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## ► To cite this version:

Erdal Şen, Erkan Aydar, Pınar Şen, Alain Gourgaud. Insight into a rift volcanism with the petrogenesis of ultramafic enclaves and the host basalts: Kula Volcanic Field, Western Anatolia, Turkey. *Italian Journal of Geosciences*, 2023, 142 (2), pp.291-315. 10.3301/IJG.2023.16 . hal-04148854

**HAL Id: hal-04148854**

**<https://uca.hal.science/hal-04148854v1>**

Submitted on 13 Nov 2023

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Journal:	<i>Italian Journal of Geosciences</i>
Manuscript ID	IJG-2022-1058.R2
Manuscript Type:	Original Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Şen, Erdal; Hacettepe University, Geological Engineering Aydar, Erkan; Hacettepe University, Geological Engineering Şen, Pinar; General Directorate of Mineral Research and Exploration Gourgaud, Alain; Université Blaise-Pascal
Keywords:	Alkaline basalt, ultramafic enclaves, fractional crystallisation, partial melting, uplift

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# Insight into a rift volcanism with the petrogenesis of ultramafic enclaves and the host basalts: Kula Volcanic Field, Western Anatolia, Turkey

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## ABSTRACT

The Quaternary Kula Volcanic Field (KVF), located on an E-W trending Plio-Quaternary horst, consists of at least 80 scoria cones, associated fissural lava flows and maars. Volcanic activity is divided into three main stages as BI (ca. 2-0.9 Ma), BII (ca. 300-50 ka) and BIII (ca. 10-0.7 ka). The volcanic products of BII and BIII contain ultramafic enclaves. They are generally spherical or elliptical varying in size from <1 to <48 cm and some samples bear vesicles and glass. Based on modal mineralogy, the dominant enclave types are hornblendite, Cpx-hornblendite, while Phl-clinopyroxenite, wehrlite, plagioclase-bearing Cpx-hornblendite and Hbl-gabbro are subordinate. They occasionally represent adcumulate and/or mesocumulate textures. The alkaline host rocks are basanite, phonotephrite, trachybasalt, picrobasalt, and foidite in composition.

LILE (Rb, Ba, Sr, and Pb) and HFSE (Nb, Ta) concentrations of host rocks indicate an Enriched Within Plate Mantle source. Additionally, they have high Nb/La (>1.3), Nb/Y (>1.7), and Nb/U (>31) ratios, reflecting that crustal contamination is insignificant. Petrogenetic modelling shows that Kula enclaves and host rocks are probably originating from 3-5% partial melting of garnet and spinel-peridotite mantle source mixtures. Rb/Sr (0.03-0.10) and slightly high Ba/Rb (9.5-23) ratios for host rocks demonstrate the presence of amphibole and phlogopite in their source, while low Rb/Sr (0.01-0.09) and high Ba/Rb (18-115) reveal

1  
2  
3 33 that amphibole is present in the source. Estimated T/P conditions of early crystallizations  
4  
5 34 are between 19.5–9.5 kbar, 63–31 km, and 1260–1130 °C for host rocks and 18.3–11.1  
6  
7 35 kbar, 59–36 km, and 1324–1208 °C for the enclaves, which suggests that the crystallization  
8  
9  
10 36 might have taken place in the lithospheric mantle.

11  
12 37 **KEYWORDS:** Alkaline basalt, ultramafic enclaves, fractional crystallisation, partial melting,  
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14 38 uplift  
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## 1. INTRODUCTION

Anatolia is located in the collision zone between African-Arabian and Eurasian plates. The convergence began in the Late Cretaceous–Eocene and ended with the continental collision in the middle Miocene (Şengör & Yılmaz, 1981; Yılmaz et al., 1987; Ring & Layer, 2003; Okay et al., 2010). This collision led to the Anatolian plate moving westwards via the North Anatolian and East Anatolian faults (Fig. 1a) (Dewey & Şengör, 1979; Şengör, 1979; Şengör & Yılmaz, 1981; Pasquaré et al., 1988; McKenzie, 2020; Şengör & Yazıcı, 2020; Seyitoğlu et al., 2022). The combined effects of the westward Anatolian migration, back-arc extension of Hellenic arc and the retreat of the trench are the main controls on subsequent expansion (Seyitoğlu & Scott, 1991, 1992; Seyitoğlu et al., 2002; Sözbilir, 2002; Westaway et al., 2005; Koçyiğit, 2005; Bozkurt & Mittwede, 2005; Ersoy & Helvacı, 2007; Jolivet et al., 2013; Gessner et al., 2013, 2018; Seyitoğlu et al., 2022). After crustal extension, metamorphic basement rocks of the Menderes Massif exhumed by a combination of west-east strike-slip faulting and successive north-south detachment faults (Bozkurt & Park, 1997; Bozkurt, 2001; Seyitoğlu, 1997; Lips et al., 2001; Gessner et al., 2001; Ring & Layer, 2003; Işık et al., 2004; Sözbilir, 2005; Bozkurt & Rojay, 2005; Ersoy et al., 2011, 2012). Gessner et al. (2013, 2018) divide the exhumation of the Menderes Massif into two stages as a resulting from of asthenospheric flow below western Anatolia. The rapid tectonic denudation was due to differential footwall uplift during the early Miocene, and the formation of the Central Menderes Metamorphic Core Complex (CMCC; ‘inner’ axial zone) by late Miocene to recent detachment fault and normal fault systems, located between northern and southern (Çine) segments of the complex (Fig. 1b). The Menderes Massif includes the NE-SW trending Miocene Gördes, Demirci, Selendi, and Uşak-Güre basins in its northern part (Seyitoğlu & Scott, 1991; Seyitoğlu & Scott, 1994; Helvacı, 1995; Helvacı & Yağmurlu, 1995; Seyitoğlu, 1997; Yılmaz et al., 2000; Bozkurt, 2003; Purvis & Robertson, 2004; Westaway et al., 2004; Erkül et al., 2005; Ersoy & Helvacı, 2007; Ersoy et al., 2010; Karaoğlu et al., 2010; Ersoy et

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2  
3 70 [al., 2011, 2012](#)). These basins were cut by seismically active E–W-trending oblique-normal  
4  
5 71 faults, resulting in the formation of the Simav and Gediz grabens under the late Miocene to  
6  
7 72 recent N-S rift-type extensional tectonics ([Seyitoğlu, 1997](#); [Cohen et al., 1995](#); [Bozkurt &](#)  
8  
9 73 [Sözbilir, 2004](#); [Rojay et al., 2005](#); [Emre & Sözbilir, 2007](#); [Çiftçi & Bozkurt, 2009](#); [Ersoy et al.,](#)  
10  
11 74 [2010, 2011, 2012](#); [Hakyemez et al., 2013](#); [Hetzl et al., 2013](#)) ([Fig 1b](#)).

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13  
14 75 Volcanism in NE-SW trending basins has been associated with lithospheric thinning, and  
15  
16 76 the volcanic products show geochemical variations during Miocene, including high-K calc-  
17  
18 77 alkaline felsic and shoshonitic, ultrapotassic-lamproitic rocks (early Miocene); high-K calc-  
19  
20 78 alkaline intermediate and high-Mg shoshonitic to ultrapotassic rocks (middle Miocene); and  
21  
22 79 K-trachybasaltic rocks (late Miocene) ([Yılmaz, 1989, 1990](#); [Seyitoğlu, 1997](#); [Bunbury et al.,](#)  
23  
24 80 [2001](#); [Erkül et al., 2005](#); [Innocenti et al., 2005](#); [Westaway et al., 2006](#); [Ersoy et al., 2008](#);  
25  
26 81 [Karaoğlu et al., 2010](#); [Çoban et al., 2012](#); [Prelevic et al., 2012](#)). The Kula Volcanism (KVF),  
27  
28 82 located within the Selendi Basin, began with eruptions of plateau lavas ~1.5-2 Ma ago and  
29  
30 83 continued until prehistoric time as monogenetic volcanoes ([Bunbury, 1996](#); [Bunbury et al.,](#)  
31  
32 84 [2001](#); [Innocenti et al., 2005](#); [Westaway et al., 2004, 2006](#)). The KVF is characterized by  
33  
34 85 high-Na alkaline volcanics in the rift-mode extension regime ([Bunbury et al., 2001](#); [Alıcı et](#)  
35  
36 86 [al., 2002](#); [Bozkurt & Sözbilir, 2004](#); [Innocenti et al., 2005](#)).

37  
38  
39 87 The KVF comprises 92 Quaternary monogenic volcanic centres (scoria cones, spatter  
40  
41 88 cones, maars) and covers an area of around 350 km<sup>2</sup>. The volcanic products contain  
42  
43 89 ultramafic and mafic enclaves, which were previously studied by [Hollnes et al. \(2005\)](#),  
44  
45 90 [Hollnes & Bunbury \(2006\)](#) and [Grützner et al. \(2013\)](#). Their previous studies mainly focused  
46  
47 91 on hornblendite and clinopyroxenite samples. In this study, we also examine olivine-rich  
48  
49 92 clinopyroxenite and wehrlite samples to demonstrate the origin of those co-genetic  
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51 93 inclusions in the host basaltic rocks and their petrological importance.  
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## 95 2. CRUSTAL EXTENSION AND UPLIFT

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3 96 It is generally accepted that Western Anatolian crust has experienced extension since the  
4  
5 97 late Miocene to Pliocene (e.g. [Angelier et al., 1981](#)). Geophysical studies indicate that the  
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7  
8 98 crust's thickness in the west, near recent Kula alkaline basaltic volcanic area, is  
9  
10 99 approximately 30 km, increasing to 34-38 km eastwards ([Saunders et al., 1998](#); [Zhu et al.,](#)  
11  
12 100 [2006](#); [Mahatsente et al., 2017](#)). The active faults point out an extending subcrustal  
13  
14 101 lithosphere as a result of mantle uplift in the region ([Saunders et al., 1998](#)). Basin  
15  
16  
17 102 sedimentation characteristics constrain uplift rates to 0.1 mm/year, for a period 2-0.2 Ma,  
18  
19 103 followed by 3.5 mm/year (since 0.2 Ma) ([Bunbury et al., 2001](#)). Alternatively, erosion is  
20  
21 104 estimated to be 0.1 mm/year, with a total amount of uplift ~ 410 m since 3.1 Ma ([Westaway](#)  
22  
23  
24 105 [et al., 2006](#)). In addition, [Bunbury et al. \(2001\)](#) suggest that the presence of the Hbl-dominant  
25  
26 106 mafic-ultramafic enclaves in the BII Kula lavas is a magmatic evidence supporting the “uplift”  
27  
28 107 model. [Doglioni et al. \(2002\)](#) proposed that the last activity of the KVF rapidly erupted in a  
29  
30  
31 108 strongly extensional regime during neotectonic period due to the “horizontal windows”  
32  
33 109 resulting from the tearing of the Aegean and Cyprus slabs ~20 Ma ago, which allowed the  
34  
35 110 asthenospheric inflow into the lithosphere. However, the interaction of the asthenospheric  
36  
37  
38 111 mantle upwelling with the lithosphere is controversial. Two hypotheses have been proposed  
39  
40 112 to explain lithospheric thinning and its relation to adiabatic upwelling of the asthenosphere.  
41  
42 113 The first one is the transformation of the lower parts of the lithosphere into asthenosphere  
43  
44 114 (asthenospherisation), resulting in the reconstruction of the paleo-depth of the Menderes  
45  
46  
47 115 lithospheric root ([Prelevic et al., 2012](#)). The second hypothesis is the delamination of  
48  
49 116 lithospheric mantle by loss of material owing to gravitational collapse ([Seyitoğlu & Scott,](#)  
50  
51 117 [1996](#); [Aldanmaz et al., 2000](#); [Ersoy et al., 2008, 2011](#); [Karaoğlu et al., 2010](#)). Geophysical  
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53  
54 118 studies support a lithospheric thinning in western Anatolia around Menderes Massif. A low-  
55  
56 119 velocity zone (ca. 80 km depth) underlying a thin lithosphere has been found near the KVF  
57  
58 120 ([Salaün et al., 2012](#); [Mahatsente et al., 2017](#)). Most of the western Anatolia has an  
59  
60 121 anomalously thin (50-80 km) and hot lithosphere that is possibly thinned to the crust (ca. 60

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3 122 km, i.e. ~30 km below from the Moho) corresponding to the depth of basaltic magma  
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5 123 generation ([Artemieva & Shulgin, 2019](#)).

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### 9 10 125 **3. GEOLOGICAL BACKGROUND**

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12 126 The bedrocks underlying the KVF comprise Palaeozoic-Triassic metamorphic units (schist,  
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14 127 gneiss, and serpentinite), Cretaceous ophiolite mélange (ultramafic rocks, listvenite), and  
15  
16 128 800 m thick Miocene-Pliocene sedimentary rocks (claystone, siltstone, sandstone,  
17  
18  
19 129 conglomerate and lacustrine limestone) ([Ercan et al., 1978](#)).

20  
21 130 [Ercan et al. \(1983\)](#) proposed three volcanic stages, while [Bunbury \(1996\)](#) and [Bunbury et](#)  
22  
23  
24 131 [al. \(2001\)](#) identified four episodes of the KVF. In this study, we divided the KVF into three  
25  
26 132 volcanic stages: BI, BII, and BIII, based on the stratigraphical, morphological and  
27  
28 133 chronological data ([Fig. 2](#)).

#### 29 30 31 134 32 33 135 **3.1. First Stage (BI):**

34  
35 136 The BI volcanics outcrop in the eastern part of the study area. K-Ar and Ar-Ar radiometric  
36  
37 137 data plot between  $0.99 \pm 0.11 - 1.94 \pm 0.16$  Ma ([Fig. 2: Bunbury et al., 2001; Westaway et](#)  
38  
39  
40 138 [al., 2004, 2006; Maddy et al., 2015](#)). The stage is primarily effusive, and its lavas flow over  
41  
42 139 the Neogene sediments. They form a flat hat in the topographic heights, and the erosion of  
43  
44 140 the concerned sediments, particularly in Gediz River gorge, formed spectacular earth pillars  
45  
46  
47 141 or fairy chimneys. Those lava flows cover an area of about 35 km<sup>2</sup>, and their thickness  
48  
49 142 ranges from 5 to 25 m.

#### 50 51 143 52 53 144 **3.2. Second Stage (BII):**

54  
55 145 This stage comprehends the predominant volcanic activities of the KVF, represented by 49  
56  
57 146 cinder cones and associated lava flows, 3 tuff rings and 1 maar. K-Ar and Ar-Ar radiometric  
58  
59 147 data of the BII basalts have ages ranging from  $50 \pm 9$  to  $300 \pm 3$  ka ([Fig. 2: Bunbury et al.,](#)



1  
2  
3 148 [2001; Westaway et al., 2004, 2006](#)). They outcrop in topographically lowlands compared to  
4  
5 149 BI and are more altered than BI lava flows. Onion-skin alterations are commonly observed  
6  
7  
8 150 at the lava fronts. We encountered evidence of hydromagmatic activities only in this stage.  
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10 151 The base surge deposits surrounding the crater comprise ash and lapilli layers, dune, anti-  
11  
12 152 dune structures and bomb sags ([Fig. 3a](#)). Kızıl Tepe tuff ring (M3) deposits contain ultramafic  
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15 153 enclaves.

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### 19 155 **3.3. Third Stage (BIII):**

20  
21 156 There are 31 cinder cones associated with at least 28 individual lava flows. In the west of  
22  
23  
24 157 the study area, lavas flowed down southwestward about 17 km ([Fig. 2](#)). BIII lava flows are  
25  
26 158 a'a type and distinct with their fresh black-coloured appearance, sharp-edged blocks, and  
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28 159 unvegetated cover. BIII cinder cones can also easily be distinguished from BII cinder cones  
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30  
31 160 due to their lower erosion, steeper slopes, clearly visible craters and lack of soil covers. We  
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33 161 also distinguished 16 small cinder cones (without crater) forming a cluster at the north of  
34  
35 162 Divlit Tepe near Kula, where there is the source area for the BIII lavas reaching the Gediz  
36  
37 163 River ([Fig. 2, 3b](#)). Most of the cinder cones are breached by lava flows, as shown in [Figure](#)  
38  
39  
40 164 [3c](#). Fissures and fractures are occasionally well-expressed by the spatter cones and tumuli.  
41  
42 165 The volcanic products of BIII are the youngest of the KVF eruptions, with radiometric ages  
43  
44 166 spanning between  $0.7 \pm 0.4$  and  $10.6 \pm 1.9$  ka ([Westaway et al., 2004, 2006; Heineke et al.,](#)  
45  
46  
47 167 [2016; Ulusoy et al., 2019](#)). Human footprints are well known on the basaltic base surge  
48  
49 168 deposits near the Lake of Demirköprü Dam, and [Ulusoy et al. \(2019\)](#) have determined an  
50  
51 169 age of  $4.7 \pm 0.5$  ka for these footprints using cosmogenic  $^{36}\text{Cl}$  and combined U-Pb and (U-  
52  
53  
54 170 Th)/He zircon double-dating methods.

## 55 56 171 **4. ENCLAVES**

57  
58 172 The lavas and cinder projections contain mafic and ultramafic enclaves varying in size from  
59  
60 173 <1 to 48 cm. They are absent in the BI lava flows, but they are generally observed within the

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3 174 ejecta of cinder cones, maars (Fig. 3a, d) and rare lava flows of the latest stage (BIII). The  
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5 175 lava flows originating from the breached Bağ Tepe cinder cone are rich in enclaves (Fig. 3e,  
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7  
8 176 f). The most characteristic feature of Kula enclaves is the presence of vesicular glass (Fig.  
9  
10 177 3g). Most of the enclaves are rounded and sub-rounded with a smooth surface. Apart from  
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12 178 these enclaves, foliated metamorphic (mica schist and mica gneiss etc.) and magmatic  
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14  
15 179 xenoliths are also present in the ejecta. In contrast to magmatic enclaves, they have an  
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17 180 angular shapes and irregular surfaces.  
18

## 19 181 20 21 182 **5. ANALYTICAL TECHNIQUES**

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24 183 Electron microprobe analyses of the cores and rims of phenocrysts, microcrysts, microlites  
25  
26 184 and glass were performed by Cameca SX100 instrument at the Blaise-Pascal University,  
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28 185 France. Operating conditions were: 15 kV accelerating voltage, 10–12 nA current and 10 s  
29  
30  
31 186 counting time for each element.

32  
33 187 Bulk-rock major and trace element analyses were performed at the Geological Engineering  
34  
35 188 Department of Hacettepe University, Turkey, using a Philips PW 1480 X-Ray Fluorescence  
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37  
38 189 spectrometer, from fused glass tablets and pressed powdered samples. Alici et al. (1998)  
39  
40 190 gave a detailed explanation of sample preparation. The spectrometer was calibrated using  
41  
42 191 international standards (USGS and GEOSTANDARTS) to ensure accurate data. The X-ray  
43  
44  
45 192 Fluorescence spectrometer was calibrated by using USGS and Geostandards to ensure  
46  
47 193 accurate data. Rare earth element (REE) analyses were performed by a JY701 inductively  
48  
49 194 coupled plasma emission spectrometer at the Blaise Pascal University in Clermont-Ferrand,  
50  
51 195 France.

## 52 53 54 196 55 56 197 **6. PETROGRAPHY**

### 57 58 198 59 60 199 **6.1. Host rock**

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2  
3 200 Lava samples from the KVF are typically porphyritic, with groundmass textures ranging from  
4  
5 201 intergranular to intersertal. Many lavas show obvious petrographic evidence of  
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7 202 disequilibrium, including strongly resorbed phenocrysts, reaction rims, zoned minerals,  
8  
9  
10 203 disequilibrium mineral assemblage, and compositions. The main phenocryst phases are  
11  
12 204 olivine, clinopyroxene and hornblende, with plagioclase, leucite, and nepheline being less  
13  
14 205 abundant than mafic minerals. Mineral abbreviations are from [Whitney & Evans \(2010\)](#).  
16  
17 206 *Olivine* (Ol) is the most abundant phenocryst phase in BI basalt, ranging from 4 to 10 vol.%  
18  
19 207 of the rock. Olivines occasionally exhibit strongly skeletal texture in the BI and BIII basalts  
20  
21 208 and are frequently euhedral, sub-rounded ([Fig. 4a-c](#)). The iddingsite sparsely replaced  
22  
23  
24 209 olivine in the groundmass of BI basalt.  
25  
26 210 *Clinopyroxene* (Cpx) is the most dominant mineral in all stages. They are euhedral,  
27  
28 211 subhedral, rounded, and strongly zoned ([Fig. 4c](#)). Some clinopyroxenes exhibit zoning,  
29  
30 212 especially in BI and BII basalts. The core zone, green in colour, is usually resorbed and  
31  
32 213 surrounded by colourless outer rim ([Fig. 4e](#)).  
33  
34  
35 214 *Hornblende* (Hbl) is present only in the BII and BIII stages. They are prismatic, locally  
36  
37 215 resorbed (BIII), and generally rimmed by opaque oxides (BII) ([Fig. 4c-d](#)). We observed a  
38  
39 216 cumulate texture consisting of hornblende assemblage in BIII basalt ([Fig 4f](#)).  
40  
41  
42 217 *Plagioclase* (Pl) is microlitic commonly with rare phenocrysts in all stages. They show some  
43  
44 218 disequilibrium features, such as honeycomb texture with numerous glass inclusions, fresh  
45  
46 219 core with dusty zone rims, and resorption.  
47  
48  
49 220 *Nepheline* is commonly present as microlite in the groundmass of the BIII basalt. *Leucite* is  
50  
51 221 abundant in the lavas of the BIII, with a high modal percentage (up to %19), and sporadically  
52  
53 222 represented in the crystal aggregates ([Fig. 4c](#)).  
54  
55  
56 223 *Fe-Ti Oxides* exist in the groundmass as titanomagnetite and spinel microphenocrysts in  
57  
58 224 BIII stage. It is also observed in the form of inclusions in olivine, clinopyroxene and leucite  
59  
60 225 ([Fig. 4b, d](#)).

## 6.2. Enclaves

Ultramafic and mafic enclaves are observed in BII and BIII stages. Modal results are as follows: Cpx-hornblendite (12), hornblendite (8), Pl bearing Cpx-hornblendite (6), wehrlite (6), Ol-Hbl-clinopyroxenite (5), Hbl-gabbro (4) and phlogopite (Phl) clinopyroxenite (1) (Fig. 5). Glass and vesicle abundances are highly variable among the enclaves (Suppl. Table 1), reaching up to 48%. Enclaves are observed not only as hand specimens, but also as micro-enclaves, including interstitial glass in thin sections (Fig. 4f-h).

