



## ORIGINAL PAPER

**GEOLOGY AND MINERAL CHEMISTRY OF THE ARSLANDEDE PLUTON  
IN THE EASTERN PONTIDES****Zikrullah Samet GÜLOĞLU <sup>1)</sup> \* and Abdullah KAYGUSUZ <sup>2)</sup>**<sup>1)</sup> Department of Mining and Mineral Extraction, Zonguldak Bülent Ecevit University, Zonguldak, Turkey<sup>2)</sup> Department of Geological Engineering, Gümüşhane University, Gümüşhane, Turkey\*Corresponding author's e-mail: [samet.guloglu@beun.edu.tr](mailto:samet.guloglu@beun.edu.tr)**ARTICLE INFO****Article history:**

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Arslandede Pluton**ABSTRACT**

The Middle Eocene Arslandede Pluton, exposed in the Bayburt region on the southern margin of the Eastern Pontides (NE Turkey), has been investigated in terms of its geology and mineral chemistry. The pluton exhibits a NW-SE elongation and covers an area of approximately 7 km<sup>2</sup>. It comprises a broad compositional spectrum ranging from monzodiorite to quartz monzonite. Major rock-forming minerals include plagioclase (An<sub>25-48</sub>), orthoclase (Or<sub>69-88</sub>), quartz, amphibole (Mg# = 0.63-0.73), biotite (Mg# = 0.52-0.62), pyroxene (Mg# = 0.70-0.75), and Fe-Ti oxides. Crystallization conditions, estimated via amphibole-plagioclase thermometry and Al-in-hornblende barometry, suggest crystallization temperatures of 737-812 °C and pressures of 0.09-1.61 kbar, corresponding to depths of 0.3-6.0 km. These results indicate that the pluton was emplaced at shallow crustal levels and subsequently solidified under low-pressure conditions. Comparison with other Middle Eocene plutons in the region reveals similar crystallization conditions, suggesting a common tectonic setting during the post-collisional extensional regime in the Eastern Pontides.

**1. INTRODUCTION**

The Eastern Pontides, located in northeastern Turkey, host a wide spectrum of plutonic and volcanic rock associations (Arslan et al., 2013; Aydınçakır et al., 2023; Kaygusuz et al., 2012, 2008; Köprübaşı et al., 2000; Temizel et al., 2022; Vural and Kaygusuz, 2021; Yücel et al., 2024). The plutonic rocks in the region span a broad temporal range from the Permo-Carboniferous to the Late Eocene (Eyuboğlu et al., 2019; Güloğlu et al., 2024; Güloğlu and Kaygusuz, 2025; Karşı et al., 2018; Kaygusuz et al., 2016; Temizel et al., 2019; Yücel et al., 2024). Notably, Middle Eocene plutonic rocks are more widely distributed in the southern part of the Eastern Pontides compared to the northern sector (Fig. 1).

