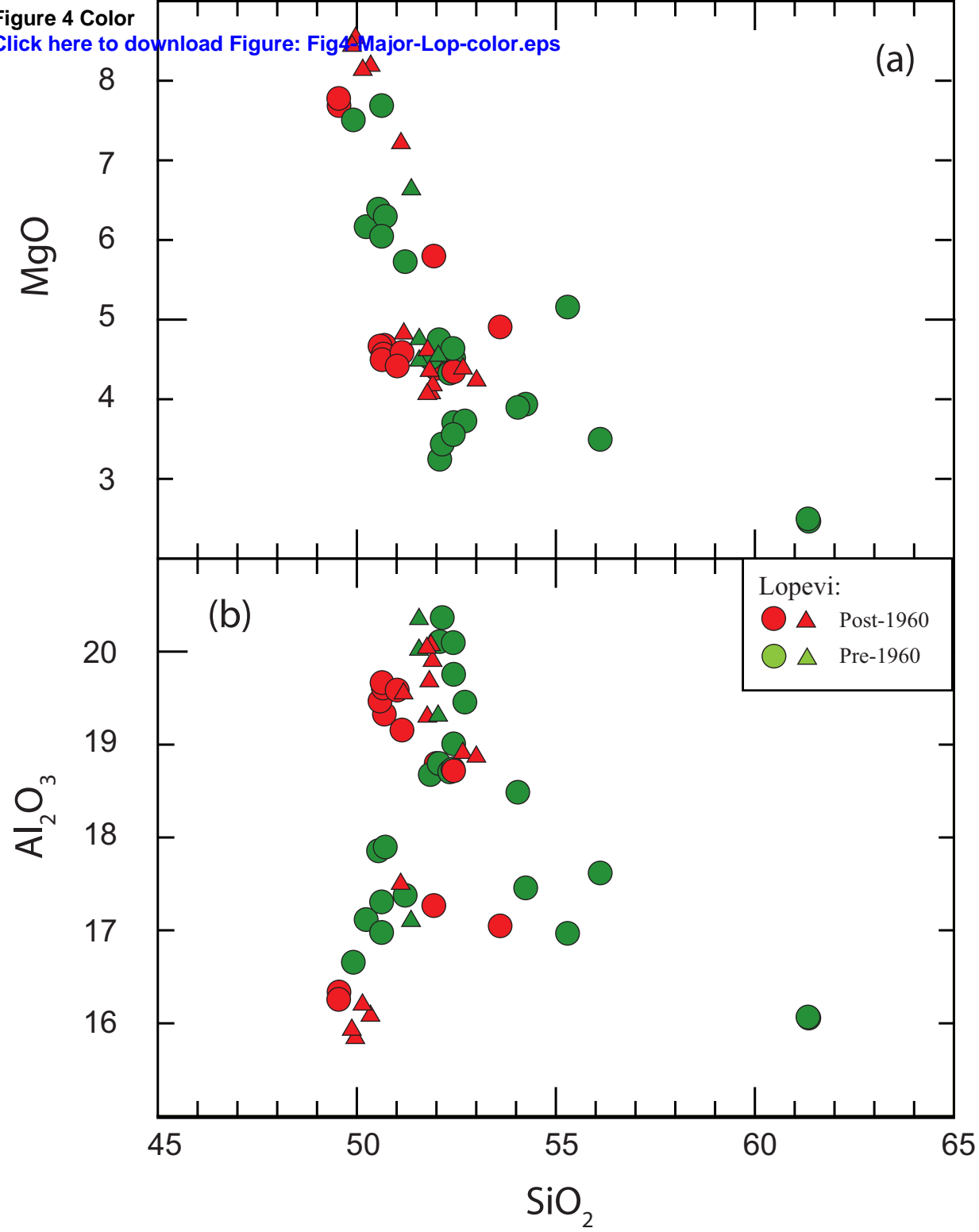