### 6.2.1. Hornblendites: Cpx-Hornblendite (BII), Hornblendite (BII, BIII), Pl-Bearing Cpx-Hornblendite (BIII)

Cpx-hornblendites and hornblendites generally exhibit porphyritic texture. The relationships among grains are largely intergranular and sub-ophitic with interstitial vesicular glass (Fig. 6a-c). They are essentially composed of long prismatic hornblendes (Fig. 6i). One of the Cpx-hornblendites contains pale blue hauyne minerals in a pocket of vesicular glass (Fig. 6d). Hornblendes commonly have fresh cores but altered rims. Some of them are resorbed and contain glass inclusions.

Apart from the porphyritic texture, plagioclase-bearing Cpx-hornblendites occasionally present adcumulate and/or mesocumulate textures with sporadically pegmatitic appearance. They bear glass, resorbed hornblende, rounded clinopyroxene, ragged phlogopite and resorbed plagioclase. Some plagioclase and apatite minerals also contain glass inclusions (Fig. 6e).

### 6.2.2. Clinopyroxenites: Phl-Clinopyroxenite (BIII) and Ol-Hbl-Clinopyroxenite (BII)

We have only one Phl-clinopyroxenite sample. It consists of strongly resorbed phlogopite (<12 mm, vol.38.5% modal) and subhedral resorbed clinopyroxene (vol.33% modal) with

1  
2  
3 252 interstitial vesicular glass (vol.25% modal). This enclave exhibits well developed embayment  
4  
5 253 textures of phlogopite (Fig. 6f).  
6  
7  
8 254 Ol-Hbl-clinopyroxenite enclaves (up to 7% Ol, 21% Hbl) show well-defined adcumulate  
9  
10 255 texture (Fig. 6j). They mainly consist of subhedral, sub-rounded pale green coloured  
11  
12 256 clinopyroxene and reddish-brown-coloured hornblende with intercumulus resorbed  
13  
14 257 phlogopite and apatite (Fig. 6j). Several samples contain coarse-grained clinopyroxene (ca.  
15  
16  
17 258 1-14 mm) replaced by hornblende along cleavage planes (Fig. 6k). Olivine is sub-rounded  
18  
19 259 and iddingsite is observed along its cracks (Fig. 6k).  
20

21  
22 260

### 23 24 261 **6.2.3. Hbl-Gabbro (BIII)**

25  
26 262 These are represented by fine grained (<1 mm), resorbed, prismatic, greenish-brown and  
27  
28 263 acicular hornblende, minor embayed olivine and dusty-rimmed plagioclase (Fig. 6l-m).  
29  
30 264 Phlogopite only occurs around olivine (Fig. 6m).  
31  
32

33 265  
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### 35 266 **6.2.4. Wehrlite (BII)**

36  
37 267 Wehrlite enclaves have poikilitic textures of strongly resorbed hornblende and sub-rounded,  
38  
39  
40 268 partially resorbed olivine (1-7 mm) in clinopyroxene (<14 mm) oikocrysts (Fig. 6g, h). Some  
41  
42 269 have orthocumulate textures comprised of euhedral-subhedral olivine (62–68%), interstitial  
43  
44 270 subhedral clinopyroxene (Fig. 6n). Minor phlogopite grains formed around olivine and  
45  
46  
47 271 hornblende in contact with glass. Apatite is accessory and only found in glass. Additionally,  
48  
49 272 euhedral Cr-spinel is found in olivine as inclusions (Fig. 6g).  
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51 273  
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## 53 54 274 **7. MINERAL COMPOSITIONS**

### 55 56 275 **7.1. Olivine**

57  
58 276 Phenocryst and microcryst are variable in composition (Fo<sub>70-87</sub>) (Suppl. Table 2).  
59  
60 277 Compositional zoning is more pronounced in enclaves (especially in wehrlite) than in the

1  
2  
3 278 host rock, but some grains are slightly richer in Fe. In contrast to wehrlite, the olivine gabbro  
4  
5 279 Mg number (Mg#) values range from 80 to 85.  
6  
7

8 280

## 10 281 **7.2. Clinopyroxene**

11  
12 282 Selected analyses are listed in [Supplementary Table 3](#). Endmember plots in [Figure 7](#)  
13  
14  
15 283 ([Morimoto, 1988](#)) for host rock and enclave minerals show that all pyroxene is diopsitic  
16  
17 284 ( $Wo_{46-57}$ ,  $En_{20-45}$ ,  $Fs_{6-30}$ ), except two clinopyroxene analyses in host rock. One of them has  
18  
19 285 spongy texture, and the other is reversely zoned with hedenbergitic composition. The Mg#  
20  
21  
22 286 of clinopyroxene slightly decrease from phenocryst (92) to microcryst (55) in the host rocks.  
23  
24 287 The compositional range is wide and noticeable variations in Mg#,  $Al_2O_3$  and  $TiO_2$  content  
25  
26 288 have been detected, particularly in BII and BIII basalt. In contrast to BII and BIII, BI  
27  
28 289 clinopyroxenes have lower Al (<6%) and Ti content (<2%).  
29

30  
31 290

## 33 291 **7.3. Amphibole**

34  
35 292 The chemical composition of hornblendes is summarised in [Supplementary Table 4](#). They  
36  
37  
38 293 are conspicuously rich in  $TiO_2$ . According to [Leake et al. \(1997\)](#), the host rock amphiboles  
39  
40 294 are mostly kaersutite with rare pargasite. Pargasites contain lower  $K_2O$ ,  $TiO_2$ , Mg# and  
41  
42 295 higher CaO content than the kaersutite composition. Some reversely zoned hornblendes  
43  
44  
45 296 exist in GIII basalt with Mg enrichment at the rim of phenocrysts.

46  
47 297 Amphiboles in the enclaves are pargasitic and kaersutitic. The Mg#s range between 57 and  
48  
49 298 77. Some microcrysts in the glass and inclusions have lower Mg# (52-62). Amphiboles in  
50  
51  
52 299 the enclaves are generally Mg-rich in their core, except those in wehrlite. Moreover,  
53  
54 300 amphiboles in the Hbl-Gabbro have lower Mg# compared to those of the other enclaves.  
55

56 301

## 58 302 **7.4. Phlogopite**

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2  
3 303 Phlogopite is only seen in Hbl-gabbro, Phl-clinopyroxenite and rarely in wehrlite. Analyses  
4  
5 304 are listed in [Supplementary Table 5](#), with Fe# ranging from 0.17 to 0.29 ([Rieder et al., 1998](#),  
6  
7 305 Fe# < 0.3). Phlogopite in Phl-clinopyroxenite has higher Fe, Al, Ti and lower Na content  
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9  
10 306 compared to phlogopite in Hbl-gabbro.  
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12 307  
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### 14 308 **7.5. Plagioclase**

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16  
17 309 The selected analyses are presented in [Supplementary Table 6](#). In the host rock,  
18  
19 310 plagioclases (An<sub>46-64</sub>) are mostly andesine, with rare labradorite. Some microlites exhibit  
20  
21 311 higher An content than the unstable phenocrysts (anal. #2b). In Hbl-gabbro, the plagioclase  
22  
23 312 composition is relatively andesine (An<sub>43-47</sub>), but in Cpx-hornblendite, they represent an  
24  
25 313 extensive compositional variation (An<sub>60-94</sub>), ranging from labradorite to pure anortite. Some  
26  
27 314 plagioclases in Cpx-hornblendite are resorbed and contain glass inclusions.  
28  
29

30 315  
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### 33 316 **7.6. Feldspathoids**

34  
35 317 The representative analyses are given in [Supplementary Table 7](#). The *nepheline* of the BII  
36  
37 318 stage has slightly higher Al<sub>2</sub>O<sub>3</sub>, FeO, CaO and lower Na<sub>2</sub>O than the nepheline of the BIII. In  
38  
39 319 the enclave, nepheline is only observed in Hbl-clinopyroxenite (BII) and exhibits  
40  
41 320 compositional similarity with those of the BII stage.  
42  
43

44 321 *Hauyne* occurs exclusively in the Cpx-hornblendite ([Fig. 6d](#), BII), with K<sub>2</sub>O and Na<sub>2</sub>O content  
45  
46 322 changing from 4.3 to 6.3% and from 7.3 to 10.3%, respectively.  
47  
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49 323  
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### 51 324 **7.7. Oxides**

52  
53 325 *Ti-magnetite* is present as microcrysts in groundmass and inclusion phases in all the three  
54  
55 326 generations of the basalt. The chemical composition of Ti-magnetite is very homogeneous,  
56  
57 327 containing approximately 22-23% TiO<sub>2</sub> ([Suppl. Table 8](#)).  
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59  
60

1  
2  
3 328 *Al-spinels* have bimodal distribution in the host rock BIII, occurring as euhedral  
4  
5 329 microphenocrysts and inclusion in olivine and leucite phenocrysts. The microphenocryst Al-  
6  
7  
8 330 spinel is more evolved, with a lower Mg# than the inclusions.

9  
10 331 *Cr-spinel* is observed as inclusion and is only present in wehrlite sample, with the Cr#  
11  
12 332 (Cr/(Cr+Al)) changing from 25 to 36.

13  
14  
15 333 *Mg-ilmenite* is only observed in Cpx-hornblendite samples, containing 7-8% MgO, 33-34%  
16  
17 334 FeO and 53-54% TiO<sub>2</sub>.

## 18 19 335 20 21 336 **7.8. Vesicular Glass**

22  
23  
24 337 The ratio of the glass and vesicles within the enclaves is highly variable (Suppl. Table 1).

25  
26 338 The glass in the enclaves of the BII stage varies in volume from 0.3 to 19%, while those of

27  
28 339 BIII range from 9 to 29%. The glass exhibits a variety of colours ranging from light brown,

29  
30 340 reddish dark brown to black, but the glass in the Hbl-gabbro is commonly colourless. Two

31  
32 341 types of glasses, similar to those identified by Yaxley et al., (1997), have been observed in

33  
34 342 the enclaves, namely “glass pocket” (Gp), and “glass associated with intergranular minerals”

35  
36 343 (Gim). The Gp is occasionally observed in the enclaves of the BII stage, which modally

37  
38 344 comprise less than 15 vol.% of the glass. In some of the Ol-Hbl-clinopyroxenite and wehrlite

39  
40 345 samples, the Gps are frequently connected with a glass film, forming a network system (Fig.

41  
42 346 6j, n). However, the Gim is commonly found in the hornblendite, Cpx-hornblendite, and Phl-

43  
44 347 clinopyroxenite samples, mostly belonging to BIII stage (Fig. 6a-d, f, i). In several enclaves,

45  
46 348 the Gp consists of disequilibrium mineral assemblage, such as resorbed minerals

47  
48 349 (hornblende, olivine, phlogopite, apatite and hauyne) (Fig. 6d, f-h). Some minerals have

49  
50 350 reacted with glass, resulting in a dark-coloured contact surface between mineral and melt,

51  
52 351 observed in both the glass veins and glass pockets (Fig. 6g-j). Relict fragments of

53  
54 352 phlogopite, completely surrounded by the glass, are optically continuous with larger primary

55  
56 353 phlogopite (Fig. 6f). The glass in the coarse-grained enclaves, especially hornblendites,



1  
2  
3 354 comprise euhedral and prismatic apatites (Fig. 6b-e, h, j). They are observed as both  
4  
5 355 isolated crystals and inclusions in hornblende and clinopyroxene.

7  
8 356 The glass contains a high concentration of vesicles, with the abundance of the vesicles  
9  
10 357 occasionally surpassing that of the glass content. The vesicles typically increase in size  
11  
12 358 from the Gim (<0.1 mm) to Gp (<1.5 mm). They are mostly spherical to elliptical in the Gp,  
13  
14 359 in contrast to those in the Gim. Some vesicle walls in the glass are collapsed or probably  
15  
16  
17 360 plucked out during thin-section preparation (Fig. 6c).

18  
19 361 The chemical composition of the glasses is given in Supplementary Table 9. The glasses  
20  
21 362 are intermediate to basic (44-56 wt.% SiO<sub>2</sub>), and are commonly foiditic, phonotephritic, and  
22  
23 363 rarely tephriphonolitic and basanitic (Fig. 8). The glass in the enclaves relatively comprises  
24  
25 364 higher SiO<sub>2</sub> and total alkaline content than their bulk rock. The glasses with the lowest SiO<sub>2</sub>  
26  
27 365 content (44-47%) occur in wehrlite, Phl-clinopyroxenite, and a Cpx-hornblendite. Although  
28  
29 366 the enclaves have different mineralogy and chemistry, Figure 9 shows that the composition  
30  
31 367 of the glass from wehrlite to Hbl-gabbro samples exhibits evident trends on the plots of SiO<sub>2</sub>  
32  
33 368 versus major oxides. Some glass composition within Phl-clinopyroxenite does not conform  
34  
35 369 to the general trends. Glass adjacent to phlogopite is commonly rich in K<sub>2</sub>O, Na<sub>2</sub>O and Al<sub>2</sub>O<sub>3</sub>  
36  
37  
38 370 and poor in MgO and CaO.

41  
42 371

## 44 372 8. GEOCHEMISTRY

46  
47 373 Major oxides, trace, and rare element compositions of representative samples from Kula  
48  
49 374 lava flows and their enclaves are listed in Supplementary Table 10. All samples exhibit an  
50  
51 375 alkaline trend (Fig. 8). The *B*I lava flows range in composition from basanite, trachybasalt  
52  
53 376 and phonotephrite. While the majority of the samples from *B*II host rocks are basanite with  
54  
55 377 lesser amount of phonotephrite, *B*III host rocks are phonotephrite in composition. Besides,  
56  
57 378 although enclaves are mantle rocks and should not be shown on the TAS diagram with host  
58  
59 379 volcanics, they are plotted on the same diagram to show similarities or variations in chemical

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2

3 380 compositions. Enclaves are definitely ultrabasic in character, with  $\text{SiO}_2$  (39-45%) and  
4  
5 381  $\text{K}_2\text{O}+\text{Na}_2\text{O}$  (1-7.5 %) values, lower than their host rocks.

7

8 382 Plots of  $\text{SiO}_2$  versus selected major oxides are shown in **Figure 9**. Increasing  $\text{SiO}_2$  is well  
9  
10 383 correlated with; i) decreasing  $\text{Fe}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{P}_2\text{O}_5$  and  $\text{TiO}_2$  in both host rocks and their  
11  
12 384 enclaves; ii) increasing  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  in host rocks. However,  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$   
13  
14 385 contents of enclaves vary within a narrow range with no systematic variation (**Fig. 9**). The  
15  
16  
17 386 decrease in  $\text{Fe}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{P}_2\text{O}_5$ , and  $\text{TiO}_2$  is coherent with crystallisation of olivine,  
18  
19 387 clinopyroxene, plagioclase, Fe-Ti oxides, and apatite.

21

22 388 The variations of  $\text{Al}_2\text{O}_3$  and  $\text{Na}_2\text{O}$  in host rocks are notably different from those in their  
23  
24 389 enclaves. As shown in **Figure 9**, while the  $\text{Al}_2\text{O}_3$  and  $\text{Na}_2\text{O}$  contents of the host rocks  
25  
26 390 increase with increasing  $\text{SiO}_2$ , the values of these elements decrease with increasing  $\text{SiO}_2$   
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28 391 content in enclaves. This indicates that the  $\text{Al}_2\text{O}_3$  contents increase from ultrabasic enclaves  
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30  
31 392 to basic host rocks, which may be linked to the plagioclase fractionation.

32

33 393 Trace element data are reported in **Supplementary Table 10** and plotted against  $\text{SiO}_2$  in  
34  
35 394 **Figure 9**. The best correlation is represented by Co, V, Rb, and Sr. Ba, Nb, Y, and Zr show  
36  
37  
38 395 no systematic variation. The contents of Co and V regularly decrease with increasing  $\text{SiO}_2$ ,  
39  
40 396 possibly indicating the fractionation of olivine, spinel/clinopyroxene and V-bearing Fe-Ti  
41  
42 397 oxides. On the other hand, Rb and Nb contents increase with increasing  $\text{SiO}_2$ .

44

45 398 MORB-normalised (**Pearce, 1983**) spider diagrams are shown in (**Fig. 10**). All samples from  
46  
47 399 host rocks exhibit typical within-plate patterns (humped-patterns) enriched in large ion  
48  
49 400 lithophile elements (LILE, e.g. Sr, K, Rb, Ba and Th), light rare earth elements (LREE), and  
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51 401 high field strength elements (HFSE, e.g. Nb, Ta and Ti) relative to the MORB (**Fig. 10a**).

53

54 402 The trace element abundances of enclaves are characterized by significant depletion in Rb,  
55  
56 403 K and Th with respect to HFS elements (**Fig. 10b**). The Kula enclaves are strongly depleted  
57  
58 404 in Rb and Th compared to their host rocks. As expected, the enclave of Phl- clinopyroxenite  
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60 405 (K97-70a2) show anomalously high K, Rb and Ba peaks.

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3 406 REE data of both Kula host rocks and enclaves are summarized on a chondrite-normalised  
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5 407 ([Nakamura, 1974](#)) diagrams. Both suites exhibit light LREE enrichment relative to chondrite  
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7 408 (i.e. La= 70 to 250 times) and also show clear fractionation between LREE and HREE.  
9  
10 409 All samples for Kula host rocks have flat patterns from Er to Lu with respect to LREE ([Fig.](#)  
11  
12 410 [10c](#)). While the abundances of LREE are variable, the HREE are relatively constant.  
13  
14 411 Herewith, LREE/HREE ratios are also variable, and the (La/Yb)<sub>n</sub> ratios of Kula host rocks  
16  
17 412 range from 13.36 to 24.56.  
18  
19 413 Enclaves of Pl-clinopyroxenite (K97-70a2), Cpx-hornblendite (K97-30a, K97-48a2),  
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21 414 hornblendite (K97-14a, K97-17a2) and plagioclase bearing Cpx-hornblendite (K97-46a)  
23  
24 415 have almost similar patterns identical to those of host rocks ([Fig. 10d](#)). They are also  
25  
26 416 characterized by LREE enrichment relative to chondrite (i.e. La= 70-250 times chondrite).  
27  
28 417 However, they have more fractionated nature relative to their host rocks with (La/Yb)<sub>n</sub> ratios  
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30 418 varying from 9.27 to 33.83. The wherlite sample (K97-10a2) also exhibits REE pattern  
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33 419 similar to other enclaves but has considerably lower REE contents.

35 420

## 38 421 **9. DISCUSSION AND CONCLUSION**

### 42 423 **9.1. Source Characteristics and Partial Melting Modeling**

45 424 The ratio plots of alkaline elements, such as Ba, Rb and Sr, are used to detect the presence  
46  
47 425 of amphibole and/or phlogopite in the source region of Kula host rocks and enclaves. These  
48  
49 426 minerals are essential for revealing the metasomatic enrichment process in the source  
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51 427 region since amphibole and/or phlogopite are major volatile bearing phases ([Ionov et al.,](#)  
52  
53 428 [1997](#)). Furthermore, the presence of apatite crystals in the Kula enclaves also supports the  
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56 429 metasomatism process. [Yaxley et al. \(1991\)](#) have demonstrated that the abundances of  
57  
58 430 apatite may be attributed to the metasomatism. If relatively low-temperature melting  
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60 431 conditions prevailed (e.g., 1100°C) in H<sub>2</sub>O-bearing depths of the upper mantle, the residual

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apatite could form (Watson, 1980). Rb and Ba, both are compatible with phlogopite ( $Kd_{Rb}$  and  $Kd_{Ba}$  are 3.06 and 1.090, respectively), whereas amphibole does not retain Rb, Sr and Ba ( $Kd_{Rb}= 0.29$ ;  $Kd_{Ba}=0.42$  and  $Kd_{Sr}=0.46$ ) (Furman & Graham, 1999; Rollinson, 1993). Ionov & Hofmann (1995) have also indicated from the mantle xenoliths that amphibole has very low Rb concentrations while phlogopite is rich in Rb. According to these criteria, melting of an amphibole-bearing mantle source can reveal lower Rb/Sr and higher Ba/Rb ratios. Conversely, melts from phlogopite-bearing mantle sources (amphibole-free) may have higher Rb/Sr ( $>0.1$ ) and lower Ba/Rb ( $<20$ ) ratios than those formed from amphibole-bearing sources (Furman & Graham, 1999).

The alkaline host rocks have generally relatively low Rb/Sr (0.03-0.10) and high Ba/Rb (9.48-23.24) ratios (Fig. 11a), suggesting the presence of mostly amphibole with lesser amount of phlogopite in their source region. They also plot close to the trend line of amphibole and phlogopite. At the same time, the Rb/Sr and Ba/Rb ratios of Kula enclaves show wide variation and range from 0.01 to 0.09 and 17.57 to 114, respectively. The majority of the samples are clearly plotted on the amphibole trend line. As expected, the enclave of K97-70a2 (Phl-clinopyroxenite) is shifted towards the phlogopite trend line due to its relatively high Rb/Sr and low Ba/Rb ratios.

Furthermore, the high  $Na_2O/K_2O$  ratios ( $>1.27$ ) of both Kula host rocks and enclaves (except sample no: K97-70a2, Phl-clinopyroxenite) further support the above arguments, as melting of amphibole bearing phases can account for  $Na_2O/K_2O > 1$  (Foley et al., 1999; Moufti et al., 2012).

