

# Mineral Chemistry and Geothermobarometry of Alkali Basalts from the Elmadağ Volcanic Complex, Ankara (Central Anatolia, Turkey)

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*Abstract:* The Miocene mafic volcanism is represented by continental alkali basalts in the Elmadağ Volcanic Complex (EVC), Ankara (Central Anatolia, Turkey). The mafic lavas can be classified as alkali olivine basalt (AOB, 0-5 wt.% normative nepheline) and basanite (BASAN, >5 wt.% normative nepheline) on the petrological and chemical grounds. All the lavas are olivine and clinopyroxene phyrlic. Their groundmass consists of mainly plagioclase, clinopyroxene, lesser opaque and rare anorthoclase. The analyzed plagioclases are mostly unzoned, and have relatively calcic compositions, ranging from labradorite to bytownite. Based on back-scattered electron image and electron microprobe data, olivine phenocrysts from both rocks typically exhibit normal zoning. The most magnesian cores retain compositions up to Fo 86, but range down to 74 in adjacent rims, with a concomitant decrease in Ni contents. Pairs of olivine core and whole rock compositions show that most of the olivines are in equilibrium with their host rocks ( $K_D$  Fe-Mg:  $0.30 \pm 0.03$ ), and yielded temperature estimates of 1257-1274 °C for AOB and 1222-1238 °C for BASAN. The clinopyroxenes straddle the boundary between augite and diopside on the pyroxene quadrilateral diagram. They are slightly normal zoned, with Mg#’s ranging from 0.71 to 0.85 (assuming all Fe as Fe<sup>2+</sup>). Based on Fe-Mg exchange coefficient ( $K_D$  Fe-Mg:  $0.27 \pm 0.03$ ), only few clinopyroxene crystals are within equilibrium range, suggesting they are mostly xenocrystic in origin. A few equilibrated pairs of clinopyroxene and whole rock compositions yielded considerably variable pressures of crystallization, ranging from 4.2 to 11.7 kbar for AOB, and from 3.4 to 9.1 kbar for BASAN. This means that EVC mafic magmas had a polybaric crystallization history, and underwent early high-pressure fractionation at the crust-mantle boundary, then ascended to the upper crustal level.

*Key-Words:* Alkali basalt, Elmadağ Volcanic Complex, Mineral chemistry, Geothermobarometry

## 1 Introduction

The Miocene mafic alkaline volcanic rocks, ranging from alkali olivine basalt (AOB) to basanite (BASAN) are scattered in the Elmadağ volcanic complex (EVC), located on İzmir-Ankara-Erzincan suture zone to the South of Ankara (Fig. 1a, b). Although the mafic volcanic rocks are not widespread, they provide good opportunity for the understanding of evolution of basaltic magma in the region.

This study presents whole-rock geochemical and electron microprobe data on mafic alkaline volcanic rocks from the EVC, and shows that EVC mafic magmas had a polybaric crystallization history, and underwent early high-pressure fractionation at the crust-mantle boundary, then ascended to the upper crustal level.

## 2 Geological Outline

The EVC is one of the most important volcanic field where intermediate to felsic calc-alkaline and mafic mildly alkaline volcanic rocks occur together in a post-collisional tectonic setting. In the study area, lavas (flows, domes & dikes), pyroclastic deposits and lacustrine sedimentary rocks cover large areas. These sedimentary deposits are interbedded with lavas and pyroclastic deposits in some places (i.e. distal zone), so that the deposition of sedimentary units was coeval with the volcanic activity. Recent K–Ar dating confirmed that the volcanic activity occurred during the Early to Middle Miocene (19.7-15.8 Ma) [1]. The Early Miocene volcanic phase is the most dominant, comprising of voluminous calc-alkaline intermediate-felsic rocks associated with small volumes of alkali basalts. In contrast, the Middle Miocene volcanic phase is mostly mafic and alkaline in composition.