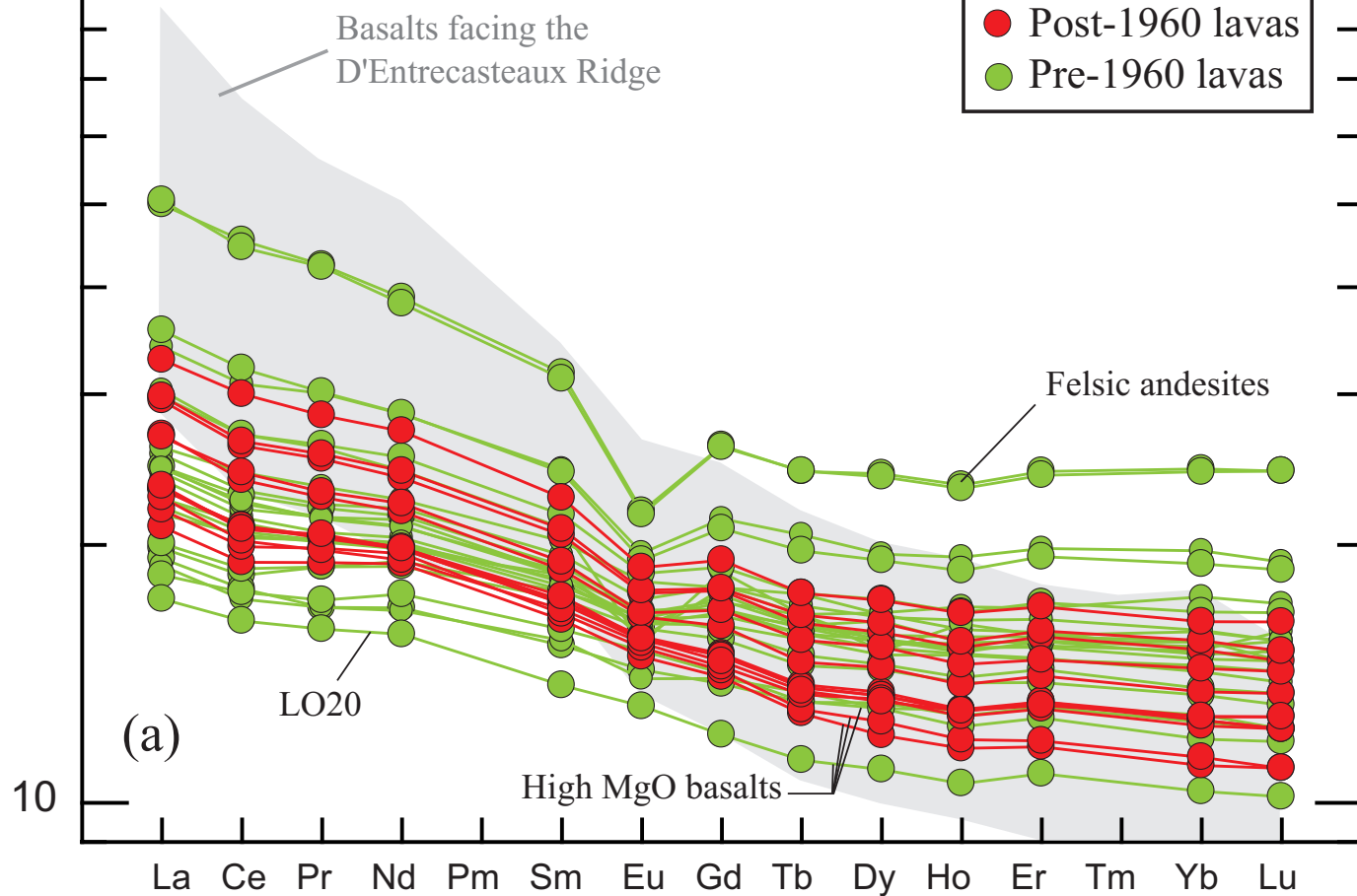