To specify the source mineralogy and melting depth of Kula enclaves and their host rocks, partial melting modelling using REE ratios was calculated. The modelling uses the non-modal batch melting equations of Shaw (1970), partition coefficients from McKenzie & O'Nions (1991) and Rollinson (1993). Partial melting calculations were carried out by the "PETROMODELER" program of Ersoy (2013). In the calculations, LREE-enriched

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3 458 compositions from [McDonough \(1990\)](#) were regarded as initial source composition. Spinel  
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5 459 and garnet mineral modes were used to make an assessment of the melting depth ([Baker](#)  
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8 460 [et al., 1997](#); [Shaw et al., 2003](#)). LREE/HREE variations are good proxies for the depth/extent  
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10 461 of melting and the residual garnet in the source. Garnet retains the HREE, and garnet-facies  
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12 462 melts are represented by higher LREE/HREE ratios relative to spinel-facies. **Figures 11b-d**  
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14 463 display Sm/Yb versus La/Yb variations for Kula host rocks and enclaves with non-modal  
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17 464 batch melting curves of spinel and garnet peridotite sources. As expressed in **Figure 11b**,  
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19 465 the genesis of Kula host rocks cannot be explained by variable degrees of melting from a  
20  
21 466 single garnet or spinel peridotitic source. Thus, binary mixing calculations of [Langmuir et al.](#)  
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23  
24 467 ([1978](#)) were performed between spinel and garnet peridotite. Kula host basalts clearly plot  
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26 468 on the lines obtained by binary mixing between 3-5% spinel and garnet peridotite melts. The  
27  
28 469 mixing proportions extend between 40%-60% melt of spinel peridotite and 30%-70% melt of  
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30  
31 470 garnet. On the other hand, enclaves shifted towards the melting curve of garnet-facies.  
32  
33 471 **Figure 11c** illustrates the  $(Tb/Yb)_n$  versus  $(La/Yb)_n$  variations in Kula host rocks and  
34  
35 472 enclaves with the horizontal line separating the garnet and spinel peridotite melting fields  
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37  
38 473 ([Wang et al., 2002; 2004](#); [Furman et al., 2004](#); [Moufti et al., 2012](#)). The  $(Tb/Yb)_n$  ratios of  
39  
40 474 Kula host rocks (1.50-2.03) are generally clustered on the horizontal line, indicating that  
41  
42 475 melts originate from both garnet and spinel bearing sources, and extend along the mixing  
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44 476 lines between 3% and 5% melt of garnet and 5% melt of spinel-peridotite. Calculations  
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46  
47 477 further support that the mixing of melts derived from both garnet and spinel peridotite  
48  
49 478 sources accounts for the generation of Kula volcanism. [Alıcı et al. \(2002\)](#) have also  
50  
51 479 suggested a mixture of asthenospheric and lithospheric mantle sources. [Grützner et al.](#)  
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53  
54 480 ([2013](#)) mention Mg-rich and green-core Mg-poor clinopyroxene in lava flows and enclaves  
55  
56 481 indicating two different melt sources. In addition, [Nikogosian et al. \(2018\)](#) note that the  
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58 482 compositional diversity of the Kula volcanism based on olivine-hosted melt inclusions  
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60 483 indicates mixing of two distinct sources originated from the mantle, and the primary melt

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3 484 generation starts from 75 km depth. However, according to [Sölpüker \(2007\)](#) Kula volcanism  
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5 485 originates from spinel peridotite with 7–9% degrees of fractional melting.  
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8 486 As can be seen in [Figures 11b-c](#), Kula enclaves are separated from their host rocks due to  
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10 487 their relatively higher (Tb/Yb)<sub>n</sub> ratios (1.96-3.20), suggesting the presence of residual garnet  
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12 488 and melting in garnet stability field ([Wang et al., 2002](#); [Khudoley et al., 2012](#)). Variations in  
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14 489 Sm/Yb, La/Yb Tb/Yb ratios in enclaves generally result from the melting of a garnet  
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16  
17 490 peridotite. If this is the case, we should not expect any variation in La/Yb and Yb diagram  
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19 491 ([Fig. 11d](#)). However, the host rocks and enclaves have variation between La/Yb and Yb,  
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21  
22 492 further suggesting the mixing between spinel and garnet peridotite sources. Moreover, the  
23  
24 493 presence of amphibole suggests the contribution of a spinel peridotite mantle source  
25  
26 494 ([Worthing & Nasir, 2008](#); [Tschegg et al., 2011](#); [Moufti et al., 2012](#)).  
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## 30 496 **9.2. Fractional Crystallisation and Crustal Contamination**

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33 497 Various types of enclaves varying from wehrlite to gabbro, indicate that magma masses had  
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35 498 sufficient time for mineral settling to form cumulates. The melts reaching volatile saturation  
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38 499 contributed to the formation of ultramafic cumulates of different mineralogical composition.  
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40 500 For example, early-crystallized minerals such as spinel, olivine and clinopyroxenes  
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42 501 produced wehrlite with subsiding evolved melts and hydrous fluids could activate the  
43  
44 502 crystallisation of hornblende and phlogopite, producing hornblendites from primitive basaltic  
45  
46  
47 503 magma with Na-alkaline affinity. The presence of nepheline and hauyne in the BII stage's  
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49 504 enclaves may indicate a magmatic evolution towards alkaline compositions.  
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51 505 The linear correlations between SiO<sub>2</sub> and some specific major and trace elements are  
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53 506 consistent with fractional crystallisation processes in the evolution of Kula host basalts and  
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55  
56 507 enclaves. This could be explained by the presence of mafic microcrysts occurring in the  
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58 508 vesicular glass. Low Ni (<106 ppm) and Cr (<205 ppm) contents in host basalts also support  
59  
60 509 the arguments of fractional crystallization, as the decrease of Ni and Cr suggests olivine and

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3 510 clinopyroxene fractionation, respectively (Wilson, 1989; Moufti et al., 2012). Furthermore,  
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5 511 Ni and Cr contents of basalts (Ni: 7-106 ppm; Cr: 2-205 ppm) and enclaves (Ni: 0.5-91 ppm;  
6  
7 512 Cr: 7-301 ppm) are lower than the values commonly accepted for primary magmas (Ni=300-  
8  
9 513 400 ppm; Cr: 300-500 ppm; Jung & Masberg, 1998), possibly reflecting their fractionated  
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11 514 nature [with the exception of one sample, wehrlite, which has high Ni (598 ppm) and Cr  
12  
13 515 values (2331 ppm)]. For instance, the negative correlation between SiO<sub>2</sub> and MgO, Fe<sub>2</sub>O<sub>3</sub>,  
14  
15 516 TiO<sub>2</sub>, and CaO, coupled with some specific elements such as Co, V and Sr are indicative of  
16  
17 517 olivine, clinopyroxene, Ca-plagioclase and Fe-Ti-oxides fractionation. P<sub>2</sub>O<sub>5</sub> also has a clear  
18  
19 518 negative correlation with SiO<sub>2</sub>, which is consistent with apatite removal. The increasing  
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21 519 trends between SiO<sub>2</sub> and K<sub>2</sub>O, Na<sub>2</sub>O and Rb also indicate fractional crystallisation processes  
22  
23 520 in the evolution of Kula host basalts.  
24  
25 521 Haase et al. (2000) argue that a high Nb/La (>1) ratio is the striking feature of  
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27 522 uncontaminated magmas from within-plate mantle sources. According to this criterion, it  
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29 523 suggests that the host basalts, having elevated Nb/La ratios (>1.3), were derived from  
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31 524 mantle sources with insignificant crustal contamination. Similarly, Nb/La ratios of the  
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33 525 enclaves (Nb/La: 1.2-2.4) also resemble those of their host rocks from within-plate settings.  
34  
35 526 Besides, Kula basalts and their enclaves have high Nb/Y ratios (>1.7), suggesting HFSE  
36  
37 527 enrichment commonly seen in lavas uncontaminated by crustal material from within-plate  
38  
39 528 mantle sources. This is a typical characteristic of uncontaminated alkaline ocean island  
40  
41 529 basalts (Pearce & Cann, 1973). Alici et al. (2002) illustrated in the OIB-normalised spider  
42  
43 530 diagram that the trace element patterns of Kula basalts are akin to OIB with considerable  
44  
45 531 enrichment in LILE (e.g. Sr, Rb, Ba, K) and HFSE (e.g. Nb, Th, U). This case can be ascribed  
46  
47 532 to mantle source enrichment during their genesis. The alkaline rocks studied here have  
48  
49 533 enriched incompatible element characteristic with high Nb/La and Nb/Y ratios, suggesting  
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51 534 derivation from a within-plate mantle source with an inconsequential crustal contamination.  
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53 535 Likewise, the Nb/U ratio of uncontaminated OIB is around 47±10 (Hofmann et al., 1986); the

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3 536 range in Nb/U (31-58) of Kula basalts rule out the significant role of crustal contamination.  
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5 537 This argument is in agreement with the assessments of Güleç (1991) and Alici et al. (2002),  
6  
7 538 who suggested based on their isotopic data that Kula host rocks have not been subjected  
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10 539 to notable crustal contamination but have been treated by the effects of fractional  
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12 540 crystallization. Tokçær et al. (2005) and Agostini et al. (2007) also suggest an OIB-like  
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14 541 asthenospheric mantle source for the KVF, without any contamination. The rapid ascent of  
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17 542 magma in Kula (Tokçær et al., 2005) and short residence time in the crust (Georgatou &  
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19 543 Chiaradia, 2020) explain the negligible role of crustal contamination. This argument relates  
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21 544 to the residence duration of basaltic magmas in the continental crust. According to Holness  
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23 & Bunbury (2006), the co-genetic enclaves occur in the magma chamber emplaced beneath  
24 545 the KVF but in the crust. However, Spera (1984); Aldanmaz et al. (2005); Demouchy et al.  
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26 546 (2006); Tang et al. (2006); Davis et al. (2007); Meng et al. (2015) and (Sun et al., 2018)  
27  
28 547 suggest that the presence of xenoliths and/or xenocrysts implies rapid ascent of magmas  
29  
30 548 without significant interaction with the crust. As the melts containing comagmatic enclaves  
31  
32 549 rise into the crust after extraction from the magma chambers in the lithospheric mantle, the  
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34 550 exsolution of volatiles increases, resulting in bulk magma volume expansion and the  
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36 551 demolition of the conduit wall-rock (Sun et al., 2018). This process explains the abundance  
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38 552 of the crustal xenoliths, such as granite, marble, schist, gneiss and migmatite, in the volcanic  
39  
40 553 deposits of the KVF. Crustal xenoliths having low-temperature minerals in the Kula lavas  
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42 554 and pyroclastics (Bayhan et al., 2002) suggest rapid ascent, thus avoiding remarkable  
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44 555 assimilation with crustal materials. These views are further supported by the presence of  
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46 556 embayed crystals indicating rapid changes in P-T conditions of magma batches. For  
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48 557 instance, embayed phlogopite, hornblende and olivine crystals are observed in Phl-  
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50 558 clinopyroxenite and wehrlite in Kula (Fig. 6). These embayed minerals may occur as a result  
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52 559 of partial melting of hydrous minerals due to decompression (Green et al., 1968; Francis,  
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54 560 1987; Grützner et al., 2013). In addition, the release of exsolved fluids from ascending  
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3 562 magma within the cumulate mush may also lead to reactions with pre-existing crystals and  
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5 563 producing hydrous phases such as phlogopite microcrysts mantling the olivine, observed in  
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7 564 BIII basalt. Furthermore, the presence of glass, including merged vesicles, implies that  
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10 565 enclaves experienced a decrease in pressure as the magma ascends rapidly to the surface.  
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12 566 [Grützner et al. \(2013\)](#) calculated the ascent rate of the magma from Moho to surface as 4–  
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14 567 11 days.  
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### 19 569 **9.3. Thermobarometry**

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21 570 The textural properties indicate that the lava and enclaves may have a simple history of  
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24 571 cooling and heating before reaching the surface. Fresh and stable mineral assemblages  
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26 572 were selected, which were in equilibrium with the host magma. Clinopyroxene is ubiquitous  
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28 573 in both host rocks and enclaves. The crystallisation temperature and pressure of  
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31 574 clinopyroxene were estimated on the basis of [Putirka \(2008\)](#) equation 33, and [Neave &](#)  
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33 575 [Putirka \(2017\)](#), respectively. The whole rock and glass compositions were regarded as liquid  
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35 576 compositions, and the tests for equilibrium based on [Putirka \(1999\)](#) has been employed to  
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37 577 get more plausible estimates from Cpx-thermometer model ([Fig. 12](#)).  
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40 578 Therefore, only the Cpx compositions having  $K_D^{(Fe-Mg)}$  values between 0.20 and 0.36 that fell  
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42 579 within the expected equilibrium range [ $K_D^{(Fe-Mg)} = 0.28 \pm 0.08$ ] based on [Putirka \(2008\)](#), and  
43  
44 580 the values (the difference between predicted and observed DiHd) approaching zero, were  
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46  
47 581 used. The diagram given here covers only predicted and observed DiHd  
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49 582 (diopside+hedenbergite) components, with the one-to-one line having an accepted deviation  
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51 583 of 10% ([Mollo et al., 2015](#); [Polo et al., 2017](#)) ([Suppl. Table 11](#)).  
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54 584 Cpx-liquid (whole rock composition) thermobarometer yields the crystallisation temperature  
55  
56 585 and pressure for BI, BII and BIII lava flows at 1217-1231°C (average of 1227°C) and 9.5-  
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58 586 10.0 kbar (average of 9.8 kbar), 1130-1242°C (average of 1208°C) and 9.5-15.4 kbar  
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587 (average of 12.8 kbar) and 1149-1227°C (average of 1193°C) and 9.4-14.3 kbar (average  
588 of 12.7 kbar), respectively (Suppl. Table 11).

589 Cpx-liquid thermobarometry was used for the enclaves, based on both Cpx-whole rock and  
590 Cpx-co-existing glass pairs. Temperature and pressure estimates, based on the  
591 compositions of Cpx and co-existing glass, give the following values: 1138-1200°C, 14.2-  
592 18.8 kbar for wehrlite; 1148-1199°C, 25.2-27.6 kbar for Phl-clinopyroxenite; 1134-1206°C,  
593 14.4-21.4 kbar for Cpx-hornblendite; and 1026-1034°C, 14.2-15.7 kbar for Hbl-gabbro.  
594 However, estimates based on Cpx-whole rock composition yield higher temperatures but  
595 lower pressures relative to the Cpx-glass composition pairs. In other words, temperature  
596 and pressure estimates based on Cpx and co-existing glass compositions indicate the  
597 different source regions. The inconsistency between the probable source characteristics  
598 might originate from the analysed glasses, resulting from decompression-induced partial  
599 melting of hydrous minerals such as amphibole and phlogopite (Fig. 6f-h).

600 BI basalts are the first products of the Kula volcanism, which developed as a result of crustal  
601 thinning caused by mantle uplift in the Selendi basin on horst about 1.2 Ma ago. P-T  
602 calculations indicate shallower sources (~ 30-36 km) for BI stage compared to other stages.  
603 The BII and BIII stages have relatively the deeper origins. As the heat from the upwelling  
604 asthenosphere rises (Prelevic et al., 2012), it might produce the initial melts of the spinel-  
605 bearing BII and BIII basalts. Thus, the depth of the partial melting point may shift to a deeper  
606 source from 30 to 50 km (Fig. 12). Most of the enclaves ranging from Phl-bearing wehrlite  
607 to hornblendite are found in the base surge deposits of the M3 tuff ring (BII). In contrast to  
608 lava flows of the BI and BIII stages, the P-T analyses of the Cpx minerals of a fusiform bomb  
609 covering the wehrlite yield crystallisation temperatures of 1174-1260°C and pressures of 13-  
610 19.5 kbar, which corresponds to depths of ~42-63 km in the lithosphere. These depths are  
611 generally compatible with the T-P conditions of the enclaves.

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3 612 The ascending melts needs to stall at depths of the lithospheric mantle to form various  
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5 613 ultramafic enclaves. So, the alkaline basaltic melts, enriched with volatiles, migrate upwards  
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7 614 from the source region by percolating into the lithosphere to form a magma storage such as  
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10 615 small magma chambers and/or feeder dykes (Grützner et al., 2013) or lens-shaped masses  
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12 616 (i.e. "sill-like" Hollnes & Bunbury, 2006). According to P-T graph (Fig. 12), the magma  
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14 617 storage depths calculated from Cpx-liquid (whole rock composition) are between about 38-  
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17 618 59 km for hornblendite (BII), 46-50 km for Phl-clinopyroxenite (BII), 39-48 km for Cpx-  
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19 619 hornblendite (BII), and 36-42 km for Hbl-gabbro (BIII). The melting temperature notably  
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21 620 controls the MgO and Al<sub>2</sub>O<sub>3</sub> content of a melt (Pilet et al., 2010). High TiO<sub>2</sub> (1.81-4.19 wt.%),  
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23 621 Al<sub>2</sub>O<sub>3</sub> (14.6-18.2 wt.%) and low MgO (5.4-12.1 wt.%) contents point out the involvement of  
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25 622 a non-peridotite source, possibly an amphibole-bearing pyroxenite. Residual amphibole can  
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27 623 be attributed to melting near the asthenosphere-lithosphere boundary and/or under  
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29 624 lithospheric conditions (Mayer et al., 2013), since amphibole is not stable above ~100 km  
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31 625 (Pilet et al., 2008). The calculated pressures correspond to depths of approximately 36 to  
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33 626 63 km, suggesting the crystallisation under lithospheric mantle conditions.

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37 627 In the light of the data, the evolution of Kula volcanism resulting from asthenospheric uplift  
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39 628 can be summarized as follows (Fig. 13):

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42 629 I. Kula host basalts and enclaves most likely originated from a mixed garnet and spinel  
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44 630 peridotite source in the presence of amphibole and lesser phlogopite, indicating  
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46 631 metasomatic enrichment processes during their genesis.  
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49 632 II. The Kula Rift Volcanism is a sodic alkaline volcanism developed within the Gediz  
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51 633 Graben of the Western Anatolian Graben system. The first basaltic phase started to  
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53 634 produce lava flows about 1.2 Ma ago. These lava flows are cut by normal faults in the  
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55 635 form of staircases after settling and descending into the graben. Although Richardson-  
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57 636 Bunbury (1996) obtained Ar-Ar ages from the amphiboles of these lava flows, we did  
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59 637 not encounter any minerals indicating the presence of aqueous phases in these lavas  
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3 638 during our extensive sampling. Our clinopyroxene geobarometer calculations indicate  
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5 639 that the crystallization occurred at a depth of 30-36 km, which is the lower crust and  
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7 lithospheric mantle transition level. We did not encounter any basic or ultrabasic  
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10 641 enclaves in these basaltic lava flows that were formed during a dry phase. Therefore,  
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12 642 we accept that these lavas originated from sub-crustal magma settlements, which  
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14 probably also contributed to the uplift.  
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17 644 III. The petrographic and compositional study of the enclaves has shown that Kula  
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19 645 enclaves record multistage fractional crystallisation histories involving the migration of  
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21 melts and aqueous fluids from asthenosphere and/or lithosphere-asthenosphere  
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23 interaction levels. Wehrlite, Cpx-hornblendite, and hornblendite enclaves are abundant  
24 647  
25 in the second phase-basalts. According to geobarometer calculations, the  
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27 crystallization depths of these enclaves are between 40-55 km, while Cpx from host  
28 649  
29 basalts exhibits a wide range of crystallization depths, as 38-60 km. While Cpx-  
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31 650 hornblendite, hornblendite, and Hbl-gabbro enclaves are commonly encountered in the  
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33 651 third-stage basalts, the crystallization depths obtained from these enclaves indicate  
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35 652 shallower depths (35-43 km) compared to other stage enclaves.  
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40 654 IV. The most striking features of enclaves are that they are as fresh as the host rock, show  
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42 655 no deformation, and contain vesiculated interstitial glass. With these features, we can  
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44 say that enclaves and host basalts originated from the same source and rose rapidly  
45 656  
46 with the lava. As the phases progress from the second to the third stage, magma  
47 657  
48 chambers in the lithospheric mantle get closer to the surface.  
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51 659 V. The tectonic regime that created the rift is still active, and considering the very young  
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53 products of the third phase, we suggest that a volcanic eruption may occur in the near  
54 660  
55 future.  
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60 663 **ACKNOWLEDGEMENTS**

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3 664 This research was supported by TÜBİTAK (Scientific and Technical Research Council of  
4  
5 665 Turkey), within the cadre of project YDABCAG-398, the Scientific Research Unit of  
6  
7  
8 666 Hacettepe University (project T07 604 002) and by the French Embassy in Ankara (French  
9  
10 667 Ministère des Affaires Etrangères). Part of this research is compiled from the PhD thesis of  
11  
12 668 Erdal Şen. We are grateful to anonymous reviewers for their constructive comments which  
13  
14  
15 669 greatly improved the manuscript. We extend our special appreciation to Editor Dr. Federico  
16  
17 670 Rossetti for his expertise and attention.

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For Review Only

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## FIGURE CAPTIONS

**Figure 1.** a) Geodynamical sketch map of Anatolian block, locations of major faults and study area shown on Digital Elevation Model (DEM) of Anatolia. (AEZ: Aegean Extension Zone; NAF: North Anatolian Fault; EAF: East Anatolian Fault; EF: Ecemiş Fault; TGF: Tuz Gölü Fault and OF: Ovacık Fault. Big arrows indicate the sense of plate motion and half arrows show the relative motion direction on the faults). b) Map showing hillshade topography of the western Anatolia. Faults and graben boundaries are taken from [Karaoğlu et al. \(2010\)](#) and [Ersoy et al. \(2011, 2012\)](#). The pale yellow-coloured dashed line refers to the Menderes Massif ([Gessner et al., 2018](#)). GG: Gediz graben, SG: Simav graben, KmG: Küçük Menderes graben, BmG: Büyük Menderes graben, GöB: Gördes basin, DB: Demirci basin, SB: Selendi basin, GüB: Güre basin, NMM: Northern Menderes Massif, CMCC: Central Menderes Core Complex, ÇS: Çine Submassif.

**Figure 2.** Geological map of the Kula Volcanic Field (modified from [Ercan et al., 1978](#)) and published age data. [1]: [Westaway et al., 2006](#), [2]: [Westaway et al., 2004](#), [3]: [Maddy et al., 2015](#), [4]: [Bunbury, 2001](#), [5]: [Heineke et al., 2016](#), [6]: [Ulusoy et al., 2019](#) (Age data is only for Çakallar Divlit Tepe cone and lava flows near Demirköprü Dam). M1-3: tuff ring, M4: maar, Gm: groundmass, Amp: amphibole, ZDD: Zircon double-dating, Cosm: cosmogenic. Geological map draped over SRTM 1 Arc-Second Global DEM hillshade ([EROS, 2018](#)); Coord. Sys: UTM, datum: ED1950.

**Figure 3.** Field photographs: a) Base surge deposits of Kızıl Tepe tuff ring (M3). Olivine bearing ultramafic enclaves are dominant in lithic-rich layers. Hammer is 30 cm long. b) Small cinder cones having basal diameter and height of 100-150 m and 20-30 m, respectively (northern side of Divlit Tepe near Kula). c) Bağ Tepe, a breached cinder cone, with lava extrusions ceased its activity. It is rich in hornblende (hammer is 30 cm long). d) Enclaves marked by red arrows in M3 tuff ring deposits (BII) varying in size

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3 1118 from <3 to 16 cm, inset images; macro and thin section view. e) and f) Rounded and sub-  
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5 1119 rounded hornblendite enclaves (marked by red arrows) in the lava flow erupted from Bağ  
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8 1120 Tepe cinder cone (BIII). Hammer is 30 cm long, inset image; broken sample. g) Wehrlite  
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10 121 sample (K97-10a2, BII) from M3 tuff ring. Notice the broken and unbroken vesicles. Inset  
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12 122 image; macro view. Cpx: clinopyroxene, Ol: olivine, Phl: phlogopite.

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16 123 **Figure 4.** Photomicrographs of the host rock in the KVF (plane-polarized). a) Skeletal olivine  
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18 124 phenocryst. Groundmass; microphenocryst to fine microlite and microcryst (BI). b) Olivine  
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20 125 phenocryst and euhedral spinel inclusions (BIII). c) Sub-rounded olivine, fresh hornblende  
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22 126 phenocrysts and leucites in the groundmass (BII). d) Hornblende and euhedral spinel  
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25 127 microphenocrysts (BIII). e) Green-coloured, relict clinopyroxene core is mantled by  
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27 128 another clinopyroxene showing a distinct pleochroism. Note the glass inclusions at the  
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29 129 reaction zone (BII). Micro-enclaves containing quenched interstitial glass: (f) hornblendite  
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32 130 (BIII), (g) Phl-Cpx-hornblendite (BIII) and (h) clinopyroxenite (BII). Ol: olivine, Cpx:  
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34 131 clinopyroxene, Hbl: hornblende, Pl: plagioclase, Lct: leucite, Nph: nepheline, Spl: spinel,  
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36 132 G: glass and V: vesicle.