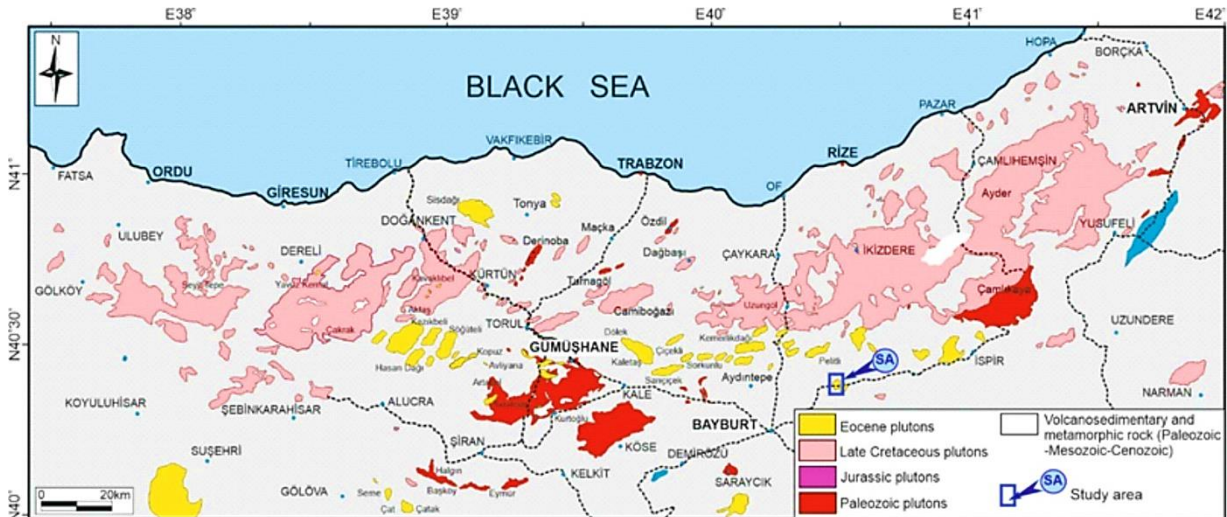
The Arslandede Pluton, which forms the subject of this study, is located in the southern part of the Eastern Pontides (Fig. 1). Previous studies have focused primarily on whole-rock geochemistry, isotope systematics, and geochronology of this pluton (Güloğlu, 2017; Güloğlu et al., 2018; Güloğlu and Kaygusuz, 2024; Kaygusuz et al., 2024). However, detailed mineral chemistry data and thermobarometric constraints have not been systematically presented. This study aims to fill this gap by providing comprehensive mineral chemistry data and thermobarometric constraints of the Arslandede Pluton, thereby offering the missing link for understanding the final crystallization stages of this plutonic body, and comparing these results with other

coeval plutonic bodies in the region to better constrain the regional magmatic evolution during the Middle Eocene.

**2. GEOLOGICAL SETTING**

The study area is located within the Eastern Pontides, which constitute a part of the Alpine-Himalayan orogenic system (Ketin, 1966; Fig. 1). The Eastern Pontides experienced a complex tectonic evolution involving subduction, accretion, and post-collisional processes from the Paleozoic to Cenozoic (Okay and Şahintürk, 1997; Topuz et al., 2011). Middle Eocene plutonic rocks in the region are interpreted to have formed during a post-collisional extensional regime following the closure of the Neo-Tethys Ocean (Kaygusuz et al., 2020; Topuz et al., 2011).

In the Eastern Pontides, Pre-Late Cretaceous rocks include Early Carboniferous metamorphic rocks (Topuz et al., 2004), Early-Late Carboniferous plutonic rocks (Dokuz, 2011; Kaygusuz, 2020; Kaygusuz et al., 2016, 2012; Topuz et al., 2010; Vural and Kaygusuz, 2019), Early-Middle Jurassic volcano-sedimentary rocks (Ağar, 1977; Saydam Eker et al., 2025, 2012), Middle-Late Jurassic plutonic rocks (Aydınçakır et al., 2023; Eyuboğlu et al., 2016; Karşı et al., 2017; Ustaömer et al., 2013) and Late Jurassic-Early Cretaceous carbonate rocks (Pelin, 1977). Volcanic, plutonic and sedimentary rocks are common in the region during the Late Cretaceous (Eyuboğlu,



**Fig. 1** Distribution of the Paleozoic to Eocene plutons in the Eastern Pontides (modified after Güven (1993) and Kaygusuz et al. (2025)).

2010; Karlı et al., 2010; Kaygusuz, 2000; Kaygusuz et al., 2021). The Cenozoic-aged units are mainly composed of volcanic, plutonic and sedimentary rocks (Aydın et al., 2008; Aydınçakır et al., 2024; Eyuboğlu et al., 2017; Karlı et al., 2007; Kaygusuz et al., 2022, 2018, 2017; Temizel et al., 2022, 2020, 2018; Topuz et al., 2011; Yücel et al., 2017). The youngest rocks in the region consist of Quaternary alluvium, travertines and slope debris.

### 3. MATERIALS AND METHODS

#### 3.1. SAMPLING STRATEGY AND FIELD DESCRIPTION

Two representative rock samples were collected from the Arslandedede Pluton for detailed mineral chemistry analyses. Sample locations and descriptions are provided below:

Sample (Monzodiorite): Coordinates: 40°17'25"N, 40°11'42"E; Elevation: 1850 m. This sample represents the mafic end-member of the pluton, collected from fresh outcrop near Arslandedede village. The rock exhibits medium-grained, equigranular texture with abundant hornblende and biotite.