Figure 4

Rock / Chondrite



Rock / N-MORB

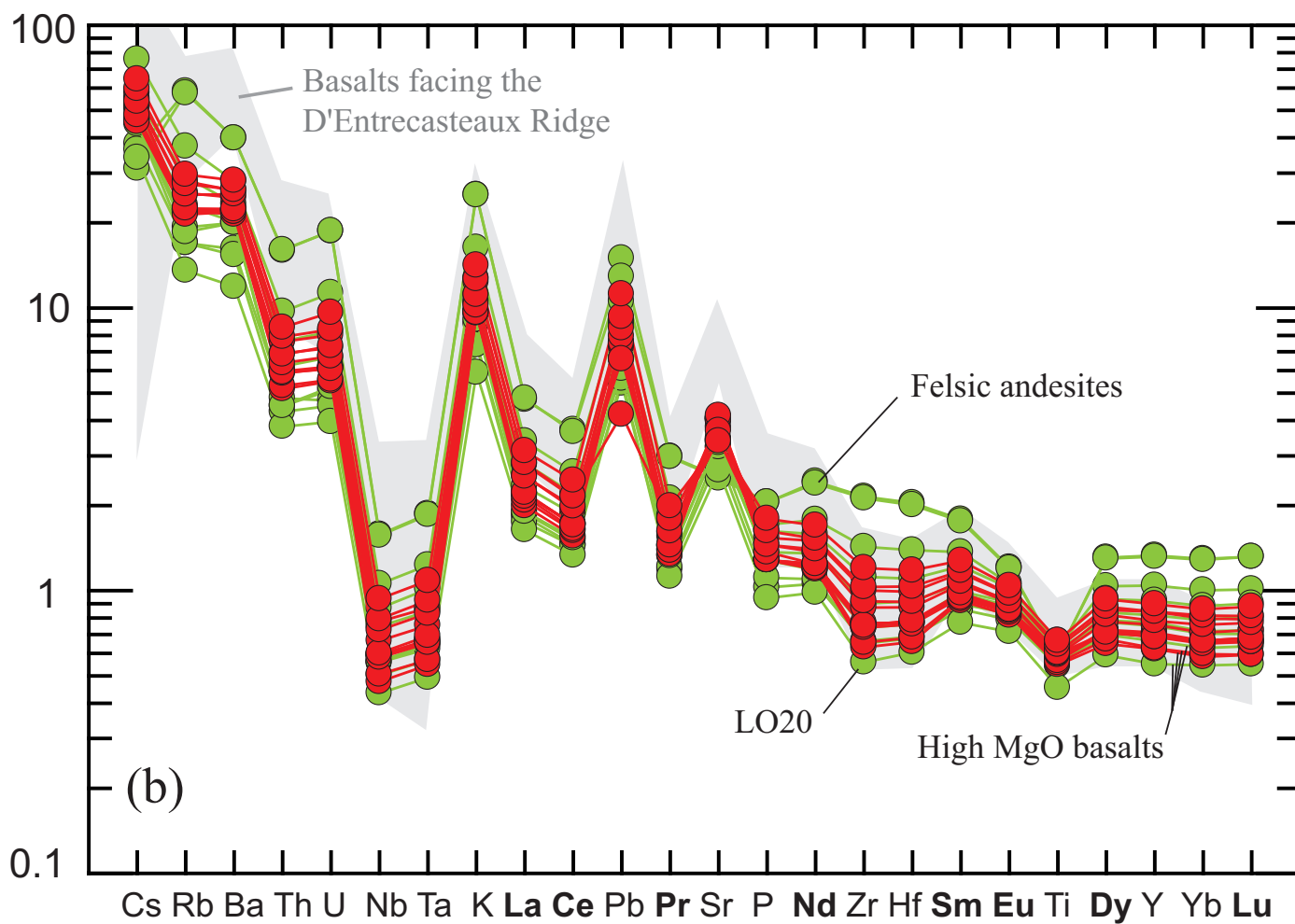


