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Crystallization conditions and petrography of eocene volcanic rocks in the Gümüşdamla-Erikdibi area (Bayburt, NE Turkey)

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Abstract
The Eocene Gümüşdamla-Erikdibi (Bayburt) volcanics in the south zone of the Eastern Pontides were studied as mineral chemistry and petrography. The main units in the study area are Late Cretaceous Ardıç Volcanites, Eocene Sırataşlar Formation, Eocene Yazyurdu Formation and Eocene Taşlıburun Diorite that cuts these units. The youngest unit in the field is Quaternary alluviums. The studied volcanic rocks are basalt, basaltic andesite and andesite in composition and the main minerals are plagioclase, alkali-feldspar, pyroxene, hornblende, biotite and opaque minerals. Pyroxenes are clino-pyroxene in composition ($Wo_{40-48}En_{39-46}Fs_{9-19}$) and differ from diopside to augite. Crystallization temperatures calculated from clinopyroxene minerals are 819 °C to 1157 °C, and pressure values are 0.14 to 7.79 kbar. Based on the obtained data, it is suggested that the magmas had undergone anhydrous and hydrous crystallizations in the shallow to mid-crustal magma chambers

Keywords: Mineralogy-petrography, clinopyroxene, geothermobarometer, eocene volcanics, Bayburt, Eastern Pontides.

1. Introduction

The Eastern Pontides (NE Turkey) located in the Alpine-Himalayan orogenic belt is one of the significant areas of volcanic and plutonic rocks that are commonly observed. Three main volcanic phase, namely Liassic, Cretaceous and Eocene (and later), have been identified in the Eastern Pontides [1-3]. The Eastern Pontides were divided into two zones as norther and southern by [4]. Accordingly, the study area is located in the southern zones in the Eastern Pontides.

Many studies conducted on the development of Eocene volcanic rocks [5-8] in the Eastern Pontides. These studies indicated that the magmas of Eocene volcanics are probably composed of an enriched mantle source (lithospheric mantle) metasomatized by previous subduction fluids ± melts and differentiated by complex magmatic processes.

In this study, mineralogical, petrographic and mineral chemical properties of the Gümüşdamla-Erikdibi (Bayburt) volcanics have been revealed and an attempt has been made to provide thermobarometer (pressure-temperature) conditions during the crystallization and to determine settlement of the volcanics. This study is a part of the master's thesis prepared by [9].

2. Geological setting

The basement rocks of the Eastern Pontides consist of Early Carboniferous metamorphic rocks [10-16]. These basement rocks are overlain by the Early and Middle Jurassic volcano-sedimentary rocks [17-18] and are cut by Early to Late Jurassic plutonic rocks [13, 19-20]. All these rocks are overlain by Late Jurassic to Early Cretaceous carbonates [21]. Late Cretaceous series that unconformably overlie these carbonates consist of volcanic, plutonic and sedimentary rocks [22-28]. Late Cretaceous rocks are overlain by Late Paleocene-Early Eocene adakitic rocks [29-31], Early to Middle Eocene volcanic-subvolcanic rocks [7-8, 29-40] and cuts by Middle Eocene plutonic rocks [41-51]. These units are overlain by Late Eocene and Oligosene volcanic rocks [7-8, 32, 52-53], and are covered by Miocene to Pliocene adakitic and non-adakitic volcanic-subvolcanic rocks [31-32, 33, 52-55]. Miocene and post-Miocene magmatisms are calc-alkaline to alkaline compositions in the Trabzon-Gümüşhane areas [39, 52, 54-55] and calc-alkaline in the Ilıca-Kandilli areas [56-57]. Quaternary units comprise alluvium and terraces.

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The study area located in the south zone of the Eastern Pontide Tectonic Unit consists of an area of about 50 km^2 and is generally dominated by volcanic, plutonic and sedimentary rocks (Figure 1).