Sample (Quartz Monzonite): Coordinates: 40°17'38"N, 40°11'55"E; Elevation: 1920 m. This sample represents the felsic facies, collected from Kakbayır Hill. The rock displays coarse-grained texture with prominent quartz and K-feldspar crystals.

Both samples were collected from unaltered portions of the pluton, avoiding weathered surfaces and contact zones. Polished thin sections were prepared at Gümüşhane University for petrographic examination under a polarizing microscope.

#### 3.2. ANALYTICAL METHODS

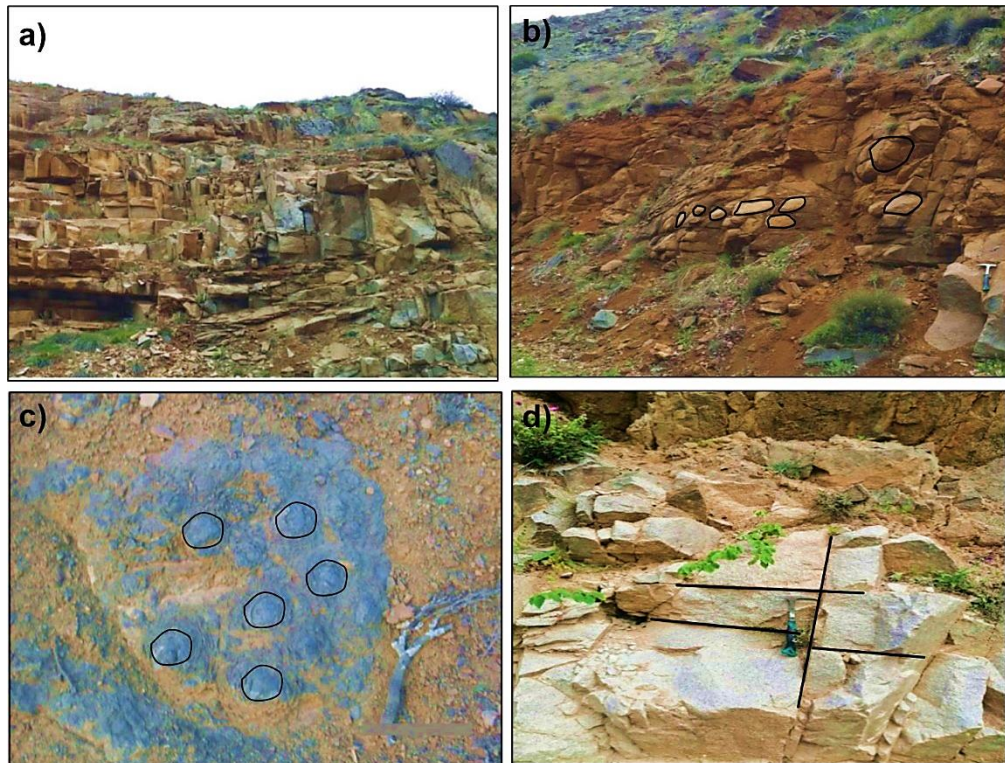
Mineral chemistry analyses were carried out on two representative rock samples (monzodiorite and quartz monzonite) collected from the Arslandedede Pluton, using electron microprobe techniques at the Geological and Mineral Research Laboratory (New

Mexico Tech University, USA). A CAMECA SX 100 electron microprobe was operated under conditions of 15 kV accelerating voltage and 20 nA beam current. A beam diameter of 10 µm with a counting time of 10 seconds was employed for the analysis of elements such as Si, Al, Ca, Ti, Mn, Mg, Fe, Na and K. For amphibole, pyroxene, and Fe-Ti oxide minerals, a focused beam diameter of 1 µm was used during analysis. In the case of mica, feldspar, an unfocused beam of 10 µm was employed to minimize possible Na loss. Standardization was performed using certified reference materials (diopside, kaersutite, albite, orthoclase, biotite, magnetite, and anorthite (UCB)) as defined by Nielsen and Sigurdsson (1981).