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40 133 **Figure 5.** Classification of the enclaves according to their modal mineralogy ([Streckeisen,](#)  
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42 134 [1976](#)).

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45 135 **Figure 6.** Photomicrographs of the enclaves containing glass (G) and vesicle (V), plane-  
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47 136 polarized: a) Hornblendite (BII); prismatic hornblende (Hbl) aggregates in very pale brown  
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50 137 coloured vesicular glass. b) Hornblendite (BIII); euhedral hornblende and clinopyroxene  
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52 138 (Cpx) in brown coloured vesicular glass. Apatite (Ap) is not only observed as inclusion in  
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54 139 Hbl and Cpx, but also in the glass. c) Same sample as (b). Note some apatites showing  
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57 140 an elongation from towards the glass. d) Cpx-hornblendite (BII); euhedral and embayed  
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59 141 hauyne (Hyn) containing glass inclusions. Some are clear and embayed. The colour of  
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1142 the glass is changing from dark brown to light brown. It is darker in colour towards to

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3 1143 hornblende and clinopyroxene in contrast to hauyne crystal. e) Pl-bearing Phl-Cpx-  
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5 1144 hornblendite (BII); plagioclase (Pl) showing sieve texture. It is enclosing euhedral apatite  
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7 1145 crystals. Note the clinopyroxene microcryst in the glass (arrowed), lining up around the  
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9 1146 hornblende crystals. f) Phl-clinopyroxenite (BIII); clinopyroxene and embayed phlogopite  
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11 1147 (Phl) crystals. Detached phlogopite pieces and main crystal show optically continuity.  
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13 1148 Note the clinopyroxene microcrysts in the black coloured glass. g) Wehrlite (BII);  
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15 1149 clinopyroxene, embayed olivines with inclusion of spinel (Spl) and embayed hornblende  
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17 1150 crystals in a Gp. Hornblende has ragged edge formed by partial melting. h) Wehrlite (BII);  
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19 1151 poikilitic hornblende enclosing olivine and clinopyroxene. Note the curved marks inside  
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21 1152 the hornblende, (BII). i) Hornblendite (BIII); oriented long prismatic hornblendes with Gim  
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23 1153 (interstitial vesicular glass). j) Hbl-clinopyroxenite (BII); inter-granular dark coloured Gp  
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25 1154 (glass pockets). k) Ol-Hbl-clinopyroxenite (BII); replacements of clinopyroxene by  
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27 1155 hornblende along cleavage planes and alteration of olivine to iddingsite along rims and  
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29 1156 cracks. l) Hbl-gabbro (BIII); dusty rimmed plagioclase enclosing clinopyroxenes and  
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31 1157 apatite. m) Hbl-gabbro (BIII); fine-grained phlogopites formed around the relict olivine. n)  
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33 1158 Wehrlite (BII); glass associated with inter-granular minerals of sub-hedral olivines,  
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35 1159 clinopyroxenes and hornblendes.  
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43 1160 **Figure 7.** Composition of clinopyroxenes from host rock and enclaves plotted in the ternary  
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45 1161 system Wo-En-Fs, with fields from [Morimoto et al. \(1988\)](#).  
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49 1162 **Figure 8.** Total Alkali Silica classification diagram ([Le Bas et al., 1986](#)) for the host rock and  
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51 1163 glass in enclaves. The dashed line separates alkali and subalkaline fields, after [Miyashiro](#)  
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53 1164 ([1978](#)). Small circle symbols of host rocks are from [Alici et al. \(2002\)](#). Phl: phlogopite,  
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56 1165 Cpx: clinopyroxene, Hbl: hornblende  
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59 1166 **Figure 9.** Major (wt.%) and trace (ppm) element abundances versus SiO<sub>2</sub> for host rock and  
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1167 enclaves.



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3 1168 **Figure 10.** a) and b) MORB-normalised (Pearce, 1983) incompatible trace element patterns  
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5 1169 of host rocks and enclaves. c) and d) Chondrite-normalised (Nakamura, 1974) REE  
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7 patterns of host rocks and enclaves.  
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11 1171 **Figure 11.** a) Ba/Rb versus Rb/Sr diagram (Furman & Graham 1999) of host rocks and  
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13 1172 enclaves. SCLM: Sub-continental lithospheric mantle. b) and c) Sm/Yb – La/Yb and  
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15 (Tb/Yb)<sub>n</sub> – (La/Yb)<sub>n</sub> non-modal batch melting (Shaw, 1970) diagrams showing the melt  
16 1173 curves of spinel (Ol<sub>0.62/0.40</sub> + Opx<sub>0.24/0.30</sub> + Cpx<sub>0.12/0.90</sub> + Spinel<sub>0.02/0.20</sub>) and garnet-peridotite  
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18 1174 (Ol<sub>0.66/0.1</sub> + Opx<sub>0.27/0.18</sub> + Cpx<sub>0.03/0.3</sub> + garnet<sub>0.04/0.42</sub>) and binary mixing line between spinel  
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20 1175 and garnet peridotite melting curves. Normalisation values are from Thompson (1982).  
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22 1176 The horizontal black dashed line separates the melting fields of garnet and spinel-  
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24 peridotite (Wang et al., 2002). d) Yb-La/Yb diagram showing spinel and garnet non-modal  
25 1177 batch melting curves. Initial concentrations for La, Sm, Yb and Tb are from McDonough  
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27 1178 (1990). Subscripts of spinel and garnet-peridotite mineral compositions refer source  
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29 1179 mode/melts modes during non-modal batch melting. Source and melt modes of spinel  
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31 and garnet peridotites are from McDonough (1990) and Wang et al. (2004), respectively.  
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33 Partial melting coefficients are compiled from McKenzie & O’Nions (1991); Rollinson  
34 1181 (1993) and Elkins et al. (2008).  
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44 1185 **Figure 12.** Pressure-temperature diagram illustrating the potential source region for host  
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46 rocks and enclaves from the KVF (adopted from Jung et al., 2012 and references therein).  
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48 Cpx pressure and temperature estimates based on Neave & Putirka (2017) and Putirka  
49 1187 (2008; eqn. 33), respectively. The average Moho depth is accepted as ~30 km from  
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51 1188 Saunders et al. (1998), Zhu et al. (2006), Mahatsente et al. (2017) and Artemieva &  
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53 1189 Shulgin (2019).  
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59 1191 **Figure 13.** Schematic illustration showing the evolution and probable conduits of the Kula  
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1192 volcanism prior to eruption. The depth of lithosphere-asthenosphere boundary (LAB) is

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3 1193 accepted as ca. 80 km from [Salaün et al. \(2012\)](#), [Mahatsente et al. \(2017\)](#) and [Artemieva](#)  
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5 1194 & [Shulgin \(2019\)](#). However, it is thought that the depth of the LAB decreases from 80 km  
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7 in the northwest and 105 km in the southeast (brown-coloured arrows) to ca. 60 km  
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9 beneath the Kula volcanic field (i.e. [Artemieva & Shulgin, 2019](#)) based on calculated P-T  
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11 values. The depth of the lens-shaped magma chambers including ultramafic cumulates  
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13 resulting from fractional crystallisation (FC) is calculated using the Cpx-melt  
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15 thermobarometers.  
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For Review Only

## TABLE CAPTIONS

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5 1202 **Supplementary Table 1.** Modal mineralogy of the glass bearing enclaves.  
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8 1203 **Supplementary Table 2.** Selected microprobe analyses of olivines from the host rocks  
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10 and enclaves.  
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13 1205 **Supplementary Table 3.** Selected microprobe analyses of clinopyroxenes from the host  
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15 rocks and enclaves. Nomenclature after [Morimoto et al. \(1988\)](#).  
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18 1207 **Supplementary Table 4.** Selected microprobe analyses of hornblendes from the host  
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20 rocks and enclaves. Nomenclature after [Leake et al. \(1997\)](#).  
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23 1209 **Supplementary Table 5.** Representative microprobe analyses of phlogopites.  
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26 1210 **Supplementary Table 6.** Selected microprobe analyses of plagioclases.  
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28 1211 **Supplementary Table 7.** Selected microprobe analyses of feldspathoids.  
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30 1212 **Supplementary Table 8.** Microprobe analyses of oxides.  
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33 1213 **Supplementary Table 9.** Microprobe analyses of the glasses from enclaves.  
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36 1214 **Supplementary Table 10.** Major and trace-element analyses for the KVF.  
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39 1215 **Supplementary Table 11.** Minimum and maximum T-P values from the clinopyroxene  
40 thermometer of [Neave & Putirka \(2007\)](#) and [Putirka \(2008, eqn. 33\)](#). Cpx-liquid test  
41 1216 between the predicted and observed Diopside-Hedenbergite (DiHd) components,  
42 1217 calculated by [Putirka et al. \(1996\)](#) and [Putirka \(1999\)](#). Blue lines are the equilibrium range  
43 1218 accepted as 10% deviation to one-to-one line.  
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48 1220 **Supplementary Data 1.** T-P calculation Excel spreadsheet.  
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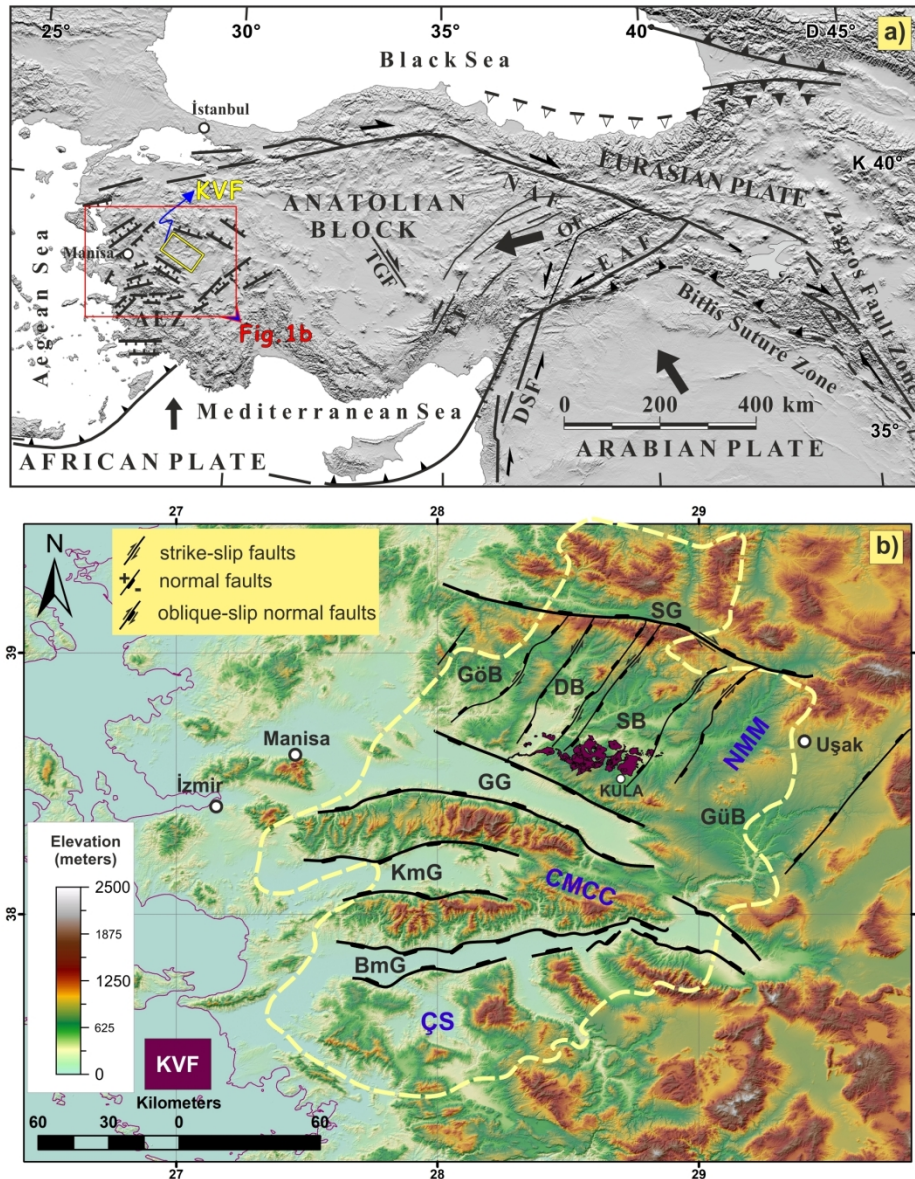


Figure 1

163x208mm (300 x 300 DPI)

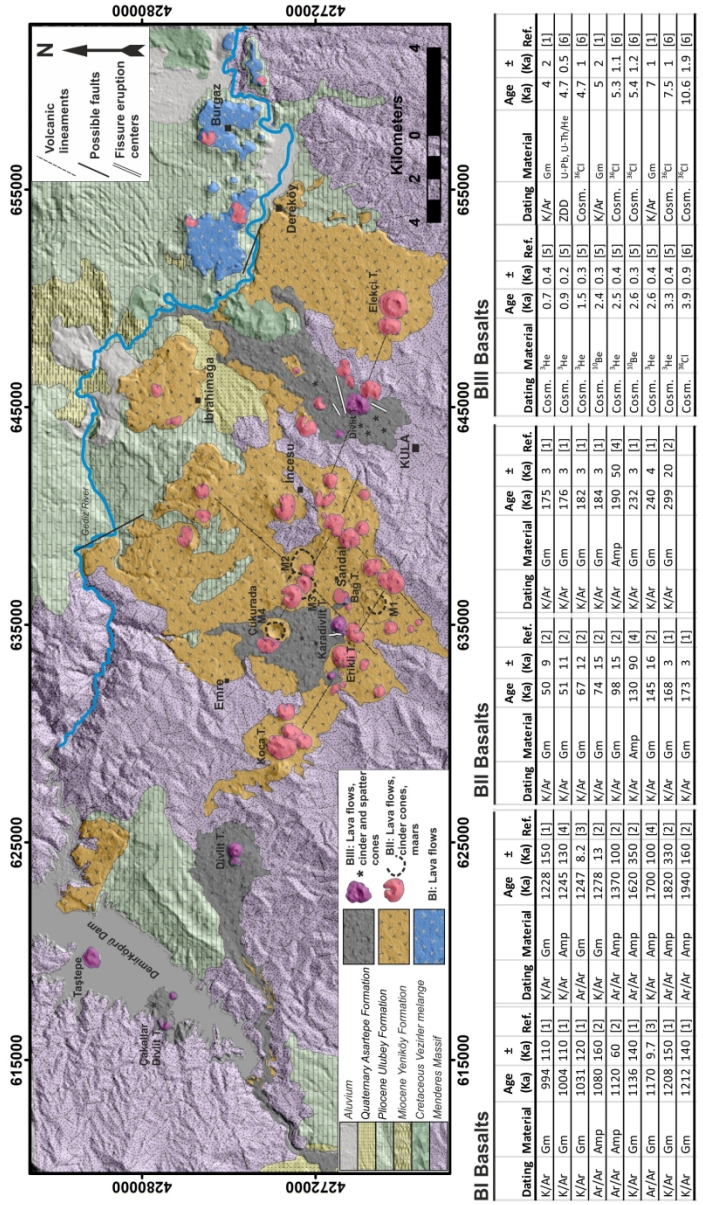


Figure 2

158x272mm (300 x 300 DPI)



Figure 3

195x268mm (300 x 300 DPI)

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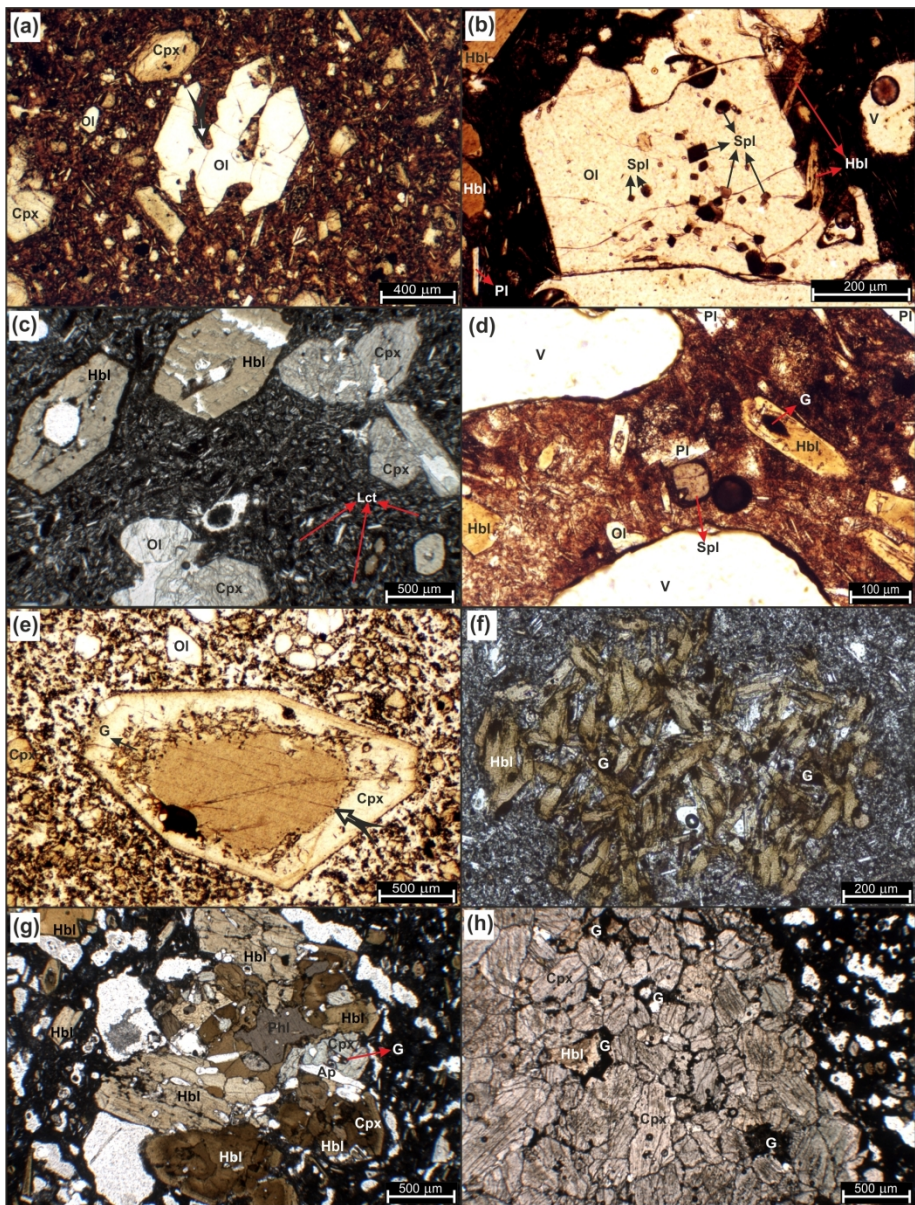


Figure 4

182x240mm (300 x 300 DPI)

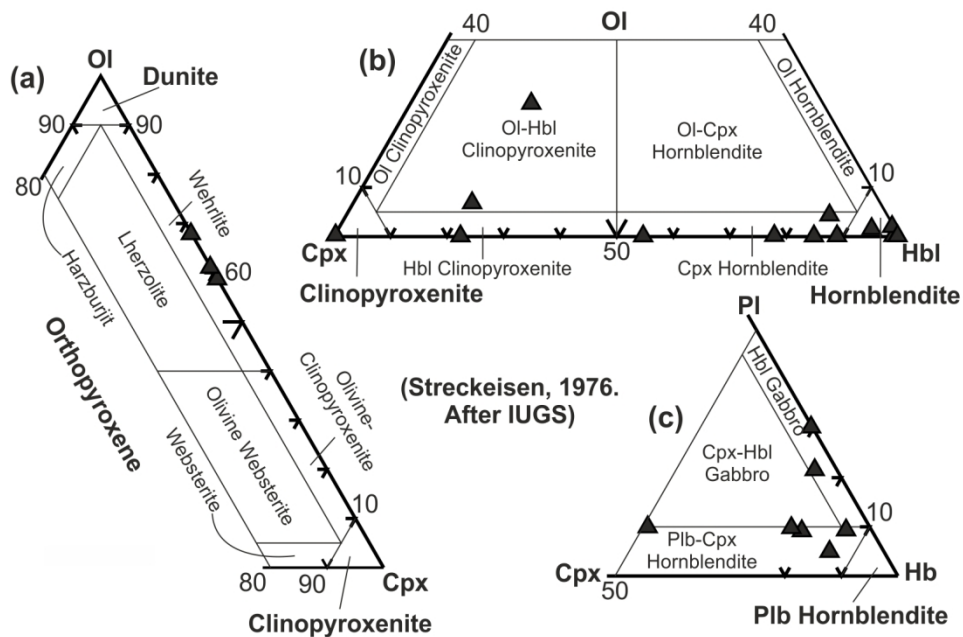


Figure 5

144x93mm (300 x 300 DPI)



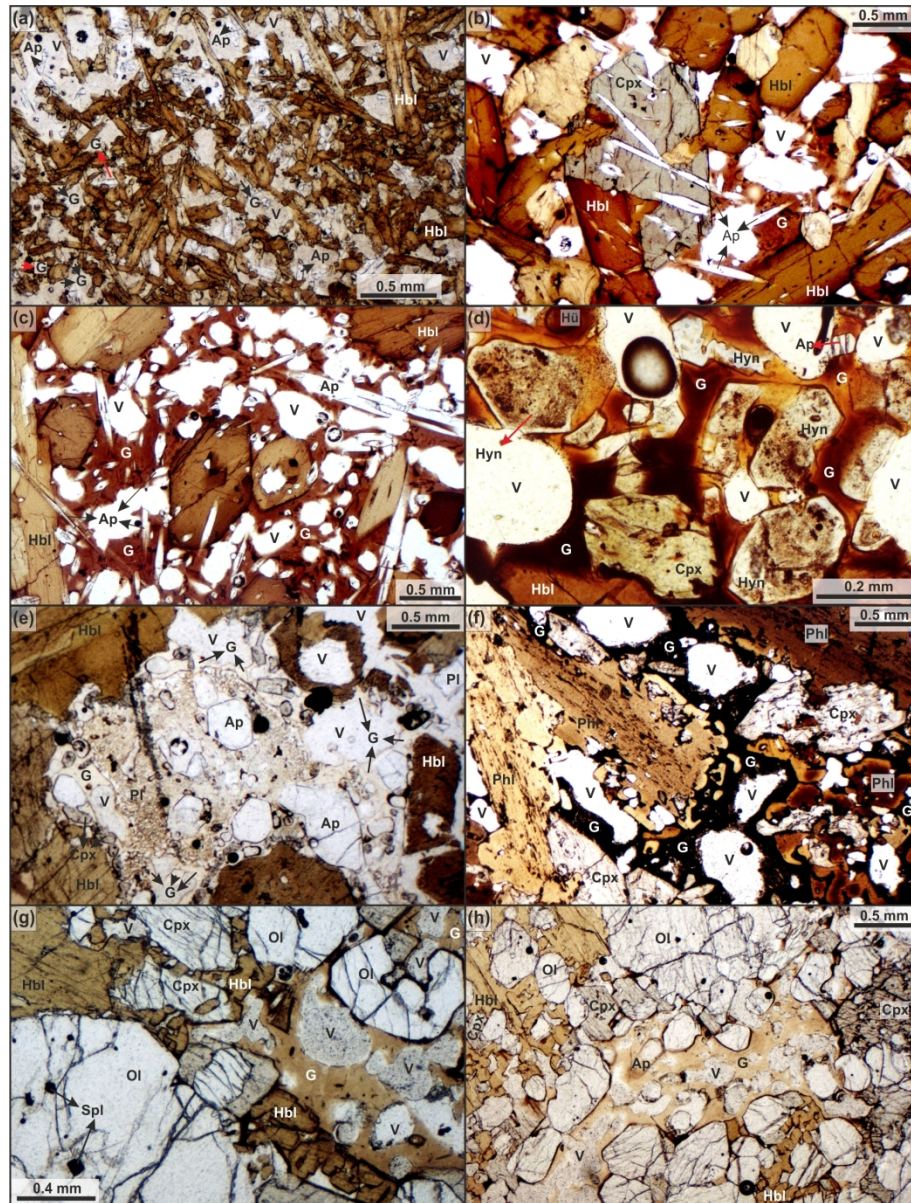


Figure 6

182x240mm (300 x 300 DPI)