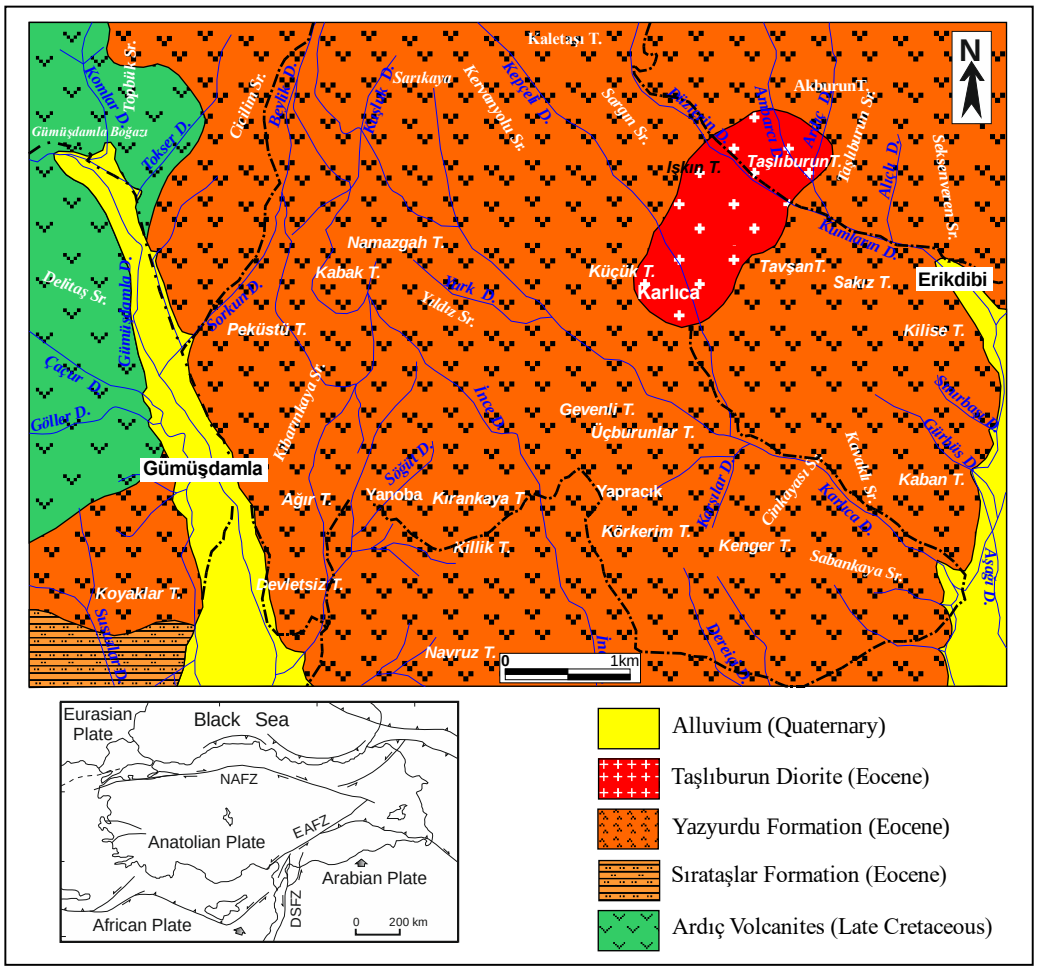

Figure 1: Geological map of the study area (modified by [9]).

The oldest rocks in the study area consists of Late Cretaceous Ardıç volcanics. This unit is incompatibly overlain by Eocene Sırataşlar Formation. Eocene Yazyurdu Formation overlies this unit. All these units were cut by Eocene Taşlıburun Diorite. Quaternary alluviums constitute the youngest unit of the study area (Figure 1).

3. Analysis methods

Within the scope of the study, thin sections of rock samples collected from the field were prepared and detailed petrographic properties were determined by polarizing microscope. Electron microprobe analyses on carbon-coated polished sections were carried out at the Ifermer Epma laboratories, Brest (France), using a Cameca SX-100 electron microprobe. Details of analysis technique are given in [38].