### 4. RESULTS

#### 4.1. GEOLOGY OF THE STUDY AREA

The Arslandedede Pluton, which forms the focus of this study, is located in the southern part of the Eastern Pontides, to the north of Bayburt province, near the village of Arslandedede (Fig. 3). Field observations reveal the widespread presence of Cenozoic volcanic and plutonic units. The Eocene-aged Yazyurdu Formation represents the oldest unit in the study area and is intruded by the Middle Eocene Arslandedede Pluton (Güloğlu, 2017). These units are unconformably overlain by Quaternary alluvium (Fig. 3). The Eocene Yazyurdu Formation comprises a sequence dominated by andesite, basalt, and associated pyroclastic deposits, interlayered with occasional sandstone beds (Figs. 2-3). The andesites and basalts are generally gray in color but may also exhibit pale yellowish or brownish tones. Hand specimen observations indicate the presence of plagioclase and mafic minerals. Volcanic breccias display dark gray to greenish hues, composed of semi-angular andesite clasts (2–40 cm) within a matrix. The tuffs are typically gray or green, porous in texture, and the voids are filled with secondary minerals such as calcite, epidote, and quartz. Field observations reveal that the Arslandedede Pluton displays a massive



**Fig. 2** a) General view of the granitoid b) Arenization observed in the granitoid c) View of exfoliation structure in the agglomerates d) View of the jointed/fractured structure in the granitoid.

appearance with well-developed jointing systems that produce large, clearly defined block structures (Fig. 2a). Localized arenization is also observed within the pluton, where granitoid blocks of varying sizes are preserved within a weathered matrix (Fig. 2b). Exfoliation structures documented in the agglomerates are characterized by rounded to sub-rounded clasts embedded within the volcanic matrix (Fig. 2c). The dominant joint sets exhibit two intersecting orientations, as illustrated by the fractured granitoid exposed at the outcrop scale (Fig. 2d).

The Arslandede Pluton covers a surface area of approximately 7 km<sup>2</sup>, with dimensions of ~3-4 km in length and ~1-2 km in width (Güloğlu, 2017; Kaygusuz et al., 2024; Fig.3). Field observations indicate that the pluton intruded coeval volcanic units and induced recrystallization in limestones at the contact zones. Cooling joints are prominent within the pluton. These joint systems exhibit spatial variability around Arslandede and Kakbayır Hill. The joint sets are limited in number but exhibit wide spacing, resulting in well-defined, large block development throughout most of the pluton body, whereas in some areas near the country rock contact, the plutonic rocks are intensely fractured and brecciated, resulting in poor block development. Overall, the Arslandede Pluton is characterized by a massive appearance, although localized arenization is also observed.

## 4.2. MINERAL CHEMISTRY

The Arslandede Pluton is mainly composed of monzodiorite and quartz monzonite. The principal minerals are plagioclase, quartz, orthoclase, hornblende, biotite, and pyroxene (Güloğlu, 2017; Kaygusuz et al., 2024).

### 4.2.1. PLAGIOCLASE

Electron microprobe analyses of plagioclase minerals from the Arslandede Pluton reveal compositional variations ranging from An<sub>25</sub> to An<sub>48</sub> (Fig. 4). Plagioclases occurring in both mafic (monzodiorite) and felsic (quartz monzonite) lithologies exhibit SiO<sub>2</sub> contents ranging from 56 to 66 wt%, Al<sub>2</sub>O<sub>3</sub> from 22 to 27 wt%, FeO<sup>T</sup> from 0.2 to 0.5 wt%, and K<sub>2</sub>O from 0.3 to 0.7 wt%.

The plagioclases in the monzodiorites of the Arslandede Pluton commonly display oscillatory zoning, characterized by distinct compositional domains. The variation of An content between An<sub>25</sub> and An<sub>48</sub> indicates periodic compositional changes during crystal growth.

### 4.2.2. K-FELDSPAR

Potassium feldspar minerals, identified through petrographic observations and confirmed by electron microprobe analyses, are present in both monzodiorite and quartz monzonite samples. Chemical analyses of these K-feldspars show variations in SiO<sub>2</sub> (65–66 wt%), Al<sub>2</sub>O<sub>3</sub> (18–19 wt%), and BaO (0.04–0.40 wt%) contents (Fig. 5).