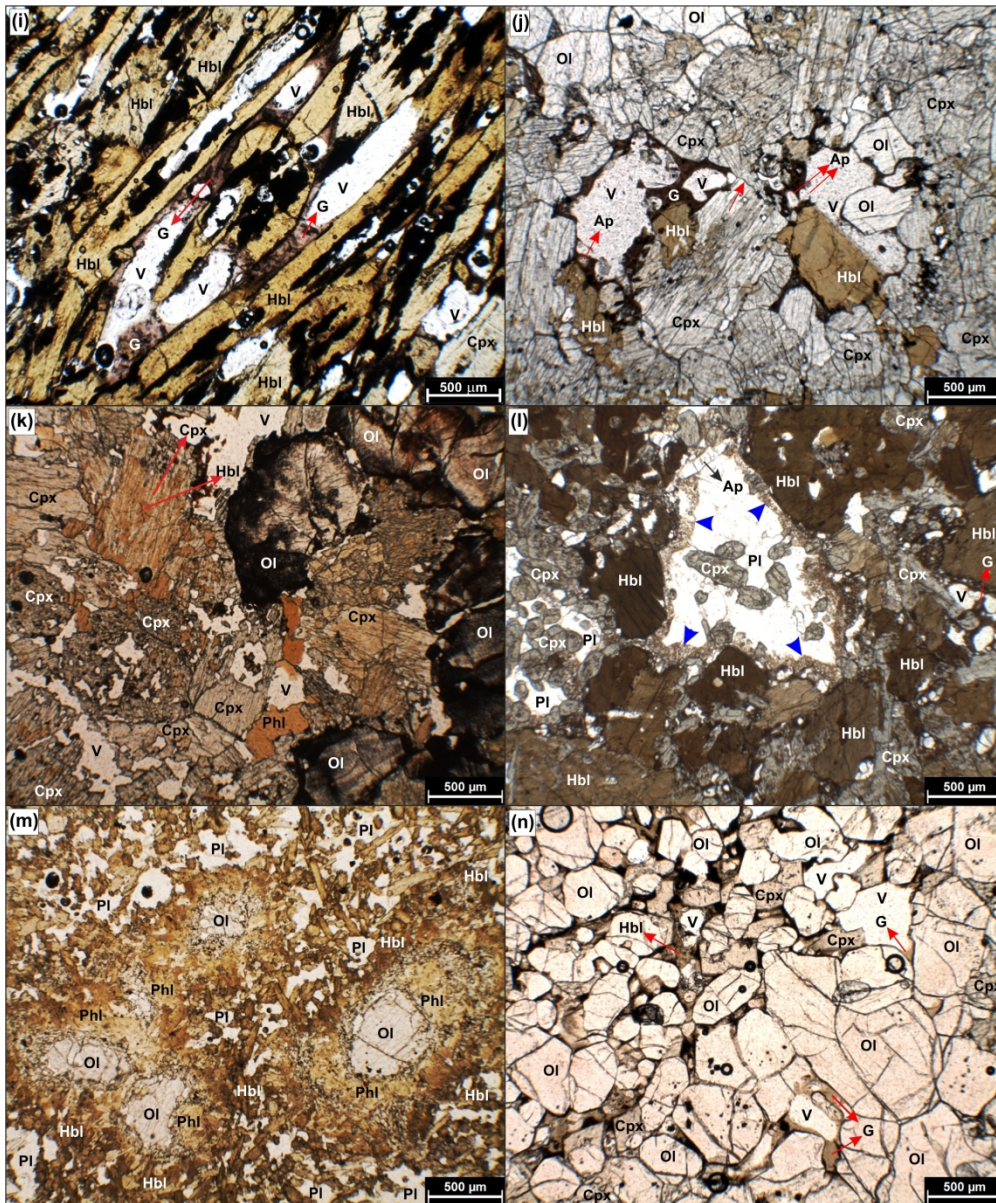


Figure 6 continued

191x229mm (300 x 300 DPI)

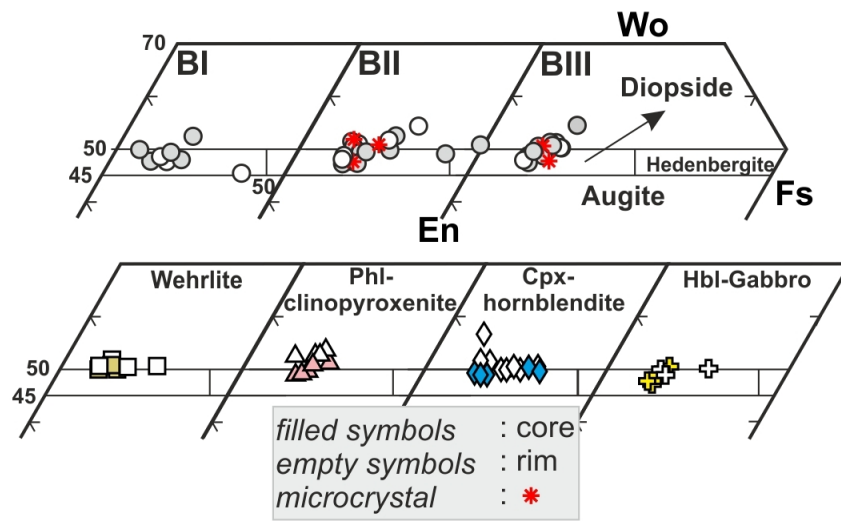


Figure 7

105x57mm (300 x 300 DPI)

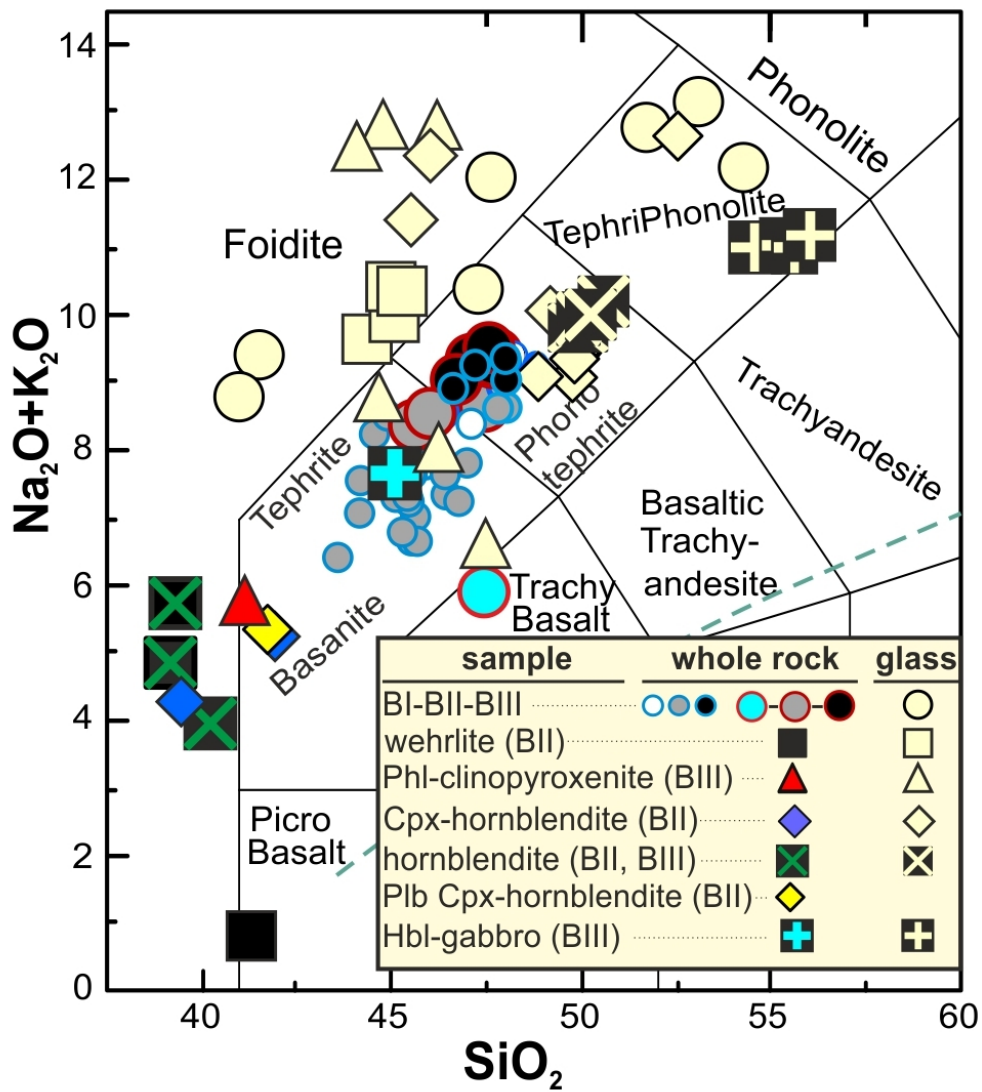


Figure 8

82x91mm (300 x 300 DPI)

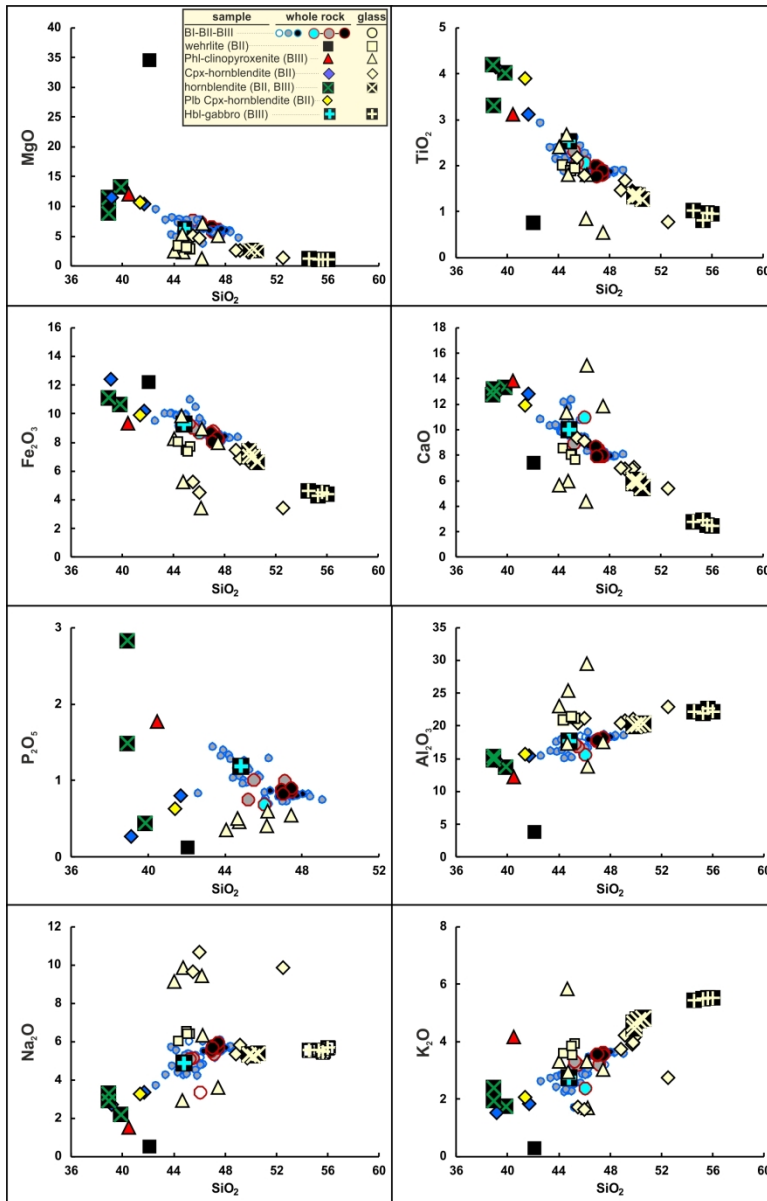


Figure 9

182x282mm (300 x 300 DPI)

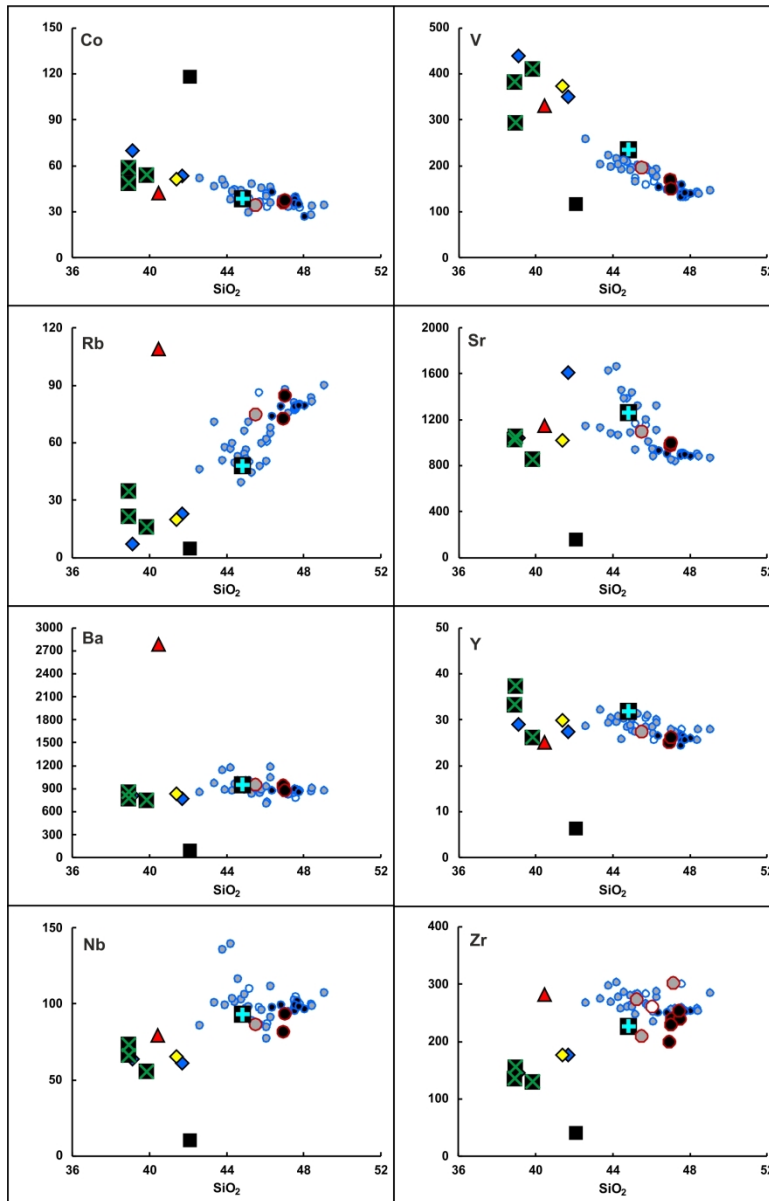


Figure 9 continued

182x281mm (300 x 300 DPI)

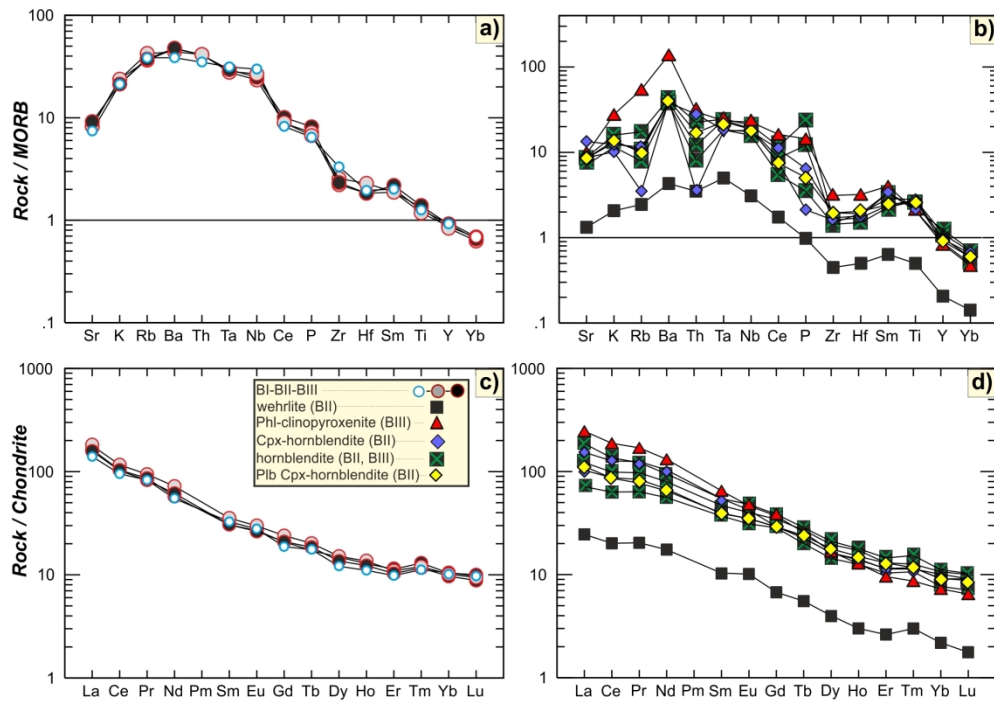


Figure 10

187x130mm (300 x 300 DPI)

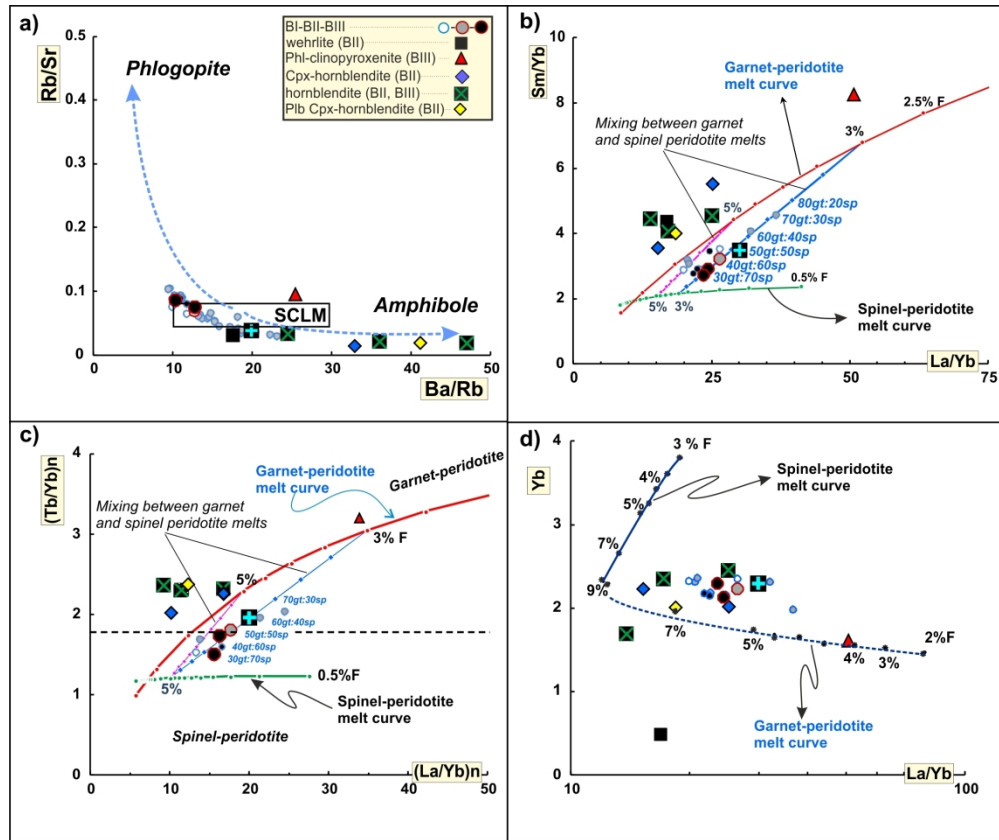


Figure 11

192x161mm (300 x 300 DPI)



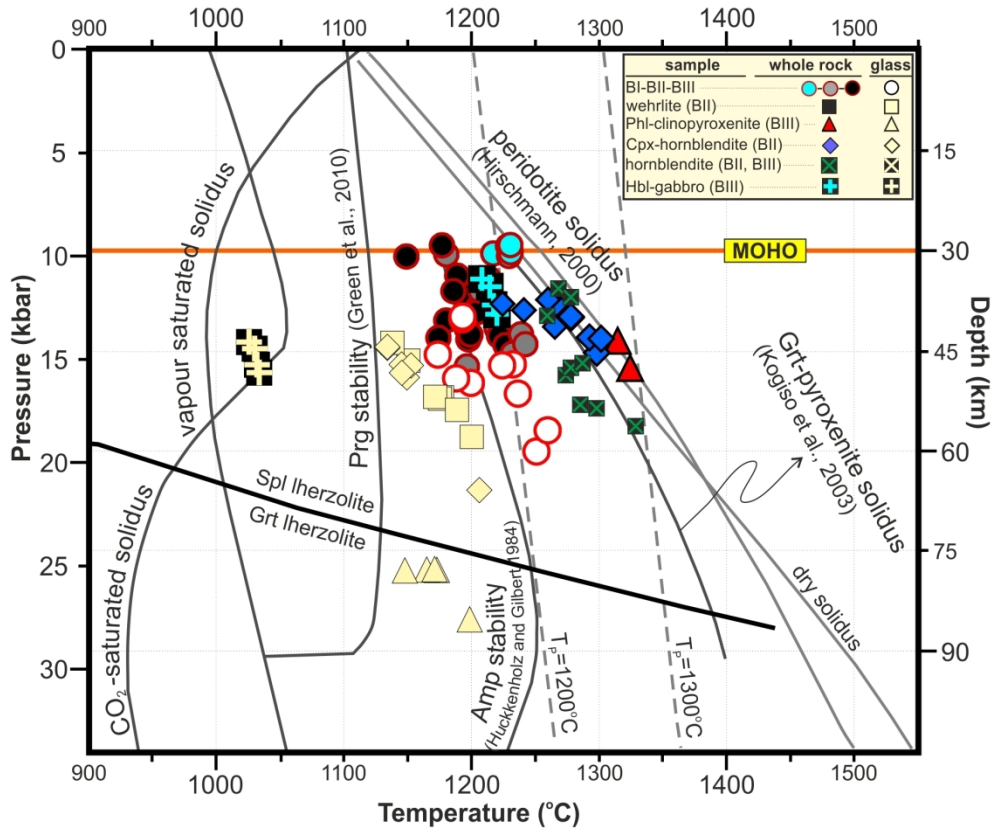


Figure 12

166x143mm (300 x 300 DPI)