4. Petrography

The Eocene Gümüşdamla-Erikdibi (Bayburt) volcanics, which constitutes the main subject of this study, consists mainly of andesite, basalt and their pyroclasts. In the microscopic examination, the andesites show microlitic porphyritic, porphyritic and partially cumulophyric texture (Figure 2 and 3). The main minerals are plagioclase, alkali-feldspar, pyroxene, amphibole, biotite and opaque minerals. Basalts show mainly microlitic and lesser extent microlitic porphyritic texture. The main minerals are plagioclase, pyroxene, olivine and opaque minerals. Their groundmass contains the microlites of plagioclase, amphibole, biotite, Fe–Ti oxide, and glass (Figure 2). Pyroclastic rocks consist of volcanic breccia and tuffs.

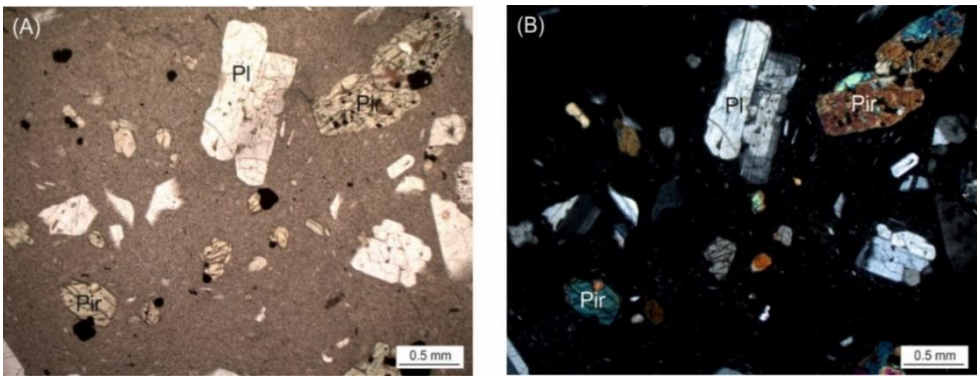

Figure 2: Porphyritic texture observed in andesites in the Yazyurdu Formation A) Crossed nicol, B) Crossed polarized light) (Pl: Plagioclase, Pir: Pyroxene, Op: Opaque minerals)

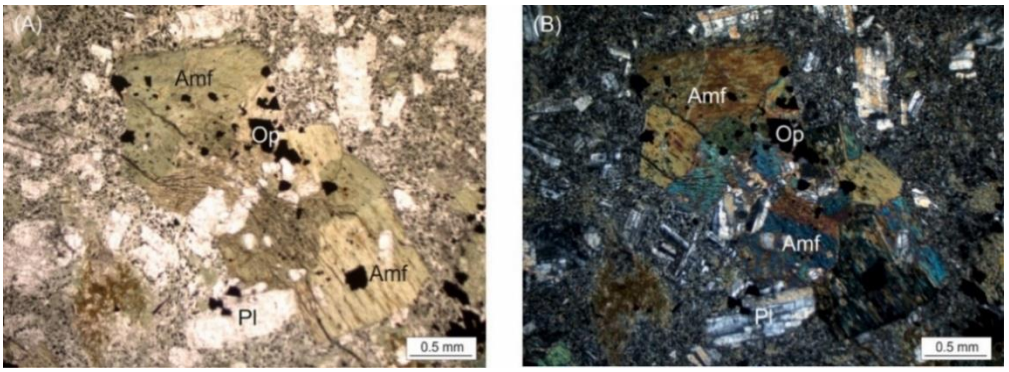

Figure 3. Cumulophyric texture observed in andesites in the Yazyurdu Formation A) Crossed nicol, B) Crossed polarized light) (Pl: Plagioclase, Pir: Pyroxene, Amf: Amphibole, Op: Opaque minerals)

5. Mineral chemistry

Clinopyroxene minerals were commonly observed in the studied volcanic rocks. The minimum and maximum values of the microprobe compositions for clinopyroxene are given in Table 1. Pyroxene forms subhedral to euhedral crystals, and mainly forms zoned phenocrysts. All the pyroxenes are of calcic clino-pyroxene ($Wo_{40-48}En_{39-46}Fs_{9-19}$) and are generally augite, and minor diopside in composition (Figure 4a). Mg number (Mg#) of clino-pyroxenes range from 0.72 to 0.83 (Table 1). They are placed in the CATS field in the Ti-Na-Al^4 diagram [58] (Figure 4b).