Figure 5

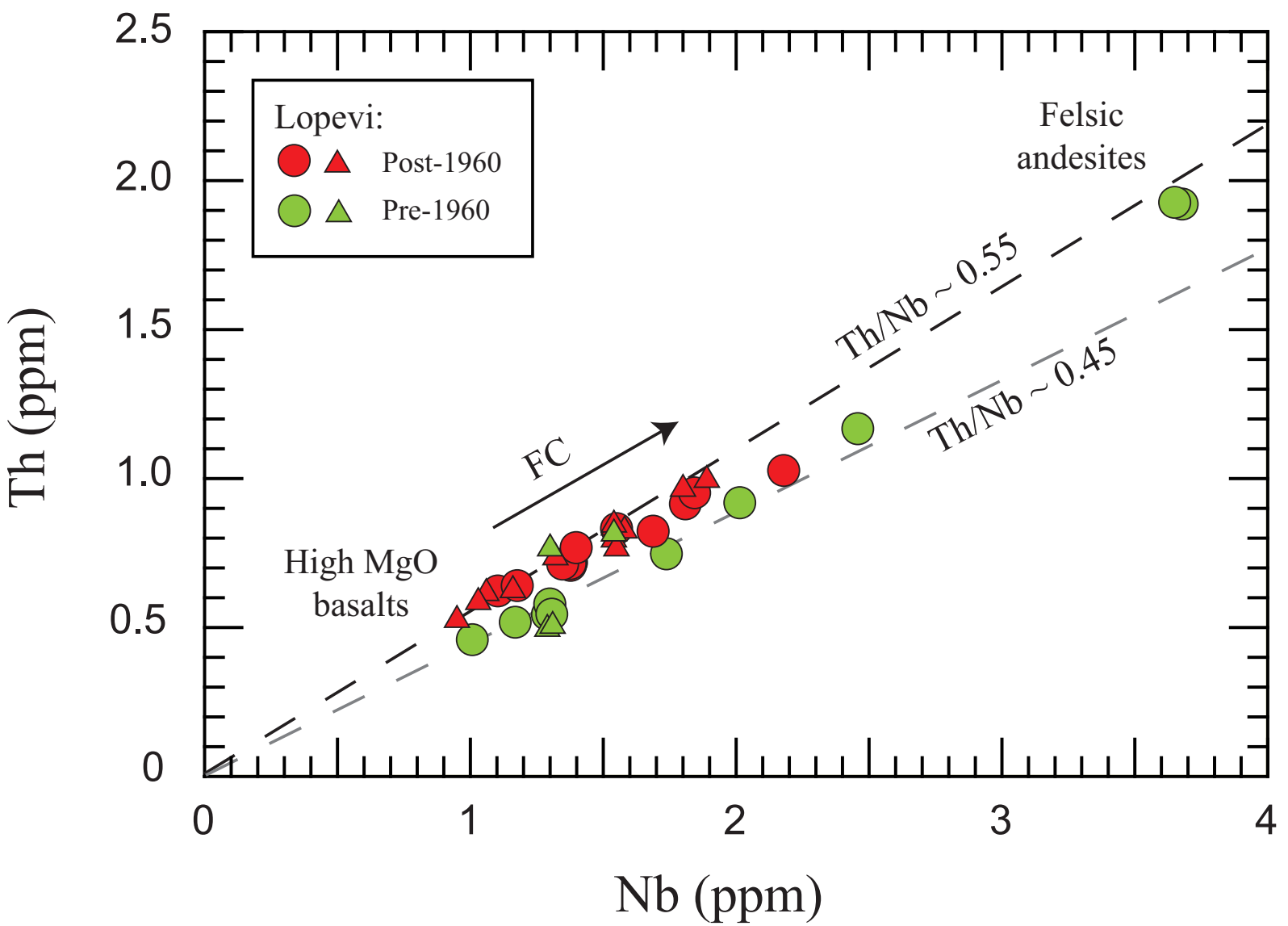


Figure 6

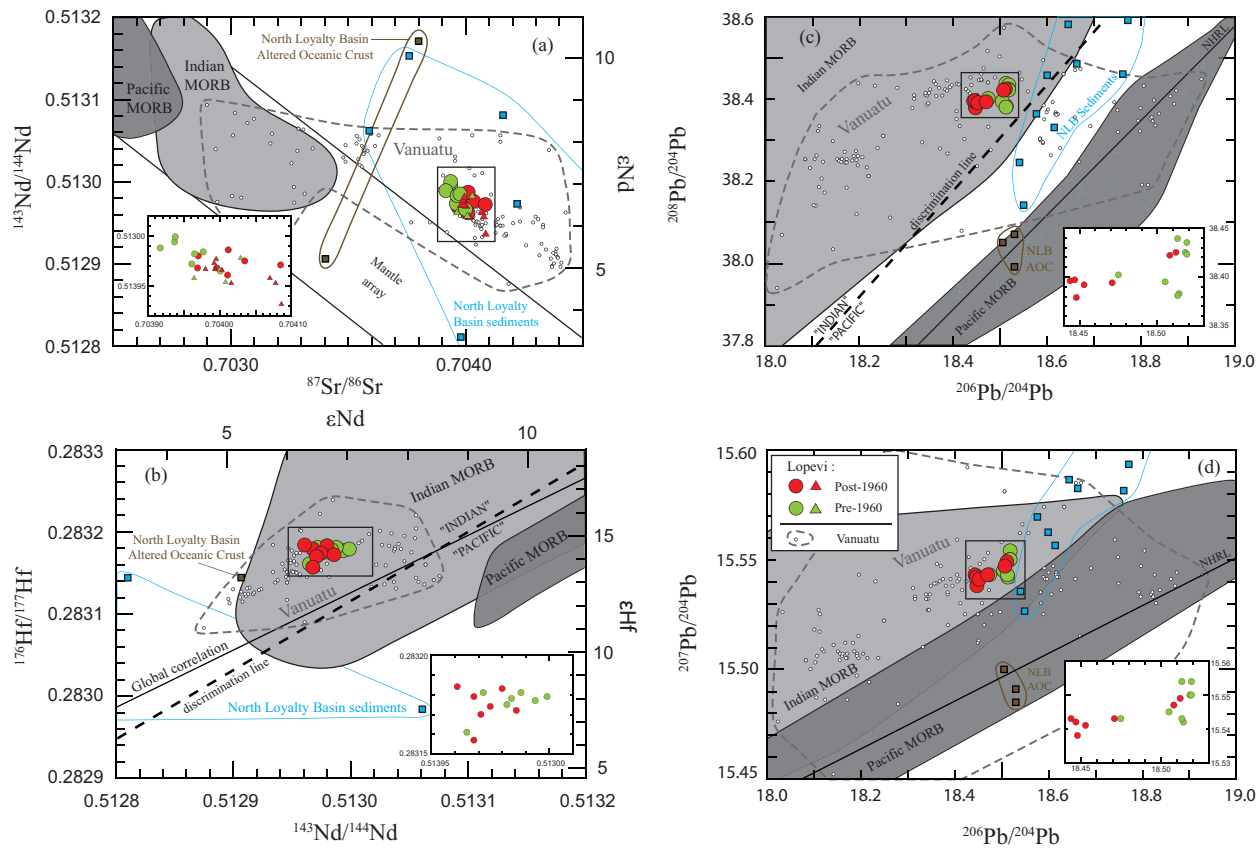