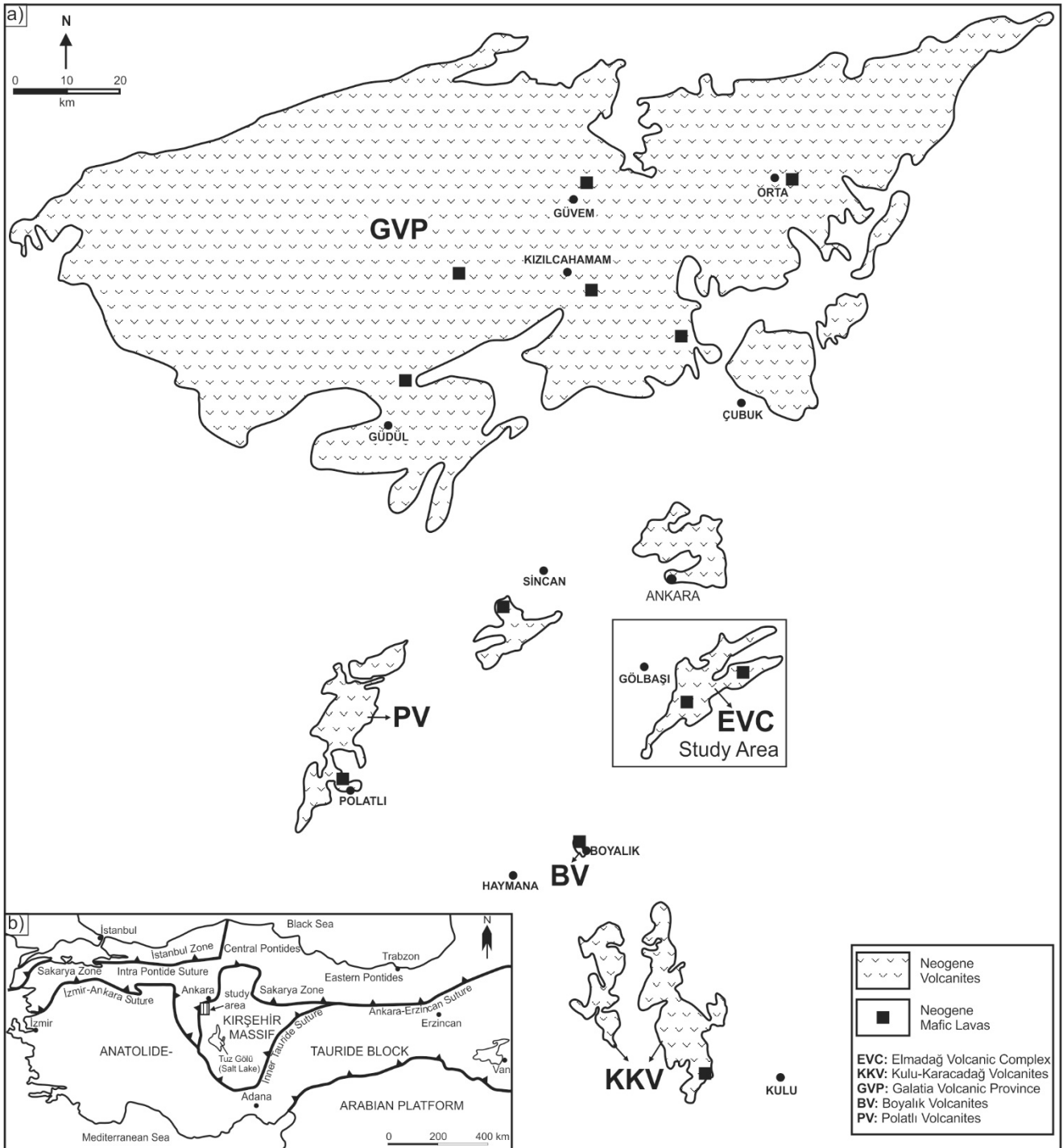


Figure 1. (a) Distribution of mafic lavas associated with Neogene volcanic rocks in northwest Central Anatolia [2-5], and (b) simplified tectonic map of Turkey [6].

### 3 Material and Methods

Mafic volcanic rock hand-samples have been collected from various stratigraphic levels of the EVC for petrography and geochemical analysis. After petrographic examination, the freshest representative subset of samples were selected for electron microprobe (data are available on request from the author) and whole-rock geochemical analysis (Table 1).

Mineral analyses were performed on carbon-coated polished thin sections using a JEOL JXA-8600 instrument equipped with four wavelength-dispersive spectrometers (WDS) and integrated with an energy-dispersive spectrometer (EDS) system at McGill University (Canada). Operating conditions were: 15 kV accelerating voltage, 20 nA beam current and 20 s counting time per each element.

Table 1. Major and trace element analysis of the EVC mafic lavas.