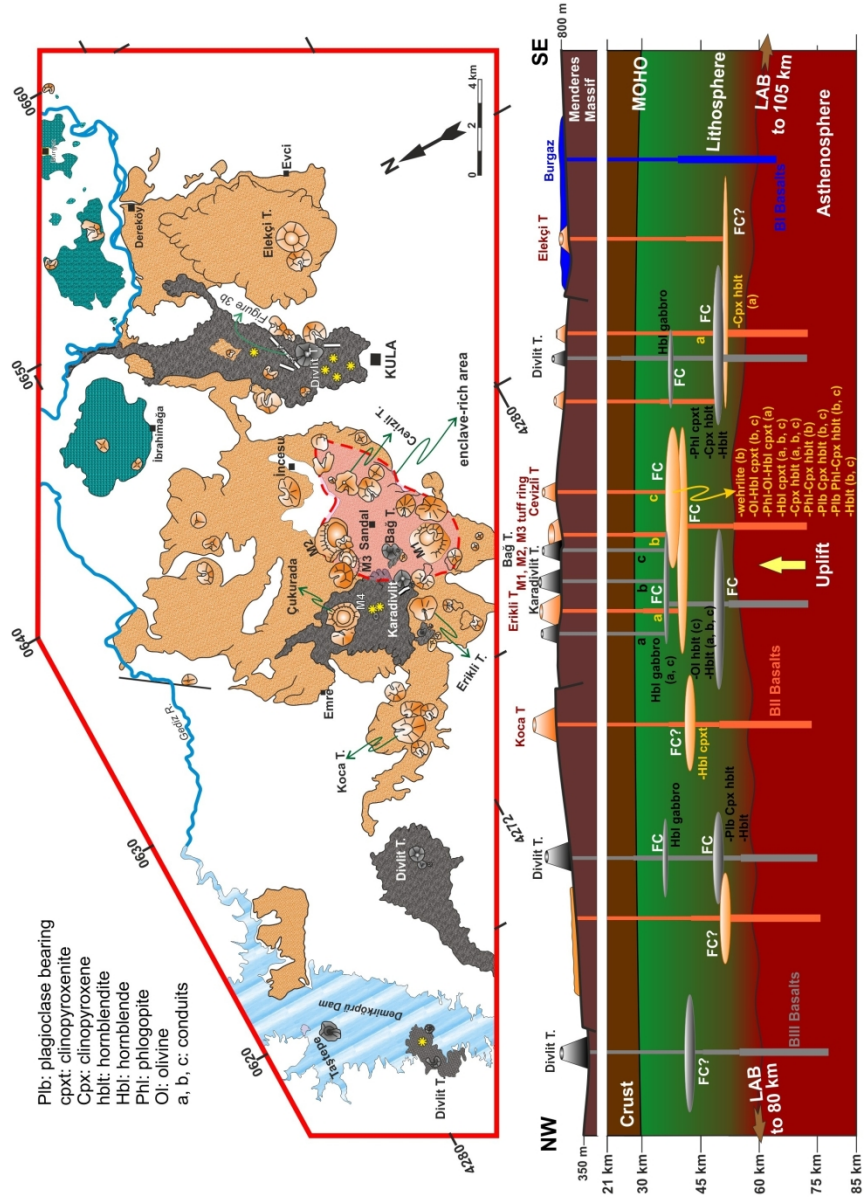


Figure 13

173x242mm (300 x 300 DPI)

1	UTM coordinates	637447 / 4272874				645204 /	635889 /	637447 /	639387 /	634570 / 4268	637447 /	634570 /	637447 /
2	(WGS84, E / N)					4270729	4269521	4272874	4271146	542	4272874	4268542	4272874
3	<b>Sample No: K97-</b>	<b>10a2(BII)</b>	<b>10a15(BII)</b>	<b>10a9(BII)</b>	<b>10a17(BII)</b>	<b>70a2(BIII)</b>	<b>49a3(BII)</b>	<b>10a16(BII)</b>	<b>30a(BII)</b>	<b>48a2(BII)</b>	<b>10a1(BII)</b>	<b>48a1(BII)</b>	<b>10a10(BII)</b>
4	<b># of points</b>	<b>3000</b>	<b>3000</b>	<b>2890</b>	<b>2759</b>	<b>3000</b>	<b>2391</b>	<b>1000</b>	<b>3000</b>	<b>3151</b>	<b>1000</b>	<b>2061</b>	<b>2000</b>
5	<b>Sample</b>	<b>Wehrlite</b>	<b>Wehrlite</b>	<b>Wehrlite</b>	<b>Hbl-Cpxt</b>	<b>Plh-Cpxt</b>	<b>OI-Hbl-Cpxt</b>	<b>Cpx-Hblt</b>	<b>Cpx-Hblt</b>	<b>Cpx-Hblt</b>	<b>Cpx-Hblt</b>	<b>Cpx-Hblt</b>	<b>Plb-Cpx-Hblt</b>
6	<b>Olivine</b>	56,9	54,8	50,3	-	-	6,7	-	-	-	-	3,25	-
7	<b>Clinopyroxene</b>	26,83	38,5	32	74	33	70,4	13,2	12,03	40,24	9,2	7,52	7,9
8	<b>Hornblende</b>	5,64	3,7	16,9	21,5	-	20,7	75,2	42,83	48,87	75,5	63,9	55,1
9	<b>Phlogopite</b>	-	-	0,3	0,2	38,5	-	-	-	-	2,1	-	18,1
10	<b>Plagioclase</b>	-	-	-	-	-	-	-	1,14	0,2	-	-	7
11	<b>Nepheline</b>	-	-	-	-	-	-	-	-	-	-	-	-
12	<b>Häüyne</b>	-	-	-	-	-	-	-	1,33	-	-	-	-
13	<b>Apatite</b>	-	-	-	-	1	0,1	3	1,67	0,06	-	-	6,5
14	<b>Sphene</b>	-	-	-	-	-	-	-	-	0,48	1,1	-	1,5
15	<b>Calcite</b>	-	0,5	-	-	-	-	-	-	-	-	-	-
16	<b>Oxides</b>	1,27	0,8	0,1	-	0,2	-	-	-	-	-	-	-
17	<b>Total</b>	<b>90,64</b>	<b>98,3</b>	<b>99,6</b>	<b>95,7</b>	<b>75,4</b>	<b>97,9</b>	<b>91,4</b>	<b>59</b>	<b>89,85</b>	<b>87,9</b>	<b>74,67</b>	<b>96,1</b>
18	<b>Glass</b>	5,8	0,6	0,3	3,2	13,9	1,3	5	19,03	6,09	4,1	11,45	1,8
19	<b>Vesicle</b>	3,56	1,1	0,1	1,1	10,7	0,8	3,6	21,97	4,06	8	13,88	2,1
20	<b>Total</b>	<b>9,36</b>	<b>1,7</b>	<b>0,4</b>	<b>4,3</b>	<b>24,6</b>	<b>2,1</b>	<b>8,6</b>	<b>41</b>	<b>10,15</b>	<b>12,1</b>	<b>25,33</b>	<b>3,9</b>
21	UTM coordinates	631879 /	644710 /	635889 /	634570 /	639684 /	624717 /	624717 /	637447 / 4272874			636125 /	632680 /
22	(WGS84, E / N)	4270995	4269654	4269521	4268542	4269941	4275318	4275318				4270660	4271325
23	<b>Sample No: K97-</b>	<b>37a4(BII)</b>	<b>17a2(BIII)</b>	<b>49a1(BII)</b>	<b>14a(BIII)</b>	<b>33a(BII)</b>	<b>44a(BIII)</b>	<b>46a(BIII)</b>	<b>10a18(BII)</b>	<b>10a8(BII)</b>	<b>42a2(BIII)</b>	<b>39a1(BIII)</b>	
24	<b># of points</b>	<b>2006</b>	<b>3000</b>	<b>1077</b>	<b>2635</b>	<b>1000</b>	<b>2211</b>	<b>3300</b>	<b>2587</b>	<b>2000</b>	<b>2000</b>	<b>1000</b>	
25	<b>Sample</b>	<b>Plh-OI-Hbl</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Plb Cpx</b>	<b>Plb Cpx</b>	<b>Plb Plh-Cpx</b>	<b>Plb Plh-Cpx</b>	<b>Hbl</b>	<b>Hbl</b>	
26		<b>Cpxt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Hblt</b>	<b>Gabbro</b>	<b>Gabbro</b>	
27	<b>Olivine</b>	22,9	-	0,8	-	1,2	0,5	-	-	-	0,8	-	
28	<b>Clinopyroxene</b>	43,5	-	2	0,5	-	31,4	9	8,1	3,5	2,8	-	
29	<b>Hornblende</b>	18,2	73,5	47,4	58,4	58,1	40,7	61,24	72,1	67,2	53,4	32,3	
30	<b>Phlogopite</b>	13,2	-	-	-	1,9	1,2	-	6,4	6,9	0,8	-	
31	<b>Plagioclase</b>	-	-	-	-	-	7,9	7,37	4,1	7,2	15,4	14	
32	<b>Apatite</b>	0,4	3	1,4	7,1	4	0,7	1,21	0,5	4,9	2,6	3,7	
33	<b>Sphene</b>	-	-	-	-	-	-	-	1,3	1,5	-	-	
34	<b>Total</b>	<b>98,2</b>	<b>76,5</b>	<b>51,6</b>	<b>66</b>	<b>65,2</b>	<b>82,4</b>	<b>78,82</b>	<b>92,5</b>	<b>91,2</b>	<b>75,8</b>	<b>50</b>	
35	<b>Glass</b>	1,1	11,5	17,9	17,7	14	9,4	11,57	4,3	4,1	11,3	29	
36	<b>Vesicle</b>	0,7	12	30,5	16,3	20,8	8,2	9,61	3,2	4,7	12,9	21	
37	<b>Total</b>	<b>1,8</b>	<b>23,5</b>	<b>48,4</b>	<b>34</b>	<b>34,8</b>	<b>17,6</b>	<b>21,18</b>	<b>7,5</b>	<b>8,8</b>	<b>24,2</b>	<b>50</b>	

*OI: olivine, Cpx: clinopyroxene, Hbl: hornblende, Plh: phlogopite, Plb: plagioclase bearing, Cpxt: clinopyroxenite, Hblt: hornblendite*

Olivine Sample	Host rock										Enclave															
	BI			BII			BIII				Wehrlite (BII)				Hornblende Gabbro (BIII)											
	K97-58			10			31			48			42			70			10a2		42a2					
wt. %	c	r	mc	c	r	mc	c	r	mc	c	r	mc	c	r	mc	c	r	c	r	c	r	c	c	r		
	#8	#9	58#	#6	#7	#22	#26	#27	#24	#26	#27	#33	#34	#42	#49	#50	#48	#49	#52	#53	#45	#46	#57	#61	#62	
SiO <sub>2</sub>	39,20	36,92	37,65	39,45	39,29	39,08	39,46	38,80	38,16	39,40	38,92	39,28	39,43	38,96	39,65	39,86	39,44	39,12	39,19	39,28	40,24	38,63	38,08	39,32	38,97	
Al <sub>2</sub> O <sub>3</sub>	0,04	0,00	0,08	0,04	0,03	0,03	0,06	0,02	0,04	0,09	0,01	0,05	0,03	0,06	0,05	0,03	0,03	0,01	0,03	0,02	0,05	0,00	0,04	0,03	0,04	
FeO <sub>t</sub>	14,92	25,74	26,75	12,34	12,77	13,62	12,87	14,20	18,47	15,72	17,49	14,16	14,34	14,28	13,63	13,07	14,79	14,98	14,70	14,30	13,90	18,29	19,81	14,50	15,38	
MgO	46,21	37,38	35,19	47,35	46,87	46,01	47,39	45,87	42,03	44,90	43,42	46,27	45,86	45,81	47,62	47,22	45,80	46,07	45,81	45,79	46,10	42,29	40,65	46,11	45,09	
CaO	0,29	0,40	0,39	0,21	0,25	0,25	0,22	0,25	0,28	0,25	0,29	0,22	0,22	0,27	0,24	0,18	0,08	0,09	0,09	0,15	0,25	0,21	0,21	0,23	0,11	
Na <sub>2</sub> O	0,00	0,04	0,02	0,03	0,03	0,02	0,01	0,00	0,00	0,04	0,00	0,00	0,00	0,02	0,03	0,00	0,01	0,02	0,04	0,04	0,02	0,00	0,01	0,01	0,01	
K <sub>2</sub> O	0,01	0,00	0,06	0,01	0,03	0,00	0,00	0,01	0,01	0,02	0,00	0,00	0,03	0,00	0,01	0,00	0,00	0,02	0,00	0,03	0,00	0,01	0,00	0,02	0,00	
TiO <sub>2</sub>	0,01	0,02	0,05	0,02	0,08	0,00	0,00	0,00	0,04	0,09	0,05	0,05	0,00	0,00	0,00	0,01	0,03	0,04	0,03	0,00	0,04	0,01	0,00	0,01	0,09	
MnO	0,20	0,48	0,58	0,19	0,24	0,17	0,25	0,29	0,36	0,24	0,26	0,22	0,20	0,29	0,21	0,13	0,24	0,25	0,25	0,19	0,21	0,50	0,55	0,26	0,29	
Cr <sub>2</sub> O <sub>3</sub>	0,05	0,00	0,00	0,03	0,04	0,03	0,00	0,02	0,02	0,03	0,00	0,02	0,00	0,05	0,00	0,01	0,02	0,00	0,01	0,00	0,00	0,00	0,00	0,03	0,11	
NiO	0,05	0,03	0,00	0,19	0,18	0,14	0,13	0,14	0,06	0,08	0,08	0,09	0,12	0,11	0,05	0,14	0,11	0,09	0,14	0,13	0,11	0,09	0,09	0,15	0,10	
<b>Total</b>	<b>100,98</b>	<b>100,99</b>	<b>100,77</b>	<b>99,86</b>	<b>99,81</b>	<b>99,34</b>	<b>100,38</b>	<b>99,58</b>	<b>99,48</b>	<b>100,86</b>	<b>100,51</b>	<b>100,35</b>	<b>100,23</b>	<b>99,84</b>	<b>101,48</b>	<b>100,64</b>	<b>100,55</b>	<b>100,69</b>	<b>100,27</b>	<b>99,93</b>	<b>100,92</b>	<b>100,02</b>	<b>99,43</b>	<b>100,66</b>	<b>100,19</b>	
<b>Calculation based on O=4 APFU</b>																										
Si	0,977	0,972	0,995	0,983	0,982	0,985	0,981	0,979	0,983	0,986	0,986	0,982	0,987	0,980	0,978	0,987	0,986	0,979	0,983	0,987	0,997	0,988	0,988	0,982	0,982	
Al	0,001	-	0,002	0,001	0,001	0,001	0,002	-	0,001	0,003	-	0,001	0,001	0,002	0,001	0,001	0,001	-	0,001	0,001	0,001	-	0,001	0,001	0,001	
Fe	0,311	0,566	0,591	0,257	0,267	0,287	0,267	0,300	0,398	0,329	0,371	0,296	0,300	0,301	0,281	0,271	0,309	0,313	0,308	0,300	0,288	0,391	0,430	0,303	0,324	
Mg	1,717	1,466	1,387	1,759	1,746	1,728	1,755	1,725	1,614	1,675	1,640	1,724	1,711	1,718	1,749	1,743	1,706	1,717	1,712	1,714	1,702	1,613	1,572	1,716	1,693	
Ca	0,008	0,011	0,011	0,006	0,007	0,007	0,006	0,007	0,008	0,007	0,008	0,006	0,006	0,006	0,007	0,006	0,005	0,002	0,002	0,004	0,007	0,006	0,006	0,006	0,003	
Na	-	0,002	0,001	0,001	0,002	0,001	0,001	-	-	0,002	-	-	-	0,001	0,001	-	-	0,001	0,002	0,002	0,001	-	0,001	0,001	-	
K	-	-	0,002	-	0,001	-	-	-	-	0,001	-	-	0,001	-	-	-	-	0,001	-	0,001	-	-	-	0,001	-	
Ti	-	-	0,001	-	0,002	-	-	-	0,001	0,002	0,001	0,001	-	-	-	-	0,001	0,001	0,001	-	0,001	-	-	-	0,002	
Mn	0,004	0,011	0,013	0,004	0,005	0,004	0,005	0,006	0,008	0,005	0,006	0,005	0,004	0,006	0,004	0,003	0,005	0,005	0,005	0,004	0,004	0,011	0,012	0,005	0,006	
Cr	0,001	-	-	0,001	0,001	0,001	-	-	0,001	-	-	-	-	0,001	-	-	-	-	-	-	-	-	-	0,001	0,002	
Ni	0,001	0,001	-	0,004	0,004	0,003	0,003	0,003	0,001	0,002	0,002	0,002	0,002	0,002	0,001	0,003	0,002	0,002	0,003	0,003	0,002	0,002	0,002	0,003	0,002	
<b>Total</b>	<b>3,021</b>	<b>3,029</b>	<b>3,004</b>	<b>3,016</b>	<b>3,017</b>	<b>3,015</b>	<b>3,019</b>	<b>3,021</b>	<b>3,015</b>	<b>3,012</b>	<b>3,013</b>	<b>3,016</b>	<b>3,013</b>	<b>3,019</b>	<b>3,023</b>	<b>3,012</b>	<b>3,013</b>	<b>3,022</b>	<b>3,017</b>	<b>3,015</b>	<b>3,002</b>	<b>3,012</b>	<b>3,012</b>	<b>3,018</b>	<b>3,015</b>	
Mg#	85	72	70	87	87	86	87	85	80	84	82	85	85	85	86	87	85,00	85,00	85,00	85,00	86,00	80,00	79,00	85,00	84,00	
Fo	84,7	72,1	70,1	87,2	86,7	85,8	86,8	85,2	80,2	83,6	81,6	85,3	85,1	85,1	86,2	86,6	84,7	84,6	84,7	85,1	85,5	80,5	78,5	85,0	83,9	