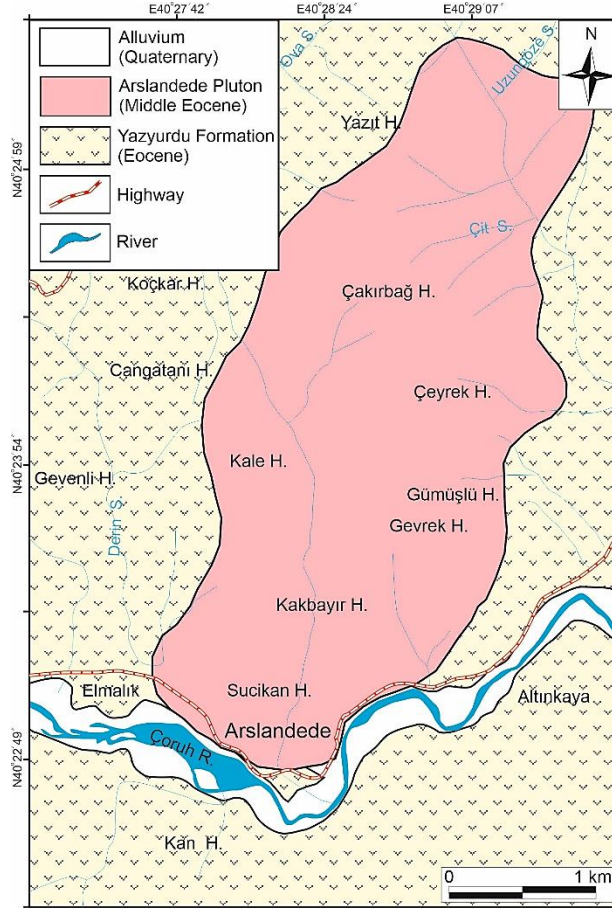


Fig. 3 Geological map of the study area (modified from Güloğlu, 2017; Kaygusuz et al., 2024).

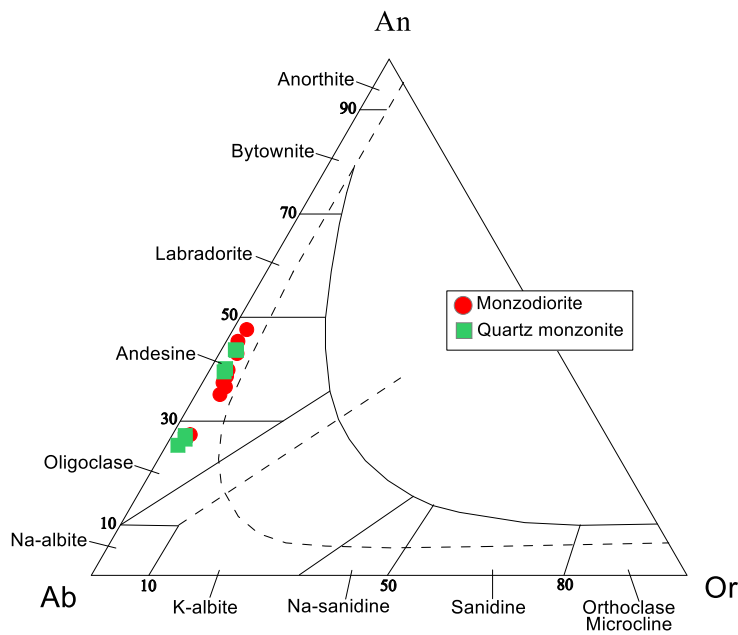
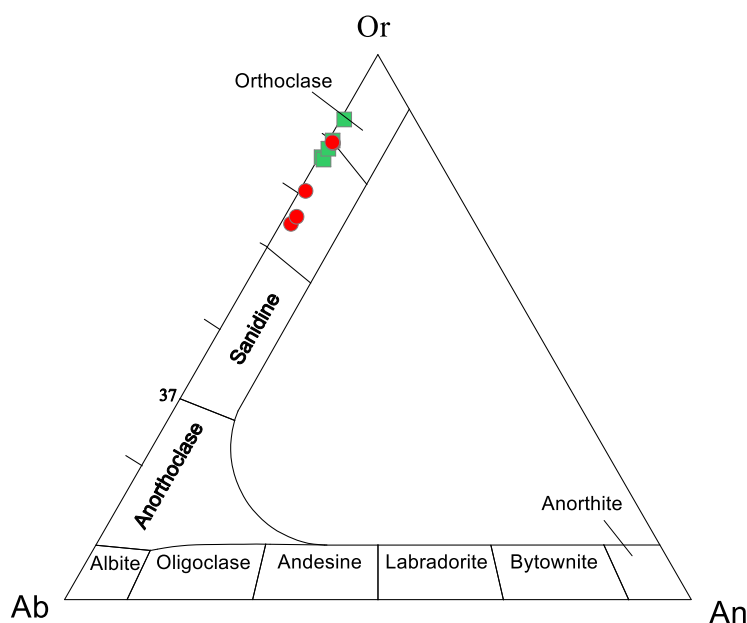