Figure 7

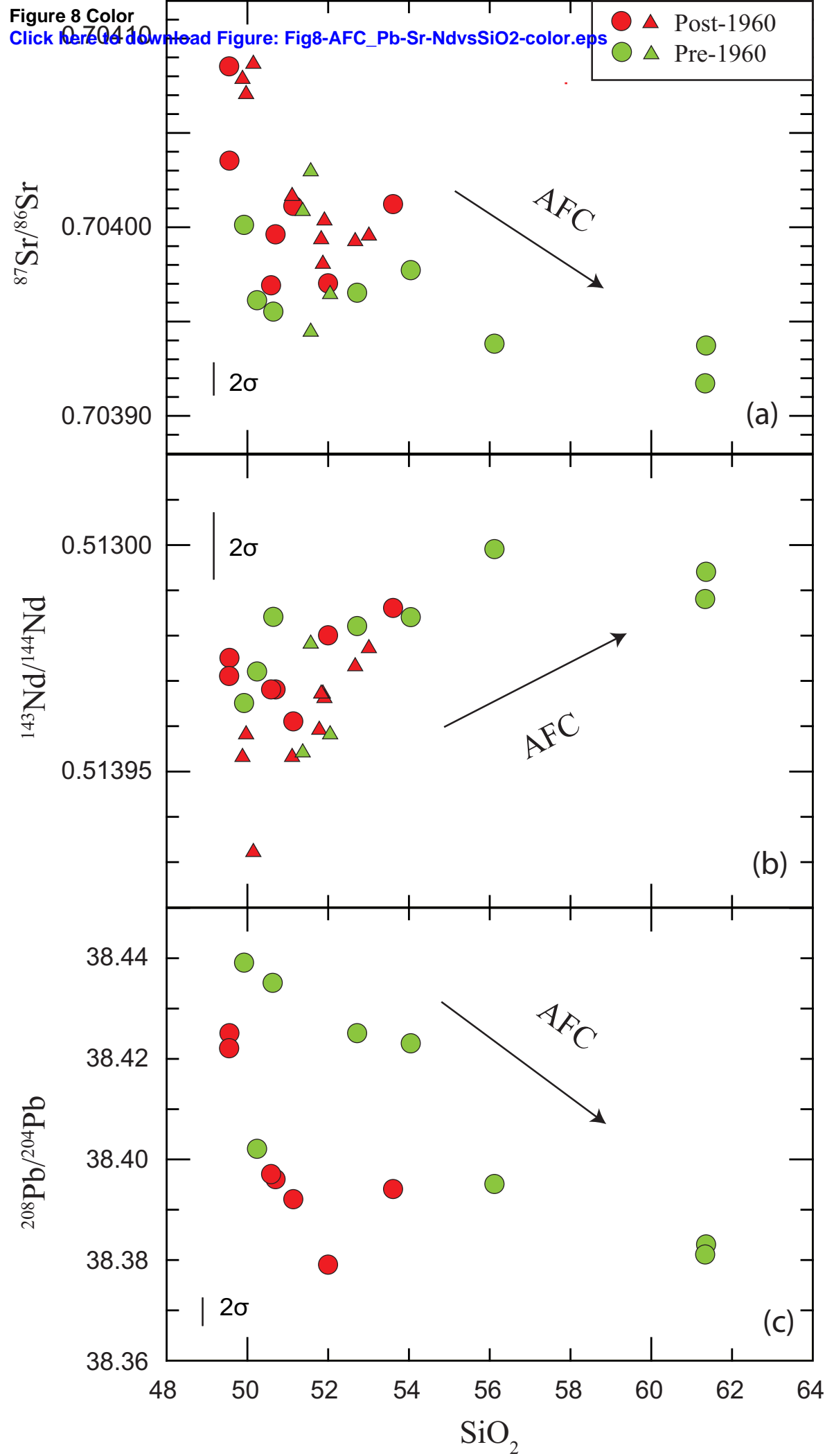


Figure 8

Figure 9 Color