c: core, r: rim, mc: microcrystal

Cpx Sample	Host rock										Enclave															
	BI		BII		BIII				Wehrlite (BII)				Cpx-hornblende (BII)				Hbl-gabbro (BII)		Phl-clinopyroxenite							
	K97-58		10		31		42		70		10a2				30a		48a		42a2		70a2					
wt. %	c	r	c	r	c	r	mc	mc	c	r	c	r	mc	c	c in g	c	c in g	c in g	c	#133	c in g	c	r	c	r	
	#13	#14	#80	#81	#90	#91	#99	#21	#45	#46	#56	#57	#67	#57	#67	#95	#5	#14	#132	#133	#152	#65	#66	#6	#7	
SiO <sub>2</sub>	52,18	49,32	44,57	47,74	45,83	48,74	47,86	50,13	48,82	49,37	40,85	46,37	45,66	47,39	43,69	46,41	45,62	45,95	46,41	45,80	49,42	49,44	48,97	51,90	44,90	
Al <sub>2</sub> O <sub>3</sub>	0,66	2,82	7,25	5,37	9,26	6,49	6,44	3,19	5,62	4,91	12,92	7,71	8,88	6,28	9,83	9,39	8,97	9,52	8,98	8,71	6,07	5,78	6,17	4,10	9,62	
FeOt	2,49	13,51	15,94	6,19	8,38	4,89	4,82	13,14	5,25	5,03	7,51	7,50	5,65	3,85	8,77	5,49	6,27	7,46	5,06	5,55	6,18	5,09	9,11	5,50	6,73	
MgO	16,96	10,58	5,98	13,97	11,13	14,43	13,52	8,91	14,71	15,06	10,09	11,95	12,90	14,69	10,49	12,89	12,54	11,83	12,98	12,64	12,64	14,83	10,38	13,59	11,32	
CaO	25,52	21,07	20,99	22,95	21,72	22,45	24,12	19,30	22,99	22,66	23,73	22,58	22,77	23,53	22,08	22,47	22,69	22,50	22,32	23,01	23,65	22,12	21,77	22,94	23,55	
Na <sub>2</sub> O	0,17	0,70	1,78	0,53	1,07	0,72	0,77	2,94	0,49	0,54	0,66	0,81	0,76	0,56	0,87	0,72	0,80	0,89	0,88	0,73	1,07	0,59	1,53	1,42	0,87	
K <sub>2</sub> O	0,01	0,02	0,00	0,01	0,02	0,00	0,00	0,00	0,01	0,01	0,00	0,03	0,03	0,02	0,04	0,02	0,01	0,01	0,03	0,04	0,00	0,00	0,01	0,02	0,01	
TiO <sub>2</sub>	0,12	1,13	1,92	1,98	2,33	1,77	1,74	0,46	1,79	1,42	3,04	1,89	2,43	1,72	3,00	2,80	2,19	2,04	2,34	2,63	1,12	1,62	1,57	0,69	3,25	
MnO	0,38	0,41	0,59	0,11	0,12	0,08	0,10	0,35	0,08	0,13	0,08	0,15	0,04	0,05	0,44	0,09	0,12	0,13	0,12	0,12	0,14	0,12	0,24	0,14	0,17	
Cr <sub>2</sub> O <sub>3</sub>	0,00	0,00	0,00	0,00	0,02	0,32	0,11	0,05	0,04	0,34	0,02	0,07	0,16	0,47	0,00	0,35	0,00	0,03	0,62	0,49	0,08	0,22	0,04	0,07	0,04	
<b>Total</b>	<b>98,50</b>	<b>99,57</b>	<b>99,02</b>	<b>98,85</b>	<b>99,87</b>	<b>99,88</b>	<b>99,49</b>	<b>98,47</b>	<b>99,80</b>	<b>99,48</b>	<b>98,91</b>	<b>99,05</b>	<b>99,30</b>	<b>98,56</b>	<b>99,20</b>	<b>100,63</b>	<b>99,21</b>	<b>100,36</b>	<b>99,75</b>	<b>99,71</b>	<b>100,37</b>	<b>99,81</b>	<b>99,79</b>	<b>100,37</b>	<b>100,44</b>	
<b>Calculation based on O=6 APFU</b>																										
Si	1,93	1,88	1,73	1,78	1,70	1,79	1,77	1,91	1,80	1,82	1,54	1,74	1,69	1,76	1,65	1,70	1,69	1,69	1,71	1,70	1,81	1,82	1,83	1,89	1,66	
Mg	0,94	0,60	0,35	0,78	0,62	0,79	0,74	0,51	0,81	0,83	0,57	0,67	0,71	0,81	0,59	0,70	0,69	0,65	0,71	0,70	0,69	0,81	0,58	0,74	0,62	
Ca	1,01	0,86	0,87	0,92	0,87	0,88	0,95	0,79	0,91	0,89	0,96	0,91	0,90	0,94	0,89	0,88	0,90	0,89	0,88	0,91	0,93	0,87	0,87	0,90	0,93	
Na	0,01	0,05	0,13	0,04	0,08	0,05	0,06	0,22	0,04	0,04	0,05	0,06	0,06	0,04	0,06	0,05	0,06	0,06	0,06	0,05	0,08	0,04	0,11	0,10	0,06	
K	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Ti	0,00	0,03	0,06	0,06	0,07	0,05	0,05	0,01	0,05	0,04	0,09	0,05	0,07	0,05	0,09	0,08	0,06	0,06	0,07	0,07	0,03	0,05	0,04	0,02	0,09	
Mn	0,01	0,01	0,02	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,01	
Cr	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,01	0,01	0,00	0,01	0,00	0,00	0,02	0,01	0,00	0,01	0,00	0,00	0,00	
Fe <sup>3+</sup>	0,08	0,10	0,23	0,13	0,13	0,09	0,14	0,23	0,10	0,10	0,23	0,14	0,15	0,12	0,17	0,08	0,16	0,15	0,11	0,12	0,12	0,07	0,09	0,10	0,15	
Fe <sup>2+</sup>	0,00	0,33	0,29	0,06	0,13	0,06	0,00	0,19	0,06	0,05	0,01	0,09	0,03	0,00	0,11	0,08	0,04	0,08	0,05	0,05	0,07	0,09	0,19	0,07	0,06	
Al <sub>IV</sub>	0,03	0,12	0,27	0,22	0,30	0,21	0,24	0,09	0,21	0,18	0,47	0,27	0,31	0,24	0,36	0,30	0,31	0,31	0,29	0,31	0,19	0,19	0,17	0,11	0,34	
Al <sub>VI</sub>	0,00	0,01	0,06	0,02	0,11	0,07	0,05	0,05	0,04	0,03	0,11	0,08	0,08	0,04	0,08	0,10	0,09	0,11	0,10	0,07	0,08	0,07	0,10	0,07	0,08	
<b>Total</b>	<b>4,02</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,01</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	<b>4,00</b>	
Fe <sub>2</sub> O <sub>3</sub>	2,77	3,41	7,94	4,66	4,70	3,22	5,21	8,05	3,68	3,62	8,13	5,03	5,21	4,28	5,93	3,06	5,53	5,32	3,83	4,42	4,41	2,40	3,27	3,56	5,21	
FeO	0,00	10,44	8,80	2,00	4,15	1,98	0,13	5,90	1,94	1,76	0,20	2,98	0,97	0,00	3,43	2,74	1,29	2,67	1,61	1,57	2,21	2,94	6,17	2,29	2,04	
Wo	49,97	45,47	50,26	48,60	49,65	48,46	51,66	45,99	48,35	47,67	54,39	50,12	50,46	50,09	50,73	50,28	50,40	50,24	50,35	51,23	51,34	47,35	50,24	49,72	52,87	
En	46,21	31,77	19,93	41,16	35,40	43,31	40,29	29,56	43,03	44,08	32,17	36,88	39,77	43,51	33,54	40,12	38,73	36,76	40,74	39,14	38,19	44,15	33,34	40,98	35,34	
Fs	3,81	22,76	29,81	10,24	14,95	8,23	8,05	24,45	8,62	8,25	13,44	13,00	9,77	6,40	15,73	9,60	10,87	13,00	8,91	9,63	10,48	8,51	16,41	9,30	11,79	
Mg*	92	58	40	80	70	84	83	55	83	84	71	74	80	87	68	81	78	74	82	80	78	84	67	82	75	

c: core, r: rim, mc: microcrystal, g: glass, Hbl: hornblend, Cpx: clinopyroxene, Phl: phlogopite

1	
2	
3	<u> (BIII)</u>
4	
5	r
6	<u>#11</u>
7	42,14
8	12,32
9	6,80
10	10,80
11	24,29
12	0,49
13	0,01
14	3,12
15	0,10
16	0,04
17	100,08
18	
19	
20	1,56
21	0,60
22	0,97
23	0,04
24	0,00
25	0,09
26	0,00
27	0,00
28	0,20
29	0,02
30	0,44
31	0,10
32	
33	<u>4,00</u>
34	6,98
35	<u>0,52</u>
36	54,45
37	33,66
38	<u>11,89</u>
39	<u>74</u>
40	
41	
42	
43	
44	
45	
46	

For Review Only

Hbl	Host rock												Enclave																			
	BII			BIII						Wehrlite (BII)		Hornblendite (BIII)				Clinopyroxene hornblendite (BII)						Hbl-Gabbro (BIII)										
Sample	K97-10			31			42			70			10a2		17a2				30a						48a				42a2			
wt.%	c	r	m	c	m	m	c	r	c	m	c	r	c	r	c	r	inc	c	r	inc	c in g	c	c	r	c	c	c in g	c				
	#92	#93	#96	#1	#12	#21	#34b	#35b	#39b	#59	#47b	#48b	#64	#65	#34	#35	#40	#18	#19	#20	#103	#107	#129	#130	#147	#42	#54	#58				
<b>SiO<sub>2</sub></b>	38,71	37,90	37,21	38,28	40,48	40,96	38,98	38,04	39,24	39,33	37,94	38,45	38,74	39,18	39,74	39,03	38,60	37,65	38,64	37,93	38,98	40,57	38,83	39,44	39,40	39,75	38,83	38,11				
<b>Al<sub>2</sub>O<sub>3</sub></b>	13,86	14,30	14,49	14,80	11,92	10,85	14,73	14,59	14,58	14,21	14,07	14,49	14,82	14,09	14,55	14,03	14,05	14,34	14,52	15,09	14,94	14,54	14,59	15,07	14,71	14,18	14,54	15,35				
<b>FeOt</b>	11,06	11,11	16,21	8,04	7,40	9,52	8,17	8,74	8,39	9,92	16,97	10,10	13,91	8,25	8,19	11,14	14,32	11,70	9,12	14,59	8,74	8,14	7,86	10,06	7,82	7,89	9,51	13,75				
<b>MgO</b>	13,20	12,41	8,88	14,03	10,36	9,21	14,23	13,85	13,93	13,44	8,43	12,77	10,78	14,65	13,92	12,39	10,73	12,13	13,33	10,25	13,97	14,41	14,25	13,49	14,62	13,94	12,90	10,39				
<b>CaO</b>	12,22	11,99	11,45	12,27	22,18	21,55	12,39	11,86	12,28	11,98	11,74	11,90	11,16	12,19	11,84	12,13	11,61	11,77	11,89	11,78	11,84	12,23	12,07	12,17	12,21	11,50	11,83	11,70				
<b>Na<sub>2</sub>O</b>	2,49	2,27	2,61	2,09	0,86	1,02	2,24	2,20	2,43	2,46	2,34	2,24	2,49	2,34	2,44	2,50	2,46	2,86	2,84	2,71	3,02	2,45	2,59	2,46	2,46	2,92	2,69	2,70				
<b>K<sub>2</sub>O</b>	1,78	1,49	1,77	2,07	0,05	0,03	1,81	1,88	1,73	1,69	1,78	1,64	2,03	1,75	1,73	1,89	1,72	1,62	1,55	1,63	1,33	1,53	1,82	2,07	1,71	1,53	1,50	1,44				
<b>TiO<sub>2</sub></b>	4,37	5,46	4,71	5,27	4,34	3,66	5,15	5,30	5,35	4,19	3,95	4,78	3,05	4,53	5,38	4,42	4,24	3,83	4,27	3,58	4,42	4,31	4,78	2,30	5,12	5,49	5,26	3,70				
<b>MnO</b>	0,20	0,10	0,31	0,04	0,11	0,18	0,10	0,10	0,07	0,12	0,25	0,15	0,21	0,06	0,07	0,10	0,19	0,18	0,13	0,27	0,13	0,15	0,10	0,09	0,08	0,10	0,16	0,23				
<b>Cr<sub>2</sub>O<sub>3</sub></b>	0,03	0,00	0,00	0,04	0,02	0,08	0,00	0,00	0,00	0,02	0,00	0,00	0,03	0,08	0,02	0,00	0,03	0,02	0,03	0,00	0,00	0,09	0,10	0,03	0,13	0,01	0,04					
<b>Tot</b>	97,91	97,02	97,65	96,92	97,70	97,05	97,78	96,56	98,00	97,36	97,46	96,53	97,22	97,10	97,87	97,64	97,96	96,09	96,32	97,82	97,37	98,33	96,97	97,24	98,15	97,41	97,24	97,40				
<b>Calculation based on O=23 APFU</b>																																
<b>Si</b>	5,77	5,69	5,70	5,69	6,01	6,17	5,73	5,68	5,76	5,84	5,83	5,77	5,87	5,80	5,82	5,83	5,82	5,74	5,79	5,74	5,76	5,90	5,75	5,87	5,75	5,84	5,77	5,76				
<b>Mg</b>	2,93	2,78	2,03	3,11	2,29	2,07	3,12	3,09	3,05	2,98	1,93	2,86	2,43	3,23	3,04	2,76	2,41	2,76	2,98	2,31	3,07	3,12	3,15	2,99	3,18	3,05	2,86	2,34				
<b>Ca</b>	1,95	1,93	1,88	1,95	3,53	3,48	1,95	1,90	1,93	1,91	1,93	1,91	1,81	1,93	1,86	1,94	1,88	1,92	1,91	1,91	1,87	1,90	1,92	1,94	1,91	1,81	1,88	1,89				
<b>Na</b>	0,72	0,66	0,78	0,60	0,25	0,30	0,64	0,64	0,69	0,71	0,70	0,65	0,73	0,67	0,69	0,72	0,72	0,84	0,83	0,80	0,86	0,69	0,74	0,71	0,70	0,83	0,77	0,79				
<b>K</b>	0,34	0,29	0,35	0,39	0,01	0,01	0,34	0,36	0,32	0,32	0,35	0,31	0,39	0,33	0,32	0,36	0,33	0,32	0,30	0,31	0,25	0,28	0,34	0,39	0,32	0,29	0,28	0,28				
<b>Ti</b>	0,49	0,62	0,54	0,59	0,48	0,41	0,57	0,60	0,59	0,47	0,46	0,54	0,35	0,50	0,59	0,50	0,48	0,44	0,48	0,41	0,49	0,47	0,53	0,26	0,56	0,61	0,59	0,42				
<b>Mn</b>	0,03	0,01	0,04	0,00	0,01	0,02	0,01	0,01	0,01	0,01	0,03	0,02	0,03	0,01	0,01	0,01	0,02	0,02	0,02	0,03	0,02	0,02	0,01	0,01	0,01	0,01	0,02	0,03				
<b>Cr</b>	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,00	0,01	0,00	0,00	0,00				
<b>Fe 3+</b>	0,13	0,09	0,02	0,00	0,00	0,00	0,00	0,14	0,00	0,08	0,00	0,05	0,31	0,11	0,00	0,00	0,16	0,11	0,00	0,13	0,07	0,00	0,00	0,17	0,00	0,00	0,09					
<b>Fe2+</b>	1,25	1,31	2,05	1,00	0,92	1,20	1,00	0,95	1,03	1,15	2,18	1,22	1,45	0,91	1,00	1,39	1,65	1,39	1,14	1,71	1,01	0,99	0,97	1,09	0,96	0,97	1,18	1,65				
<b>Al<sub>iv</sub></b>	2,25	2,32	2,30	2,30	1,38	1,21	2,26	2,33	2,22	2,17	2,16	2,24	2,17	2,21	2,17	2,15	2,20	2,27	2,20	2,27	2,25	2,10	2,24	2,15	2,25	2,14	2,21	2,25				
<b>Al<sub>vi</sub></b>	0,18	0,21	0,31	0,29	0,91	0,91	0,29	0,23	0,31	0,32	0,39	0,32	0,46	0,24	0,35	0,33	0,29	0,30	0,37	0,41	0,35	0,39	0,32	0,49	0,29	0,33	0,34	0,48				
<b>Tot</b>	16,04	15,89	16,01	15,93	15,80	15,79	15,92	15,92	15,91	15,95	15,96	15,89	16,00	15,96	15,85	15,99	15,96	16,11	16,01	16,05	16,00	15,87	15,98	16,08	15,92	15,89	15,91	15,98				
<b>Mg#</b>	68	66	49	76	71	63	75	74	75	70	47	69	58	76	75	66	57	65	72	55	74	76	76	70	77	76	70	57				
<b>Naming</b>	Prg	Krs	Krs	Krs	Prg	Prg	Krs	Krs	Krs	Prg	Prg	Krs	Prg	Krs	Krs	Prg	Prg	Prg	Krs	Prg	Prg	Prg	Krs	Prg	Krs	Krs	Krs	Prg				

c: core, r: rim, mc: microcrystal, g: glass, inc: inclusion, Prg: pargasite, Krs: kaersutite, Hbl: hornblend

Phi	Phi-clinopyroxenite (BIII)				Hbl-Gabbro (BIII)		
	Sample	K97-70a2		42a2			
		c	r	c	r	mc	mc
wt.%		#4	#5	#12	#13	#48	#60
<b>SiO<sub>2</sub></b>		36,44	35,63	36,27	36,38	38,45	37,40
<b>Al<sub>2</sub>O<sub>3</sub></b>		17,17	16,95	15,81	17,21	14,69	15,78
<b>FeOt</b>		11,82	10,23	12,21	9,64	7,73	9,67
<b>MgO</b>		16,84	17,60	17,06	18,44	21,41	18,86
<b>CaO</b>		0,03	0,10	0,00	0,05	0,06	0,07
<b>Na<sub>2</sub>O</b>		0,46	0,46	0,51	0,61	0,86	0,96
<b>K<sub>2</sub>O</b>		9,67	9,67	9,56	9,34	9,06	9,02
<b>TiO<sub>2</sub></b>		3,95	4,33	2,58	3,33	2,96	3,27
<b>MnO</b>		0,19	0,14	0,17	0,14	0,11	0,12
<b>Total</b>		96,57	95,11	94,17	95,15	95,33	95,14
<b>Calculation based on O=22 APFU</b>							
<b>Si</b>		5,73	5,66	5,83	5,73	6,05	5,95
<b>Al</b>		3,18	3,17	2,99	3,19	2,73	2,96
<b>Fe<sup>3+</sup></b>		0,49	0,59	0,85	0,64	0,77	0,65
<b>Fe<sup>2+</sup></b>		1,07	0,77	0,79	0,63	0,23	0,62
<b>Mg</b>		3,95	4,16	4,09	4,33	5,02	4,47
<b>Ca</b>		0,01	0,02	0,00	0,01	0,01	0,01
<b>Na</b>		0,14	0,14	0,16	0,19	0,26	0,30
<b>K</b>		1,94	1,96	1,96	1,88	1,82	1,83
<b>Ti</b>		0,47	0,52	0,31	0,39	0,35	0,39
<b>Mn</b>		0,03	0,02	0,02	0,02	0,01	0,02
<b>Fe</b>		1,56	1,36	1,64	1,27	1,02	1,29
<b>Total</b>		17,00	17,00	17,00	17,00	17,26	17,22
<b>Fe<sub>2</sub>O<sub>3</sub></b>		4,13	4,91	7,04	5,36	6,62	5,49
<b>FeO</b>		8,11	5,82	5,87	4,82	1,77	4,73
<b>Mg/Fe</b>		2,54	3,07	2,49	3,41	4,94	3,47
<b>Fe#</b>		0,28	0,25	0,29	0,23	0,17	0,22

c: core, r: rim, mc: microcrystal



Pl	Host rock									Enclave														
	BI			BII			BIII			Hornblende gabbro (BIII)					Cpx-hornblendite (BII)									
Sample	K97-58			31			48			42			70			K97-42a2					K97-48a			
	c	r	m	m	m	m	m	m	m	m	c	r	c	m	m	m	c	c	r					
wt. %	#10b	#11b	#2b	#14	#23	#37b	#40b	#70	#82	#42b	#43b	#43	#55	#67	#70	#140	#141	#142						
<b>SiO<sub>2</sub></b>	53,54	52,89	50,95	54,12	51,45	53,71	52,12	53,02	54,17	55,85	54,95	55,83	55,78	56,42	57,50	44,36	51,50	43,70						
<b>Al<sub>2</sub>O<sub>3</sub></b>	28,94	29,29	30,08	27,11	29,13	28,36	30,02	28,32	25,90	28,19	28,66	27,10	27,04	26,96	26,70	34,09	29,21	35,06						
<b>FeOt</b>	0,38	0,34	0,69	0,49	0,46	0,68	0,63	0,55	1,25	0,21	0,32	0,29	0,23	0,27	0,25	0,18	0,56	0,23						
<b>MgO</b>	0,03	0,05	0,07	0,03	0,01	0,04	0,05	0,14	0,62	0,01	0,03	0,03	0,01	0,02	0,00	0,03	0,03	0,00						
<b>CaO</b>	11,47	11,73	12,93	9,31	11,86	10,53	11,88	11,04	9,87	9,59	10,58	9,47	9,35	8,73	8,54	17,96	12,05	18,70						
<b>Na<sub>2</sub>O</b>	4,67	4,50	3,88	5,94	4,68	5,28	4,38	4,95	6,13	5,62	5,31	5,89	5,94	6,19	6,16	1,17	4,55	0,69						
<b>K<sub>2</sub>O</b>	0,64	0,61	0,45	0,61	0,26	0,43	0,46	0,61	0,89	0,65	0,58	0,58	0,69	0,66	0,66	0,06	0,26	0,04						
<b>TiO<sub>2</sub></b>	0,08	0,09	0,16	0,11	0,20	0,17	0,12	0,08	0,53	0,05	0,00	0,03	0,03	0,04	0,04	0,03	0,20	0,07						
<b>Total</b>	99,74	99,49	99,20	97,71	98,04	99,18	99,66	98,71	99,36	100,16	100,43	99,21	99,06	99,27	99,84	97,88	98,35	98,49						
<b>Calculation based on O=32 APFU</b>																								
<b>Si</b>	9,74	9,65	9,37	10,01	9,54	9,81	9,51	9,75	9,96	10,04	9,89	10,14	10,15	10,22	10,33	8,37	9,53	8,20						
<b>Al</b>	6,20	6,30	6,53	5,91	6,37	6,11	6,46	6,14	5,61	5,97	6,08	5,80	5,80	5,76	5,66	7,58	6,37	7,76						
<b>Fe</b>	0,06	0,05	0,11	0,08	0,07	0,10	0,10	0,08	0,19	0,03	0,05	0,05	0,04	0,04	0,04	0,03	0,09	0,04						
<b>Mg</b>	0,01	0,01	0,02	0,01	0,00	0,01	0,01	0,04	0,17	0,00	0,01	0,01	0,00	0,01	0,00	0,01	0,01	0,00						
<b>Ca</b>	2,23	2,29	2,55	1,84	2,36	2,06	2,32	2,18	1,94	1,85	2,04	1,84	1,82	1,70	1,64	3,63	2,39	3,76						
<b>Na</b>	1,64	1,59	1,38	2,13	1,68	1,87	1,55	1,77	2,19	1,96	1,85	2,07	2,09	2,18	2,15	0,43	1,63	0,25						
<b>K</b>	0,15	0,14	0,11	0,15	0,06	0,10	0,11	0,14	0,21	0,15	0,13	0,13	0,16	0,15	0,15	0,01	0,06	0,01						
<b>Ti</b>	0,01	0,01	0,02	0,02	0,03	0,02	0,02	0,01	0,07	0,01	0,00	0,00	0,00	0,01	0,01	0,01	0,03	0,01						
<b>Total</b>	20,04	20,05	20,08	20,14	20,12	20,08	20,07	20,12	20,35	20,01	20,05	20,05	20,07	20,05	19,98	20,06	20,10	20,03						
<b>An</b>	56,8	58,3	64,4	46,1	58,8	52,6	59,7	54,6	46,2	48,1	52,0	46,9	46,1	43,5	43,0	89,7	59,9	93,9						
<b>Ab</b>	39,4	38,1	32,9	50,2	39,6	44,9	37,6	41,8	48,9	48,0	44,5	49,7	49,9	52,6	53,0	10,0	38,5	5,9						
<b>Or</b>	3,8	3,6	2,7	3,6	1,6	2,5	2,7	3,6	5,0	3,9	3,4	3,4	4,0	3,9	4,0	0,3	1,5	0,2						

c: core, r: rim, m: microlite

<b>Nepheline</b>								
	<b>BII</b>				<b>BIII</b>	<b>Hbl-clinopyroxenite (BII)</b>		
<b>Sample</b>	<b>K97-31</b>	<b>48</b>		<b>70</b>	<b>31a</b>			
	m	m	c	r	c	c	c	c
<b>wt.%</b>	<b>#13</b>	<b>#15b</b>	<b>#17b</b>	<b>#18b</b>	<b>#83</b>	<b>#33</b>	<b>#38</b>	<b>#45</b>
<b>SiO<sub>2</sub></b>	43,37	43,98	44,07	43,05	52,76	43,31	43,11	42,85
<b>Al<sub>2</sub>O<sub>3</sub></b>	28,18	33,85	33,86	34,12	25,85	34,23	34,19	33,50
<b>FeOt</b>	3,29	0,58	0,20	0,23	2,56	0,15	0,14	0,14
<b>MgO</b>	1,17	0,00	0,04	0,02	0,28	0,02	0,01	0,00
<b>CaO</b>	4,79	1,48	1,80	1,25	0,54	2,58	2,73	2,04
<b>Na<sub>2</sub>O</b>	14,23	15,43	15,82	16,21	13,24	15,75	15,94	16,03
<b>K<sub>2</sub>O</b>	2,39	4,04	4,16	4,37	1,67	4,35	3,84	4,37
<b>TiO<sub>2</sub></b>	1,45	0,07	0,00	0,00	0,77	0,00	0,01	0,00
<b>Total</b>	<b>98,85</b>	<b>99,43</b>	<b>99,95</b>	<b>99,24</b>	<b>97,67</b>	<b>100,40</b>	<b>99,97</b>	<b>98,93</b>
<b>Calculation based on O=32 APFU</b>								
<b>Si</b>	8,48	8,40	8,39	8,27	9,96	8,24	8,23	8,28
<b>Al</b>	6,49	7,62	7,60	7,73	5,75	7,68	7,69	7,63
<b>Fe</b>	0,54	0,09	0,03	0,04	0,40	0,03	0,02	0,02
<b>Mg</b>	0,34	0,00	0,01	0,01	0,08	0,00	0,00	0,00
<b>Ca</b>	1,00	0,30	0,37	0,26	0,11	0,53	0,56	0,42
<b>Na</b>	5,39	5,72	5,84	6,04	4,85	5,81	5,90	6,01
<b>K</b>	0,60	0,98	1,01	1,07	0,40	1,06	0,94	1,08
<b>Ti</b>	0,21	0,01	0,00	0,00	0,11	0,00	0,00	0,00
<b>Total</b>	<b>23,06</b>	<b>23,13</b>	<b>23,24</b>	<b>23,42</b>	<b>21,68</b>	<b>23,35</b>	<b>23,34</b>	<b>23,44</b>