Fig. 4 An–Ab–Or ternary diagram showing the feldspar compositions of the studied pluton (Smith and Brown, 1988).



**Fig. 5** An–Ab–Or classification diagram of K-feldspars (Deer et al., 1992).

K-feldspars generally display an orthoclase composition. Almost all K-feldspar crystals exhibit a homogeneous composition, with no evidence of chemical zoning. The overall rock compositions range between Or<sub>69</sub> and Or<sub>88</sub> (Fig. 5).

#### 4.2.3. BIOTITE

Electron microprobe analyses of biotites reveal TiO<sub>2</sub> contents ranging from 4.4 to 5.3 wt%, Al<sub>2</sub>O<sub>3</sub> contents between 12 and 13 wt%, and MgO contents from 13 to 15 wt%. The Mg# (Mg/(Mg + Fe<sup>2+</sup>)) and Fe# (Fe<sup>2+</sup>/(Fe<sup>2+</sup> + Mg)) ratios vary between, 0.52–0.62 and 0.38–0.48 respectively. These values indicate that the biotites crystallized as solidified melt products with compositions between the annite and phlogopite end-members, lying close to the Mg-rich side of the phlogopite solid-solution series (Figs. 6a–b).

Furthermore, microprobe analyses show that the biotites are classified within field C (calc-alkaline suite) in the FeO<sup>(T)</sup>–Al<sub>2</sub>O<sub>3</sub> diagram (Fig. 6c; Abdel-Rahman, 1994). On the MgO–FeO<sup>(T)</sup> diagram (Abdel-Rahman, 1994), biotites cluster in field C (calc-alkaline affinity; Fig. 6d). In the MgO–FeO + MnO–TiO<sub>2</sub>\*10 ternary diagram (Abdel-Rahman, 1994), they are classified as primary brown biotites (field A: magmatic origin; Fig. 6e). Based on the FeO<sup>(T)</sup>–Al<sub>2</sub>O<sub>3</sub>–MgO ternary diagram (Abdel-Rahman, 1994), the biotites are interpreted to occur in association with hornblende, pyroxene, or olivine (calc-alkaline to transitional series; Fig. 6f).

#### 4.2.4. HORNBLLENDE

Amphiboles from the studied rocks reveal Al<sub>2</sub>O<sub>3</sub> contents ranging from 4.7 to 5.6 wt%, SiO<sub>2</sub> contents between 48.0 and 49.9 wt%, and Mg# values varying

from 0.63 to 0.73. Classification diagrams indicate that all amphiboles fall within the calcic amphibole field based on the (Ca + Na) versus Na ratio (Fig. 7a), and according to (Leake et al., 1997), they correspond to magnesio-hornblende compositions (Fig. 7b).