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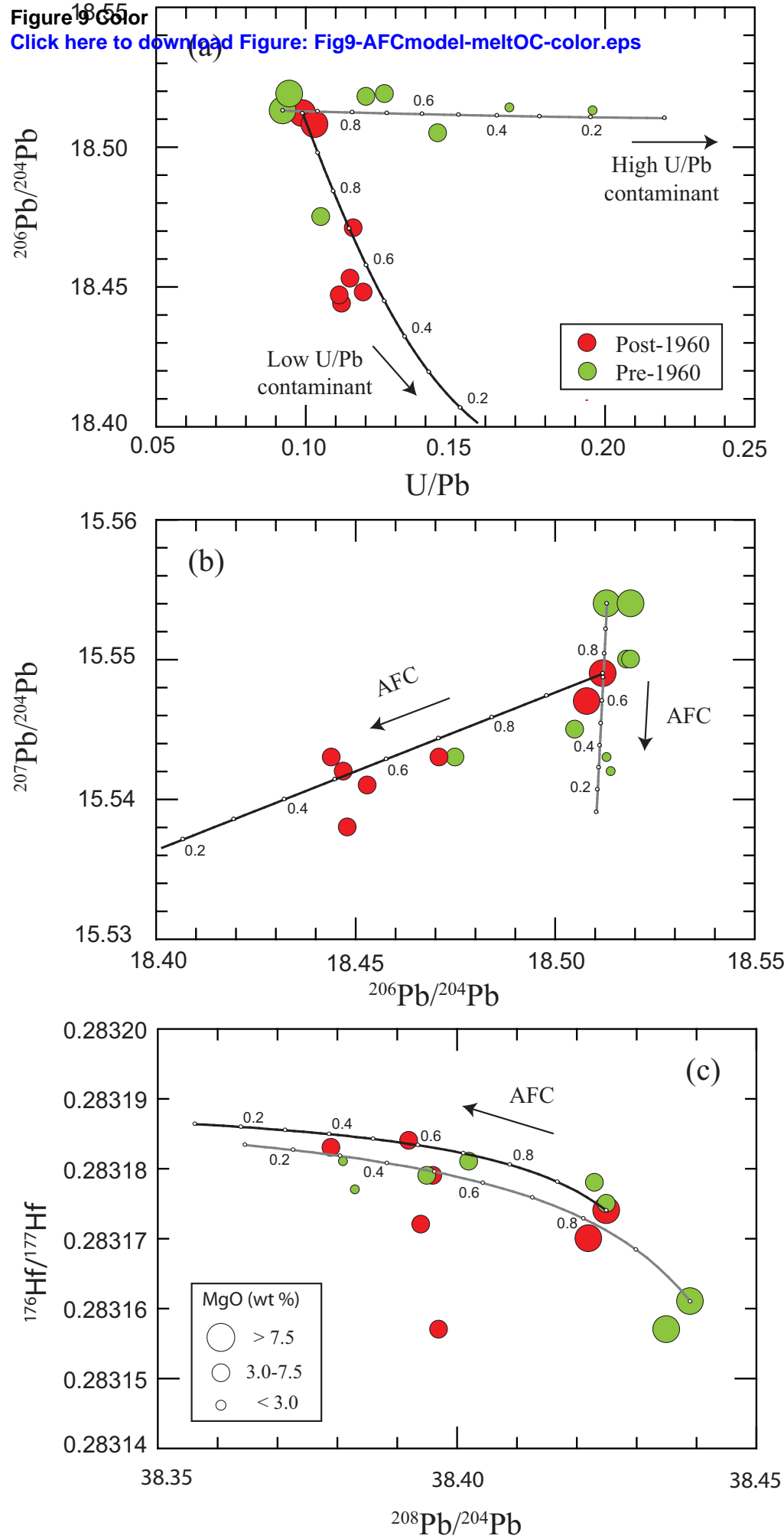