Table 1: Minimum, maximum and average values of microprobe analyze for pyroxene

(n=27)	**SiO_2**	**TiO_2**	**Al_2O_3**	**Cr_2O_3**	**FeO**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**Total**	
min	48.94	0.35	1.54	0.00	5.32	0.07	13.41	18.67	0.18	0.00	99.31	
max	52.80	1.02	5.35	0.71	11.25	0.45	16.32	23.14	0.39	0.03	101.10	
avg	51.41	0.57	3.06	0.05	8.27	0.28	15.05	21.14	0.29	0.00	100.14	
sd	0.89	0.17	1.07	0.16	1.24	0.11	0.73	1.04	0.06	0.01	0.42	
	Structural formula based on 6 oxygen atoms											
	Si	Ti	Al	Cr	Fe(ii)	Mn	Mg	Ca	Na	K	Wo	En
min	1.84	0.01	0.07	0.00	0.16	0.00	0.75	0.75	0.01	0.00	38.24	39.36
max	1.95	0.03	0.23	0.02	0.35	0.01	0.90	0.92	0.03	0.00	48.09	45.87
avg	1.91	0.02	0.13	0.00	0.26	0.01	0.83	0.84	0.02	0.00	43.39	42.96
sd	0.03	0.01	0.05	0.00	0.04	0.00	0.04	0.04	0.01	0.00	2.33	1.67
min: minimum values, max: maximum values, n= sample number, avg: average, sd: standard deviation												

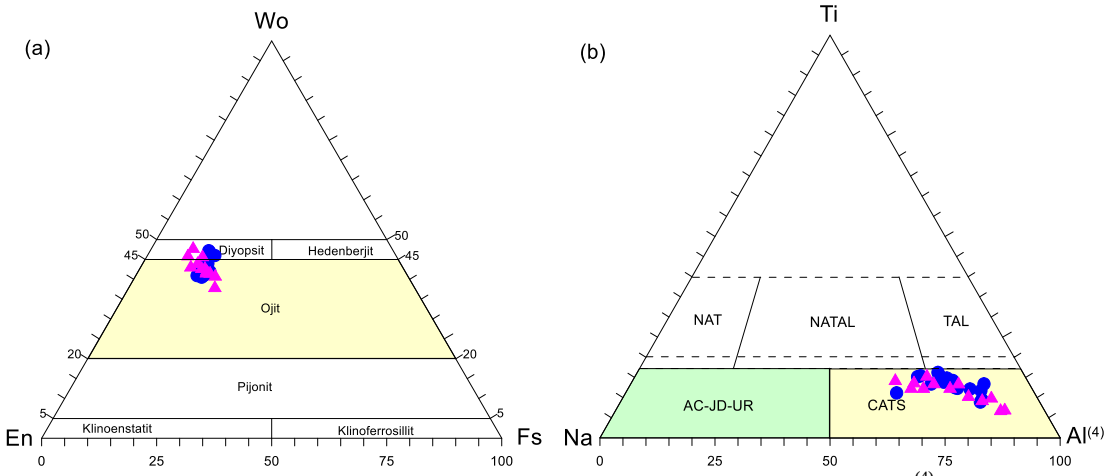

Figure 4: Classification diagrams of pyroxene, a) Wo-En-Fs [48], b) Ti-Na-Al$^{(4)}$ [58].

6. Intensive parameters

6.1. Clinopyroxene thermobarometry

Estimates of quantitative pressure and temperature on the clinopyroxene composition were re-evaluated by [59]. [59] gave an equilibrium constant using the Fe–Mg exchange and $K_D(Fe\text{-}Mg)^{cpx\text{-}melts} = 0.27\pm0.03$. The calculated results of the studied rocks show pressures ranging from 0.24 to 3.62 kbar and temperatures ranging from 1021 to 1077 °C (Table 2).