#### 4.2.5. PYROXENE

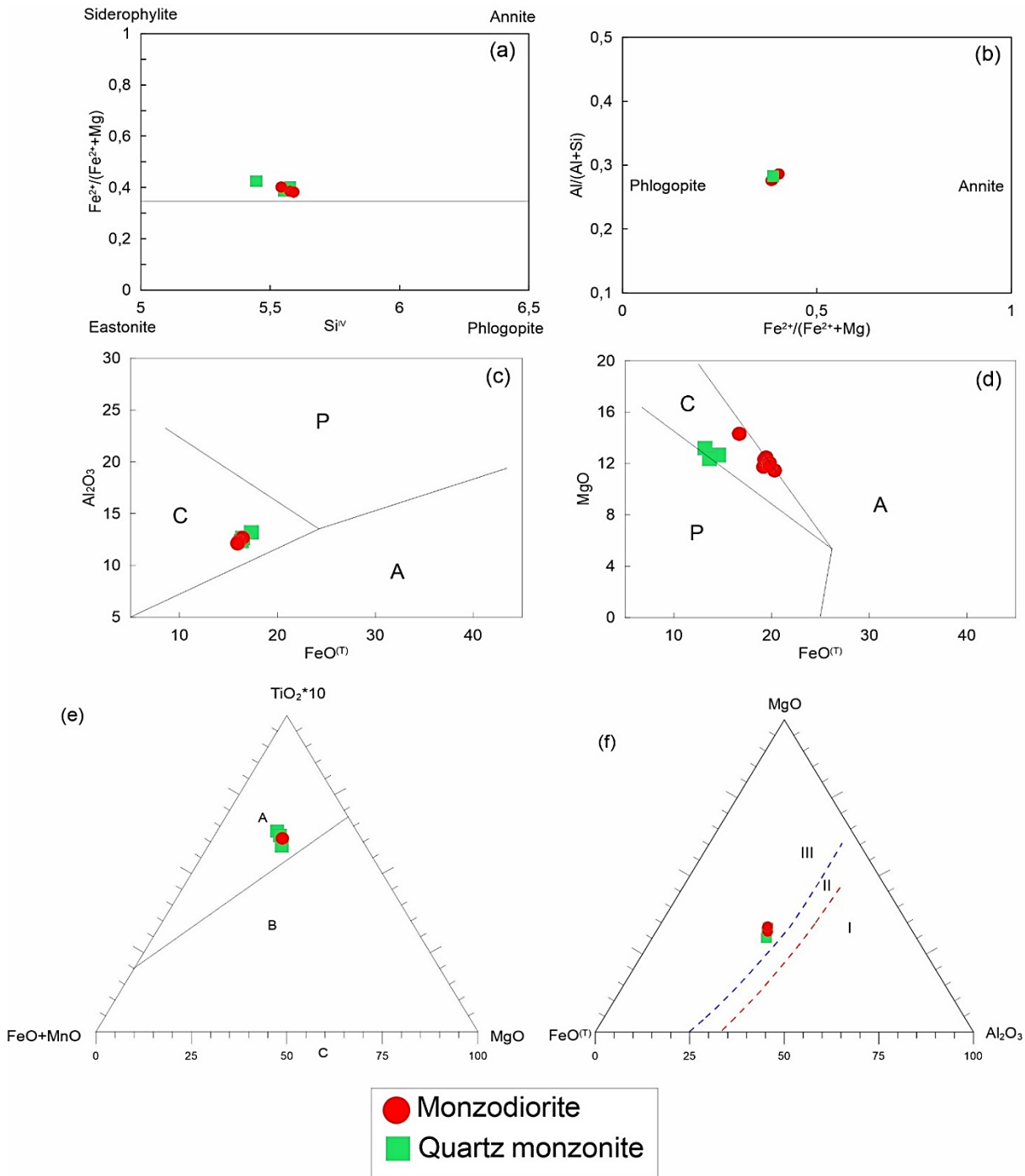
According to electron microprobe analyses of pyroxenes, Al<sub>2</sub>O<sub>3</sub> values range from 0.5 to 1.4 wt%, SiO<sub>2</sub> contents vary between 52.0 and 53.1 wt%, and Mg# content falls between 0.70 and 0.75. The analytical results indicate that the samples cluster within the augite field of the Wo–En–Fs ternary diagram (Fig. 8a).