Majors (%)	E4	E34	E76	E78	E82	E85	E-103	E-113
	AOB	AOB	BASAN	BASAN	BASAN	BASAN	AOB	BASAN
SiO <sub>2</sub>	47.73	49.44	48.58	48.80	50.30	48.81	48.29	47.09
Al <sub>2</sub> O <sub>3</sub>	16.46	16.03	15.88	16.22	16.78	16.05	15.83	14.49
FeOt	9.70	8.28	8.24	8.45	8.09	8.35	8.53	8.57
MgO	7.44	7.10	5.44	6.32	4.25	6.27	5.54	7.79
CaO	9.46	8.51	9.90	8.08	9.08	9.03	8.10	9.35
Na <sub>2</sub> O	3.86	4.15	4.32	4.50	4.61	4.02	4.07	3.50
K <sub>2</sub> O	1.21	1.12	2.01	1.98	1.58	1.94	1.70	2.28
TiO <sub>2</sub>	1.70	1.34	1.31	1.33	1.32	1.33	1.68	1.30
P <sub>2</sub> O <sub>5</sub>	0.62	0.69	0.85	0.92	0.84	0.93	0.96	1.16
MnO	0.16	0.14	0.18	0.15	0.13	0.16	0.13	0.15
LOI	1.30	2.70	2.80	2.70	2.60	2.60	4.70	3.60
Total	99.67	99.58	99.54	99.48	99.59	99.49	99.58	99.39
Trace elements (ppm)								
Ba	432.0	885.0	1182.0	1260.0	981.0	1340.0	1096.0	1221.0
Co	33.80	27.80	26.00	27.60	26.40	25.90	30.90	35.50
Hf	3.90	4.30	4.70	4.50	5.00	4.70	4.50	4.10
Nb	19.10	25.50	29.60	30.20	30.10	30.90	36.80	38.90
Rb	17.90	8.60	35.20	38.30	12.60	20.30	37.40	79.90
Sr	775.8	944.3	1216.4	1306.0	1110.4	1336.4	1084.7	2020.2
Ta	1.10	1.30	1.60	1.60	1.50	1.70	2.00	1.90
Th	2.80	9.40	13.40	15.10	10.00	15.30	3.50	14.40
U	0.70	2.30	2.90	3.00	2.30	3.10	0.80	2.90
Zr	168.4	182.6	203.4	218.0	204.3	210.0	193.2	201.6
Y	23.90	24.30	25.20	25.60	25.40	25.20	21.80	23.60
La	28.70	51.60	64.80	74.50	58.40	74.80	38.40	80.60
Ce	58.70	93.90	114.70	132.30	107.50	132.00	84.70	150.9
Pr	7.28	10.15	13.03	14.18	11.67	13.94	9.66	16.04
Nd	29.00	37.70	47.90	51.70	41.70	51.40	37.60	56.50
Sm	5.65	6.34	7.38	7.83	6.98	7.77	5.97	7.77
Eu	1.67	1.71	2.01	2.16	1.90	2.04	1.79	2.19
Gd	5.48	5.76	6.49	6.74	6.25	6.58	5.17	6.15
Tb	0.80	0.79	0.86	0.92	0.87	0.87	0.77	0.86
Dy	4.80	4.70	4.67	4.91	4.82	4.92	4.16	4.51
Ho	0.87	0.81	0.83	0.91	0.89	0.88	0.78	0.82
Er	2.40	2.42	2.42	2.51	2.56	2.47	2.28	2.36
Tm	0.38	0.36	0.37	0.38	0.39	0.36	0.31	0.36
Yb	2.30	2.39	2.44	2.48	2.42	2.35	2.05	2.16
Lu	0.34	0.33	0.35	0.36	0.37	0.34	0.32	0.32
Ni	70.90	107.00	94.50	87.80	107.10	87.60	89.40	157.00
Sc	24.00	18.00	14.00	15.00	16.00	15.00	17.00	16.00
Cr	184.73	212.10	116.31	109.47	136.84	116.31	143.68	246.31

Following removal of weathered surfaces, samples were crushed in a jaw-crusher, and then powdered in an agate ball mill for whole-rock major, trace and rare earth elements. Major and trace elements were analyzed by inductively coupled plasma emission spectroscopy (ICP-ES), and rare earth elements (REE) were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at the ACME Laboratories (Canada).

#### 4 Petrography and Classification

The mafic lavas of the EVC are continental alkali basalts (Fig. 2), ranging from alkali olivine basalt (AOB, 0-5 wt.% normative nepheline) to basanite (BASAN, >5 wt.% normative nepheline) on the petrological and chemical grounds.

All the mafic lavas are olivine and clinopyroxene phyric. Their groundmass consists of mainly plagioclase, clinopyroxene, lesser opaque and rare anorthoclase.

Olivine phenocrysts have typically irregular internal cracks and sometimes skeletal crystal forms. They are mostly iddingsitized along cracks and margins or completely pseudomorphed by iddingsite.

Clinopyroxene occurs as isolated phenocrysts and micro-phenocrysts in groundmass. Some of them form cumulophyric clusters with or without plagioclase and olivine. Some clinopyroxenes are zoned and twinned. Clinopyroxene phenocrysts display sometimes resorbed internal structures with infilling of groundmass-like material.

Plagioclase occurs as subhedral elongated phenocrysts and micro-phenocrysts in groundmass. They are mostly twinned and unzoned.