Figure 9



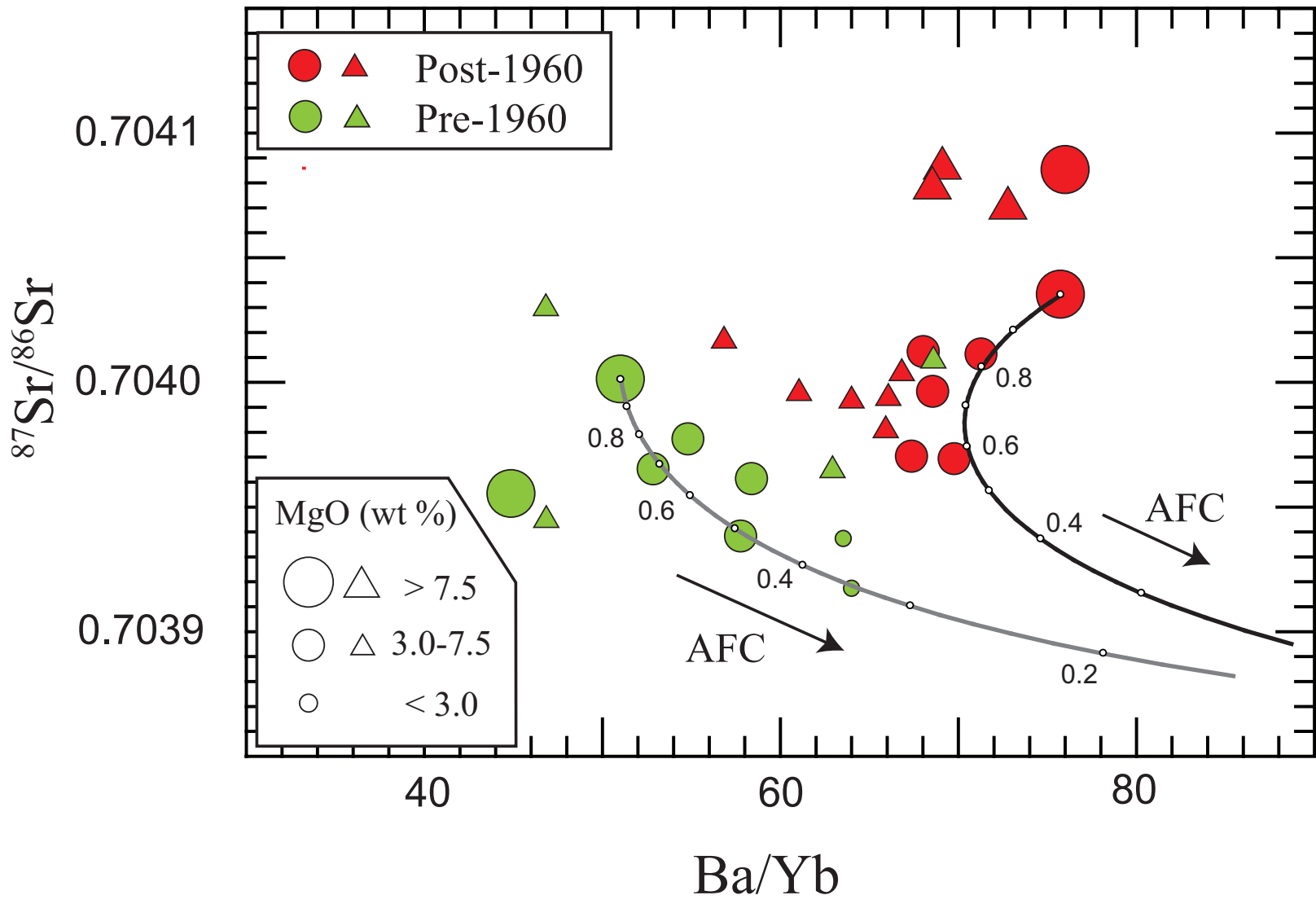