Table 2. Clinopyroxene temperature and pressure calculations in the studied volcanic rocks

(n=15)	P (kbar)	T (^{0}C)	KD $_{(Fe\text{-}Mg)}$
Minimum	0.24	1021	0.26
Maximum	3.62	1077	0.27

7. Discussion and conclusions

Although there were different opinions [20, 28, 34, 45], the most accepted opinion [7-8, 19, 22, 30-31, 33, 35-36, 39, 42, 49, 53-55] suggest that the Eocene magmatism had generally post-collision characteristics and were derived from a sub-continental lithospheric mantle source previously modified by fluids and/or sediments from a subduction zone. In addition, the crustal structure throughout the Eastern Pontides is not homogeneous with varying thicknesses from 29 to 40 km [60] and 29 to 47 km [61]. For this reason, petrographic and mineral chemical properties of the volcanic rocks would be changed depending on the magma chamber processes at different crustal levels. The petrographic characteristics of the studied Eocene volcanics have anhydrous and hydrous suites. Hydrous suites crystallize from water rich magma and affects the melt dynamics and controls magmatic processes such as differentiation, assimilation, contamination and mixing [62-63]. Amphibole-bearing magmas have disputed water content, ranging 2 to 3 wt.% according to [64], to approximately 5 wt.% according to [65-67], and to 6 wt.% according to [68]. [38] indicated that the estimated H_2O melt content ranges from 3.9 to 5.8 wt.% for the Aydıntepe-Yazyurdu volcanics rocks in the Bayburt area.

According to [54], the magma increased because of the decreasing density or replenishment of fresh magma associated with volatile release under extensional tectonic regime and ascending magma stalls at mid-crustal level. This mid-crustal magma reservoir is characterized by the occurrence of clinopyroxene at a depth of 8 to 16 km on the basis of clinopyroxene barometry. The crystallization of Al–Fe rich diopside, augite, and medium An plagioclases starts at this level [54]. [54] indicated that the crystallization pressure estimates, which are constrained by the presence of brown mica, show that the ascending magma ponded at depths ranging from 5 to 6 km form shallow crustal magma chambers. The dominated mineral assemblage that crystallized in the magma chambers are brown mica and low An plagioclase at lower temperatures.

[38] indicated that the calculated crystallization

temperatures and pressures using the chemical analysis of amphibole and orthopyroxenes in the Bayburt volcanics are 819 to 1157 °C and 0.1 to 7.8 kbar, respectively. [54] stated that the oxygen fugacity (log10 fO_2) values of the volcanics varied between -11.0 and -12.1. On the basis of clinopyroxene thermobarometric calculations, magmas of Eocene volcanic suites in Tonya and Trabzon area crystallized at pressure ranging from 1.84 to 5.39 kbar and temperature ranging from 1100 to 1244 °C. Hornblende thermobarometry, oxygen fugacity, and hygrometer argued that the crystallization pressure ranging from 6.49 to 6.52 kbar, the temperature ranging from 956 to 959 °C and the water content ranging from 7.83 to 8.57 wt.% in the Eocene volcanic suites [54]. The petrographic and mineral chemistry properties of the studied Gümüşdamla-Erikdibi volcanic suggest that they developed in hydrous and anhydrous environments. The calculated crystallization temperatures and pressures in the studied volcanic rocks using the chemical analysis of orthopyroxenes are 1021 to 1077 °C and 0.24 to 3.62 kbar, respectively (Table 2). The combined petrographic, mineral chemistry, and thermobarometric features indicate that the magmas had undergone anhydrous and hydrous crystallizations in shallow to mid-crustal levels (Figure 5).

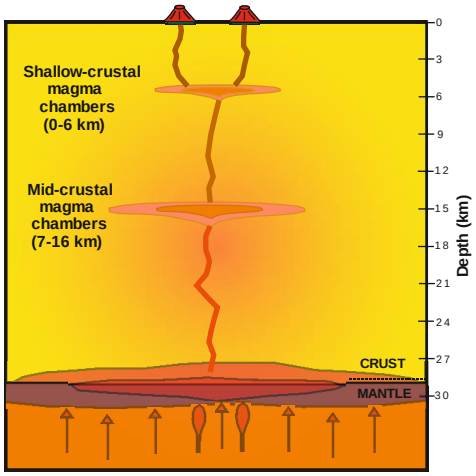

Figure 5: Schematic illustration of pre-eruptive crystallization paths for the studied volcanic rocks in the Eastern Pontides.

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