<b>Leucite</b>					<b>Hauyne</b>			
	<b>BI</b>	<b>BII</b>	<b>BIII</b>		<b>Cpx-hornblendite (BII)</b>			
<b>Sample</b>	<b>56</b>	<b>48</b>	<b>42</b>	<b>70</b>	<b>30a</b>			
	c	c	m	c	C	C	C	C
<b>wt.%</b>	<b>16</b>	<b>#28</b>	<b>#30</b>	<b>#81</b>	<b>#2</b>	<b>#3</b>	<b>#12</b>	<b>#105</b>
<b>SiO<sub>2</sub></b>	54,87	54,39	55,04	54,40	34,37	35,68	34,11	34,02
<b>Al<sub>2</sub>O<sub>3</sub></b>	22,94	23,10	24,26	23,51	28,12	26,78	27,29	28,13
<b>FeOt</b>	0,42	0,27	0,23	0,29	0,23	0,57	0,21	0,80
<b>MgO</b>	0,01	0,00	0,00	0,01	0,23	0,25	0,16	0,22
<b>CaO</b>	0,00	0,00	0,06	0,04	7,57	6,78	7,59	7,71
<b>Na<sub>2</sub>O</b>	0,09	0,29	0,50	0,10	10,35	7,26	8,07	8,36
<b>K<sub>2</sub>O</b>	21,20	21,11	19,49	21,32	4,29	5,40	5,28	6,30
<b>TiO<sub>2</sub></b>	0,12	0,16	0,00	0,24	0,02	0,00	0,06	0,00
<b>Total</b>	<b>99,76</b>	<b>99,32</b>	<b>99,57</b>	<b>99,92</b>	<b>85,17</b>	<b>82,71</b>	<b>82,75</b>	<b>85,55</b>
<b>Calc. based on O=32 APFU</b>					<b>Calc. based on O=21 APFU</b>			
<b>Si</b>	2,00	1,99	1,99	1,98	5,16	5,46	5,26	5,13
<b>Al</b>	0,99	1,00	1,03	1,01	4,97	4,83	4,95	5,00
<b>Fe</b>	0,01	0,01	0,01	0,01	0,03	0,07	0,03	0,10
<b>Mg</b>	0,00	0,00	0,00	0,00	0,05	0,06	0,04	0,05
<b>Ca</b>	0,00	0,00	0,00	0,00	1,22	1,11	1,25	1,25
<b>Na</b>	0,01	0,02	0,04	0,01	3,01	2,15	2,41	2,44
<b>K</b>	0,99	0,99	0,90	0,99	0,82	1,05	1,04	1,21
<b>Ti</b>	0,00	0,00	0,00	0,01	0,00	0,00	0,01	0,00
<b>Total</b>	<b>4,00</b>	<b>4,01</b>	<b>3,96</b>	<b>4,01</b>	<b>15,27</b>	<b>14,73</b>	<b>14,98</b>	<b>15,19</b>

c: core, r: rim, m: microlite

Oxides	Host rock			Enclave									Cpx-hornblendite	
	BI		BIII	Wehrlite (BII)									48a	
Sample	K97-58			70			10a2						48a	
	Titanomagnetite			Spinel			Chromian spinel						Magnesian ilmenite	
wt. %	mc #5	mc #6	mc #7	inc #66	inc #78	inc #79	mp #86	inc #50	inc #51	inc #54	inc #55	inc #56	c #155	c #156
SiO <sub>2</sub>	0,10	0,10	0,07	0,05	0,12	0,11	0,02	0,05	0,02	0,00	0,00	0,03	0,24	0,42
Al <sub>2</sub> O <sub>3</sub>	4,10	4,09	3,68	55,08	59,64	59,65	61,19	38,13	37,98	32,42	32,39	36,52	0,41	0,24
FeO <sup>t</sup>	65,78	64,87	65,64	27,54	19,19	19,54	28,64	25,50	25,70	24,33	25,05	25,23	33,28	33,15
MgO	4,21	3,95	3,85	16,19	20,08	19,88	9,60	14,89	14,59	13,85	13,72	13,70	8,42	8,46
CaO	0,16	0,24	0,14	0,02	0,04	0,00	0,04	0,00	0,04	0,02	0,00	0,01	0,02	0,16
Na <sub>2</sub> O	23,14	23,05	22,23	1,04	0,95	1,17	0,31	1,41	1,42	0,86	0,90	0,87	53,74	53,46
MnO	0,69	0,72	0,76	0,27	0,06	0,07	0,26	0,15	0,13	0,07	0,06	0,16	0,49	0,39
Cr <sub>2</sub> O <sub>3</sub>	0,09	0,04	0,02	0,05	0,01	0,04	0,00	18,97	19,03	27,21	26,89	22,33	0,02	0,05
<b>Total</b>	<b>98,28</b>	<b>97,07</b>	<b>96,38</b>	<b>100,25</b>	<b>100,10</b>	<b>100,46</b>	<b>100,06</b>	<b>99,10</b>	<b>98,91</b>	<b>98,76</b>	<b>99,00</b>	<b>98,84</b>	<b>96,61</b>	<b>96,32</b>
	<b>Calculation based on O=32 APFU</b>												<b>O=6 APFU</b>	
Si	0,03	0,03	0,02	0,01	0,03	0,02	0,01	0,01	0,00	0,00	0,00	0,01	0,01	0,02
Al	1,37	1,39	1,26	13,76	14,39	14,38	15,61	10,30	10,30	9,04	9,02	10,02	0,02	0,01
Fe <sup>3+</sup>	4,65	4,55	4,98	1,87	1,26	1,21	0,28	1,75	1,74	1,56	1,64	1,55	0,01	0,01
Fe <sup>2+</sup>	10,98	11,08	10,98	3,01	2,02	2,13	4,90	3,14	3,21	3,25	3,32	3,37	1,35	1,35
Mg	1,78	1,69	1,67	5,12	6,13	6,06	3,10	5,09	5,01	4,89	4,83	4,76	0,61	0,62
Ca	0,05	0,07	0,04	0,00	0,01	0,00	0,01	0,00	0,01	0,01	0,00	0,00	0,00	0,01
Ti	4,95	5,00	4,86	0,17	0,15	0,18	0,05	0,24	0,25	0,15	0,16	0,15	1,97	1,97
Mn	0,17	0,17	0,19	0,05	0,01	0,01	0,05	0,03	0,02	0,01	0,01	0,03	0,02	0,02
Cr	0,02	0,01	0,00	0,01	0,00	0,01	0,00	3,44	3,46	5,09	5,02	4,11	0,00	0,00
<b>Total</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>24,00</b>	<b>4,00</b>	<b>4,00</b>
Fe <sup>2+</sup> O <sup>3</sup>	21,76	20,98	22,75	11,75	8,20	7,89	1,74	10,15	10,02	8,79	9,20	8,82	0,20	0,26
FeO	46,20	45,99	45,16	16,96	11,81	12,44	27,08	16,37	16,69	16,42	16,77	17,28	33,10	32,91
Mg#	10	10	9	51	65	64	37	51	50	50	49	49	31	31
Cr# = Cr/(Cr+Al)	0,015	0,007	0,003	0,001	0,000	0,000	0,000	0,250	0,252	0,360	0,358	0,291	0,024	0,117
Fe <sup>2+</sup> /(Mg+Fe <sup>2+</sup> )	0,860	0,867	0,868	0,370	0,248	0,260	0,613	0,382	0,391	0,399	0,407	0,414	0,688	0,686
Fe <sup>3+</sup> /(Cr+Al+Fe <sup>3+</sup> )	0,769	0,765	0,798	0,120	0,081	0,078	0,018	0,113	0,112	0,100	0,104	0,099	0,233	0,377

c: core, mc: microcrystal, mp: microphenocryst, inc: inclusion

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3	<b>(BII)</b>
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5	<b>ite</b>
6	c
7	<b>#160</b>
8	0,02
9	0,35
10	33,97
11	7,93
12	0,01
13	52,94
14	0,40
15	0,05
16	95,67
17	
18	<b>J</b>
19	0,00
20	0,02
21	0,04
22	1,37
23	0,59
24	0,00
25	1,98
26	0,02
27	0,00
28	4,01
29	0,98
30	33,08
31	29
32	0,088
33	0,700
34	0,618
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For Review Only

Glass	Wehrlite (BII)				Phl-clinopyroxenite				Cpx-hornblendite (BII)							Hornblendite (BIII)				Hbl-Gabbro (BIII)							
Sample	K97-10a2				70a2				48a2				30a			17a2				42a2							
wt.%	Gim	Gim	Gp	Gp	Gim	Gim	Gim	Gim	Gim	Gim	Gp	Gp	Gim	Gim	Gim	Gim	Gim	Gim	inc (Hyn)	Gp	Gp	Gim	Gim	Gim	Gim	Gp	inc (Pl)
	#62	#63	#66	#74	#8	#9	#14	#19	#24	#25	#138	#144	#153	#6	#11	#15	#24	#102	#106	#27	#29	#36	#41	#44	#53	#56	#71
<b>SiO<sub>2</sub></b>	44,33	45,04	44,96	45,25	46,18	44,75	47,46	44,64	44,05	46,22	45,49	46,00	52,54	49,91	49,76	49,81	49,17	49,20	48,86	50,58	49,91	49,91	50,24	55,31	55,63	54,58	56,04
<b>TiO<sub>2</sub></b>	2,02	1,96	1,89	1,94	0,85	1,81	0,55	2,67	2,40	1,80	2,18	1,79	0,77	1,33	1,44	1,43	1,68	1,53	1,46	1,27	1,32	1,37	1,34	0,81	0,95	1,01	0,94
<b>Al<sub>2</sub>O<sub>3</sub></b>	20,86	21,12	21,25	21,09	29,38	25,27	17,51	17,22	22,97	13,67	20,31	21,04	22,85	20,42	20,68	20,93	20,63	20,68	20,29	20,18	20,00	19,98	20,08	21,88	22,57	22,08	22,09
<b>Fe<sub>2</sub>O<sub>3</sub></b>	8,06	7,33	7,47	7,67	3,35	5,22	7,91	9,77	8,20	8,87	5,22	4,46	3,37	6,64	7,42	7,54	6,82	7,23	7,42	6,58	7,38	6,98	7,00	4,25	4,46	4,62	4,38
<b>MnO</b>	0,18	0,19	0,16	0,13	0,16	0,21	0,26	0,26	0,26	0,28	0,21	0,14	0,00	0,17	0,17	0,17	0,14	0,17	0,20	0,15	0,18	0,17	0,16	0,15	0,13	0,14	0,10
<b>MgO</b>	3,48	3,33	3,11	2,94	1,25	2,40	5,13	5,31	2,48	7,19	5,01	4,59	1,42	2,32	2,48	2,35	2,58	2,11	2,65	2,32	2,63	2,57	2,76	1,08	0,98	1,11	1,03
<b>CaO</b>	8,55	8,11	8,00	7,65	4,30	5,92	11,81	11,26	5,60	15,00	9,27	9,07	5,36	6,99	6,89	5,66	6,86	5,93	6,95	5,40	6,00	5,81	5,86	2,88	2,51	2,72	2,43
<b>Na<sub>2</sub>O</b>	6,04	6,41	6,55	6,41	9,46	9,86	3,59	2,94	9,17	6,33	9,67	10,70	9,88	5,27	5,15	5,37	5,84	4,44	5,34	5,38	5,33	5,28	5,23	5,53	5,46	5,54	5,66
<b>K<sub>2</sub>O</b>	3,58	3,55	3,86	3,93	3,33	2,93	3,03	5,84	3,31	1,71	1,72	1,64	2,74	4,17	3,92	3,97	4,21	3,49	3,74	4,81	4,47	4,65	4,76	5,49	5,52	5,44	5,51
<b>P<sub>2</sub>O<sub>5</sub></b>					0,40	0,45	0,54	0,49	0,35	0,59																	
<b>Total</b>	97,1	97,0	97,2	97,0	98,7	98,8	97,8	100,4	98,8	101,6	99,1	99,4	98,9	97,2	97,9	97,2	97,9	94,8	96,9	96,7	97,2	96,7	97,4	97,4	98,2	97,2	98,2
<b>FeO<sub>t</sub></b>	7,3	6,6	6,7	6,9	3,0	4,7	7,1	8,8	7,4	8,0	4,7	4,0	3,0	6,0	6,7	6,8	6,1	6,5	6,7	5,9	6,6	6,3	6,3	3,8	4,0	4,2	3,9
<b>Mg#</b>	44	45	43	41	40	45	54	49	35	59	63	65	43	38	37	36	40	34	39	39	39	40	41	31	28	30	30

Gp: glass pockets, Gim: glass associated with intergranular minerals, inc: inclusion, Hyn: hauyne, Pl: plagioclase. Hbl: hornblend, Cpx: clinopyroxene, Phl: phlogopite

Equation (13) Putirka RiMG '08 T(C)	Equation (14) Putirka RiMG '08 T(C)	Equation (15) Putirka RiMG '08 T(C)	Equation (16) Putirka RiMG '08 T(C)	Helz & Thornber '87 Mg-thermometer T(C)
1086	1143	1169	1163	1084
1086	1143	1180	1187	1084
1086	1143	1180	1187	1084
1086	1143	1180	1187	1084
1082	1140	1166	1147	1081
1082	1140	1178	1170	1081
1082	1140	1178	1170	1081
1082	1140	1178	1170	1081
1076	1139	1161	1142	1077
1076	1139	1173	1166	1077
1076	1139	1173	1166	1077
1076	1139	1173	1166	1077
1072	1131	1154	1131	1073
1072	1131	1166	1155	1073
1072	1131	1166	1155	1073
1072	1131	1166	1155	1073

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	Helz & Thornber '87 Ca-thermometer T(C)
7	1110
8	1110
9	1110
10	1110
11	1103
12	1103
13	1103
14	1103
15	1103
16	1101
17	1101
18	1101
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Sample-K97- wt.%	Host rock									Enclave								
	BI	BII	BIII			Wehrlite			Phi-Cpxt	Cpx-Hornblendite		Hornblendite		Pib Hblt	Cpx-Hblt	Hbl-Gabbro		
	58	30	31	48	14	17	42	46	70	10a2	70a2	30a	48a2	14a	17a2	46a	42a2	
1																		
2	SiO <sub>2</sub>	46,04	47,12	45,49	45,22	47,05	47,45	46,94	47,44	47,01	42,05	40,45	41,69	39,12	38,94	38,92	41,39	44,83
3	Al <sub>2</sub> O <sub>3</sub>	15,59	17,54	16,81	17,19	17,92	17,89	17,69	18,18	17,84	3,82	12,1	15,32	14,6	15,25	14,8	15,55	17,66
4	Fe <sub>2</sub> O <sub>3</sub>	8,69	8,76	8,98	9,31	8,5	8,21	8,65	8,31	8,01	12,16	9,3	10,13	12,34	11,1	11,05	9,83	9,24
5	MnO	0,13	0,16	0,16	0,17	0,15	0,14	0,15	0,16	0,14	0,17	0,15	0,14	0,21	0,15	0,13	0,13	0,16
6	MgO	7,22	5,78	7,7	6,07	5,94	6,1	6,52	5,4	5,71	34,63	12,1	10,4	11,57	8,8	11,38	10,66	6,34
7	CaO	10,95	8,48	9,24	8,89	8,31	7,88	8,65	8,01	7,89	7,35	13,76	12,72	12,77	13,15	12,69	11,88	9,95
8	Na <sub>2</sub> O	3,36	5,37	5,15	5,09	5,77	5,68	5,53	5,93	5,69	0,53	1,53	3,37	2,73	3,3	2,89	3,25	4,87
9	K <sub>2</sub> O	2,37	3,21	3,19	3,3	3,55	3,62	3,55	3,55	3,57	0,31	4,16	1,85	1,52	2,39	1,94	2,06	2,74
10	TiO <sub>2</sub>	2,05	1,96	2,07	2,32	1,9	1,81	1,99	1,89	1,77	0,75	3,12	3,11	4,14	3,3	4,19	3,89	2,53
11	P <sub>2</sub> O <sub>5</sub>	0,69	0,99	1	0,75	0,85	0,86	0,88	0,9	0,82	0,12	1,76	0,79	0,26	2,82	1,48	0,62	1,18
12	LOI	1,93	0,42	0,2	1,05	-0,03	0,58	-0,18	0,06	0,19	-0,41	1,95	0,73	0,49	0,51	0,47	0,62	0,32
13	<b>TOTAL</b>	<b>99,02</b>	<b>99,79</b>	<b>99,99</b>	<b>99,36</b>	<b>99,91</b>	<b>100,22</b>	<b>100,37</b>	<b>99,83</b>	<b>98,64</b>	<b>101,48</b>	<b>100,38</b>	<b>100,25</b>	<b>99,75</b>	<b>99,71</b>	<b>99,94</b>	<b>99,88</b>	<b>99,82</b>
14	(ppm)																	
15	Sr			1101				980		998	159	1149	1609	1041	1049	1022	1019	1256
16	Ba			956				940		881	86	2771	761	804	852	768	819	951
17	Rb			74,7				72,9		84,5	4,9	109	23,1	7	34,7	21,3	19,9	47,9
18	Ni			69				55		50	598	91	23	13	< .5	39	39	18
19	Co			34,2				35,9		37,2	117,8	41,5	53	69,5	48,5	58,6	50,7	38,2
20	Cr	182	141	167	94	113	68	78	68	59	2331	301	96	34	7	42	94	68
21	V			195				169		149	115	329	349	437	293	382	372	234
22	Zr	260	301	230	273	239	239	242	254	227	35	303	261	193	205	189	228	252
23	Y			27,4				25,1		26,2	6,2	24,9	27,3	28,8	37,2	33,2	29,8	31,7
24	Nb			86,8				81,9		93,8	10,8	79,2	61	63,5	73,1	66,2	65,2	93,1
25	Ga			20,7				20,6		22,8	6	18,5	17,9	19,1	18,3	17,2	17,7	20,7
26	Cs			1,1				1,2		1,4	< .1	1,3	0,2	< .1	0,4	0,2	0,3	0,7
27	Hf			4,4				4,4		5,5	1,2	7,7	4,6	4,1	4,3	4,6	4,9	5,2
28	Ta			5,3				5		5,1	0,9	4,2	3,3	3,2	4,4	4,3	4,1	5,5
29	Th			8,2				8,3		8,3	0,7	6	5,6	0,7	4,5	2,4	3,4	6,9
30	Tl			0,3				0,1		< .1	0,4	0,2	0,2	0,1	0,2	0,4	0,1	0,3
31	U			2,8				1,8		2,8	0,5	1,1	2	0,1	1,6	0,6	0,9	2,6
32	Zr			209,8				199,8		229,5	40,2	280,8	175,7	144,4	154	134,4	175,2	226,2
33	La			59				52,1		53,9	8,1	81,2	50,7	33,9	61,5	40,3	37	68,8
34	Ce			100,7				88,3		89,5	17,4	162,5	109,5	75,5	117,1	85,4	74,6	117,3
35	Pr			10,55				9,2		9,68	2,28	18,98	14	9,37	13,69	10,88	8,64	12,26
36	Nd			45,5				38,8		36,2	11	82,8	65,2	42,7	59,6	50,1	40,9	49
37	Sm			7,2				6,2		6,2	2,1	13,2	11,1	7,9	11,1	9,5	8	8
38	Eu			2,29				2,03		2,07	0,78	3,58	3,26	2,7	3,69	3,08	2,68	2,69
39	Gd			6,62				5,78		5,74	1,86	10,22	8,05	8,03	10,63	9,52	8,03	7,98
40	Tb			0,95				0,87		0,81	0,26	1,21	1,07	1,06	1,34	1,27	1,12	1,06
41	Dy			5,19				4,66		5,08	1,37	5,73	5,54	5,56	7,23	6,72	6,1	6,09
42	Ho			0,95				0,86		0,9	0,21	0,89	0,97	0,99	1,25	1,2	1,05	1,07
43	Er			2,47				2,32		2,55	0,59	2,15	2,58	2,55	3,26	2,92	2,92	2,88
44	Tm			0,36				0,35		0,39	0,09	0,26	0,35	0,34	0,46	0,38	0,35	0,36
45	Yb			2,23				2,13		2,29	0,48	1,6	2,01	2,22	2,45	2,34	2	2,29
46	Lu			0,32				0,3		0,34	0,06	0,22	0,3	0,3	0,35	0,34	0,31	0,37
47	Pb			2				3		4	< 2	< 2	3	< 2	< 2	< 2	< 2	3



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			T°C		P(kbar)	
			min	max	min	max
Host rocks	BI		1217	1231	9,5	10,0
	BII	<i>Cpx-whole rock</i>	1130	1242	10,0	15,4
	BIII		1149	1227	9,5	14,3
	<b>Bomb in M3 (BII)</b>	<i>Cpx-coexisting glass</i>	1174	1260	13,0	19,5
Enclaves	Wehrlite (BII)	<i>Cpx-coexisting glass</i>	1138	1200	14,2	18,8
	Hornblendite (BII)	<i>Cpx-whole rock</i>	1259	1329	11,6	18,3
	Phlogopite clinopyroxenite (BIII)	<i>Cpx-whole rock</i>	1314	1324	14,1	15,5
		<i>Cpx-coexisting glass</i>	1148	1199	25,2	27,6
	Clinopyroxenite hornblendite (BII)	<i>Cpx-whole rock</i>	1221	1266	12,1	13,4
	Clinopyroxenite hornblendite (BII)	<i>Cpx-whole rock</i>	1277	1301	13,0	14,7
	Clinopyroxenite hornblendite (BII)	<i>Cpx-coexisting glass</i>	1134	1206	14,4	21,4
	Hornblende gabbro (BIII)	<i>Cpx-whole rock</i>	1208	1220	11,1	12,8
	Hornblende gabbro (BIII)	<i>Cpx-coexisting glass</i>	1026	1034	14,2	15,7