Figure 10

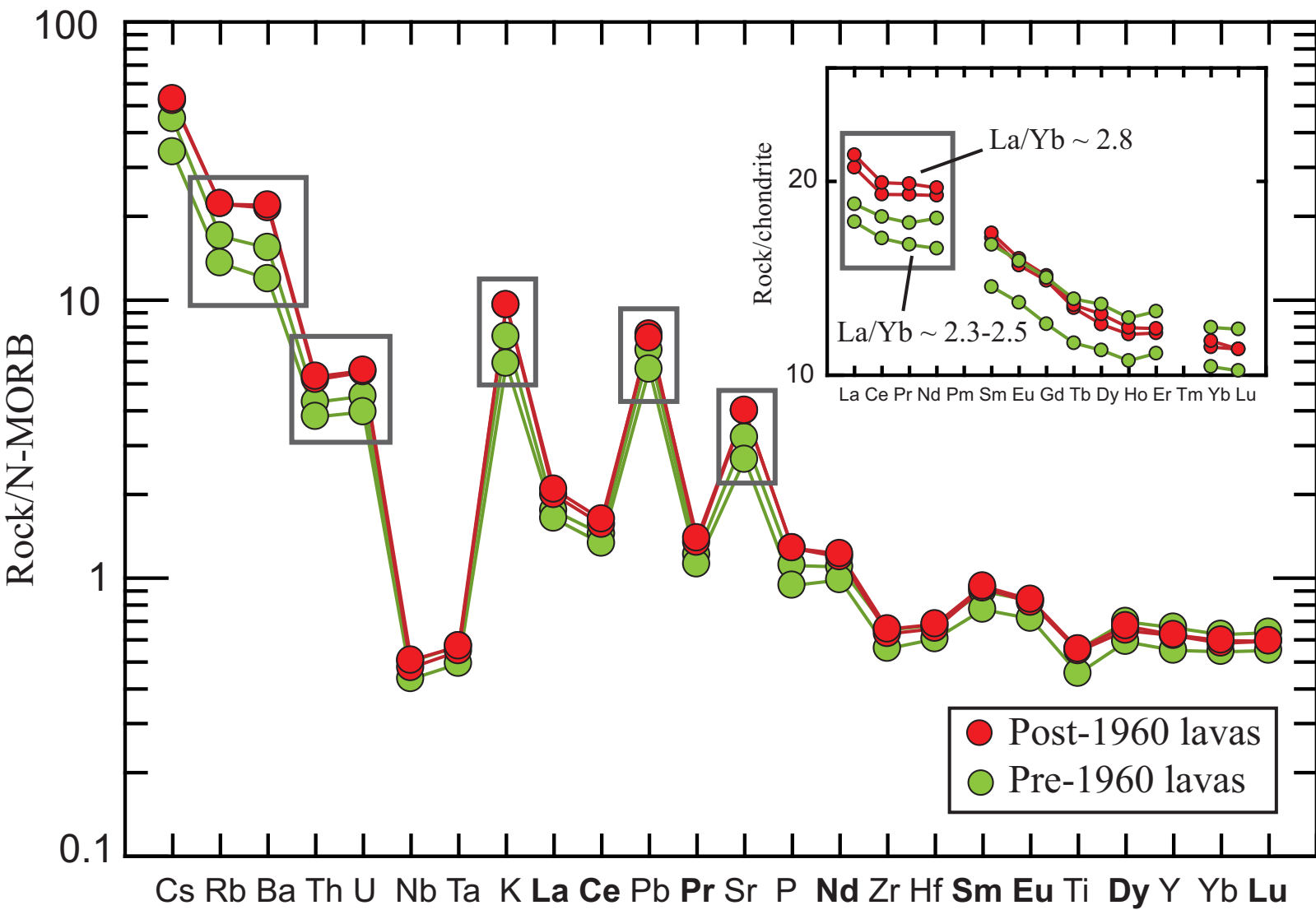


Figure 11