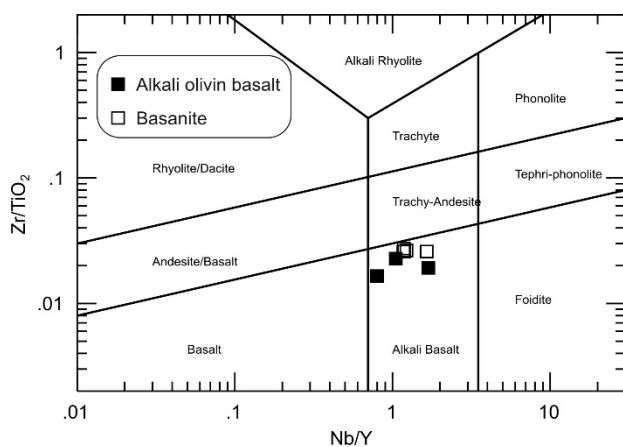


Figure 2.  $Zr/TiO_2$  vs.  $Nb/Y$  rock classification diagram for the EVC mafic lavas [7].

## 5 Mineral Chemistry

Based on back-scattered electron image and electron microprobe data, olivine phenocrysts from both rocks typically exhibit normal zoning (Fig. 3). The most magnesian cores retain compositions up to Fo 86, but range down to 74 in adjacent rims, with a concomitant decrease in Ni contents.

The clinopyroxenes straddle the boundary between augite and diopside on the pyroxene quadrilateral diagram. They are slightly normal zoned, with  $Mg\#$ 's ranging from 0.71 to 0.85 (assuming all Fe as  $Fe^{2+}$ ).

The analyzed plagioclases are mostly unzoned, and have relatively calcic compositions, ranging from labradorite to bytownite.

## 6 Geothermobarometry

Pressure and temperature of crystallization were calculated by using K. Putirka's spreadsheets [8]. Whole rock compositions were used for liquid, and

equilibrium between liquid and minerals (i.e. olivine and clinopyroxene) was tested by comparing observed and predicted values for Fe-Mg exchange coefficient.

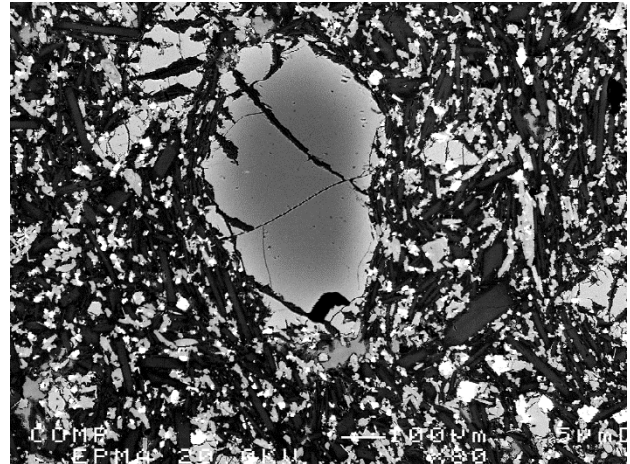


Figure 3. Back-scattered electron image from an olivine phenocryst showing the normal zoning, with a darker more Mg-rich core and a brighter more Fe-rich rim.

Pairs of olivine core and whole rock compositions show that most of the olivines are in equilibrium with their host rocks ( $K_D$  Fe-Mg:  $0.30 \pm 0.03$ ), and yielded temperature estimates of 1257-1274 °C for AOB and 1222-1238 °C for BASAN.

Based on Fe-Mg exchange coefficient ( $K_D$  Fe-Mg:  $0.27 \pm 0.03$ ), only few clinopyroxene crystals are within equilibrium range, suggesting they are mostly xenocrystic in origin. A few equilibrated pairs of clinopyroxene and whole rock compositions yielded considerably variable pressures of crystallization, ranging from 4.2 to 11.7 kbar for AOB, and from 3.4 to 9.1 kbar for BASAN.

According to pressure estimates, the EVC mafic magmas had a polybaric crystallization history, and underwent early high-pressure fractionation at the crust-mantle boundary, then ascended to the upper crustal level.

## 7 Conclusion

The EVC mafic lavas are continental alkali basalts (i.e. alkali olivine basalt and basanite). All the lavas are olivine (Fo<sub>74-86</sub>) and clinopyroxene phyric ( $Mg\#$ : 0.71 to 0.85). The groundmass plagioclases range from labradorite to bytownite.

Geothermobarometric calculations yielded temperature estimates of 1257-1274 °C for AOB and

1222-1238 °C for BASAN, pressures of crystallization, ranging from 4.2 to 11.7 kbar for AOB, and from 3.4 to 9.1 kbar for BASAN.

Pressure estimates show that the EVC mafic magmas had a polybaric crystallization history, and underwent early high-pressure fractionation at the crust-mantle boundary, then ascended to the upper crustal level.

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