#### 4.2.6. FE-TI OXIDE

Fe–Ti oxides exhibit Fe# (Fe<sup>2+</sup>/(Fe<sup>2+</sup> + Mg)) values ranging from 0.35 to 0.37. As shown in Figure 9, the samples cluster within the magnetite field in the TiO<sub>2</sub>–FeO–Fe<sub>2</sub>O<sub>3</sub> ternary diagram. The distribution of the samples in the FeO–TiO<sub>2</sub>–Fe<sub>2</sub>O<sub>3</sub> diagram indicates that the chemical compositions of the minerals are concentrated within a specific field, particularly in the region dominated by FeO and Fe<sub>2</sub>O<sub>3</sub> components.

### 4.3. THERMOBAROMETRY AND CRYSTALLIZATION CONDITIONS

To estimate the crystallization temperatures of the magmas, the amphibole–plagioclase thermometer (Blundy and Holland, 1990) was applied. In this thermometer, temperature is calculated using the equation:



**Fig. 6** Composition of biotites in the studied rocks illustrated through various diagrams: a)  $\text{Si}^{\text{IV}} - (\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Mg}))$  diagram of Parsons et al. (1991), b)  $\text{Al}/(\text{Al} + \text{Si}) - (\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Mg}))$  diagram, c)  $\text{FeO}^{(\text{T})} - \text{Al}_2\text{O}_3$  diagram, d)  $\text{FeO}^{(\text{T})} - \text{MgO}$  diagram, e)  $\text{MgO} - (\text{FeO} + \text{MnO}) - \text{TiO}_2 \cdot 10$  ternary diagram of Abdel-Rahman (1994), and f)  $\text{FeO}^{(\text{T})} - \text{Al}_2\text{O}_3 - \text{MgO}$  ternary diagram of Speer (1984). Field labels in panels c–e are defined after Abdel-Rahman (1994). In the binary  $\text{FeO}^{(\text{T})} - \text{Al}_2\text{O}_3$  diagram (panel c) and  $\text{FeO}^{(\text{T})} - \text{MgO}$  diagram (panel d), three compositional fields are shown: Field A = calc-alkaline suite; Field C = peraluminous suite; Field P = peralkaline suite. In the  $\text{MgO} - (\text{FeO} + \text{MnO}) - \text{TiO}_2 \cdot 10$  ternary diagram (panel e), fields represent biotite genesis: Field A = primary magmatic biotites (crystallized directly from melt); Field B = re-equilibrated biotites (modified by late-stage fluids or subsolidus re-equilibration); Field C = xenolithic biotites (derived from metamorphic or restitic sources). In panel f ( $\text{FeO}^{(\text{T})} - \text{Al}_2\text{O}_3 - \text{MgO}$  ternary diagram), fields are defined after Speer (1984): Field I = biotites associated with olivine and/or pyroxene (subaluminous to peralkaline host rocks); Field II = biotites associated with hornblende (metaluminous to weakly peraluminous, calc-alkaline host rocks); Field III = biotites associated with muscovite (strongly peraluminous host rocks).

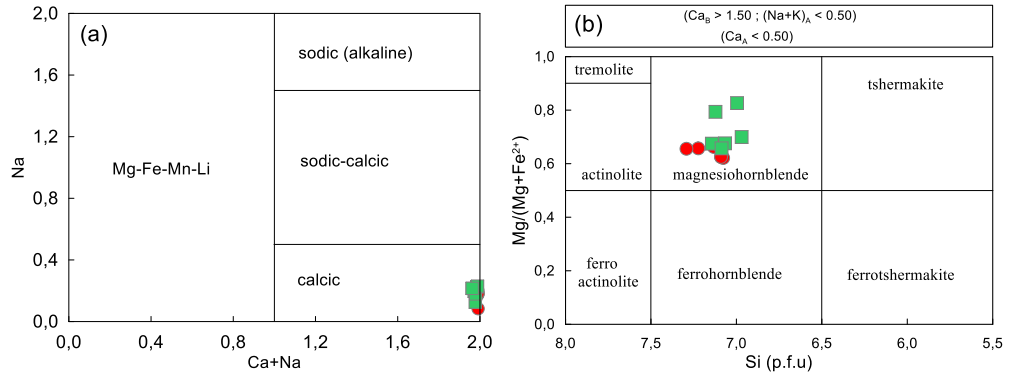


Fig. 7 Amphibole composition in the studied rocks of Leake et al. (1997).

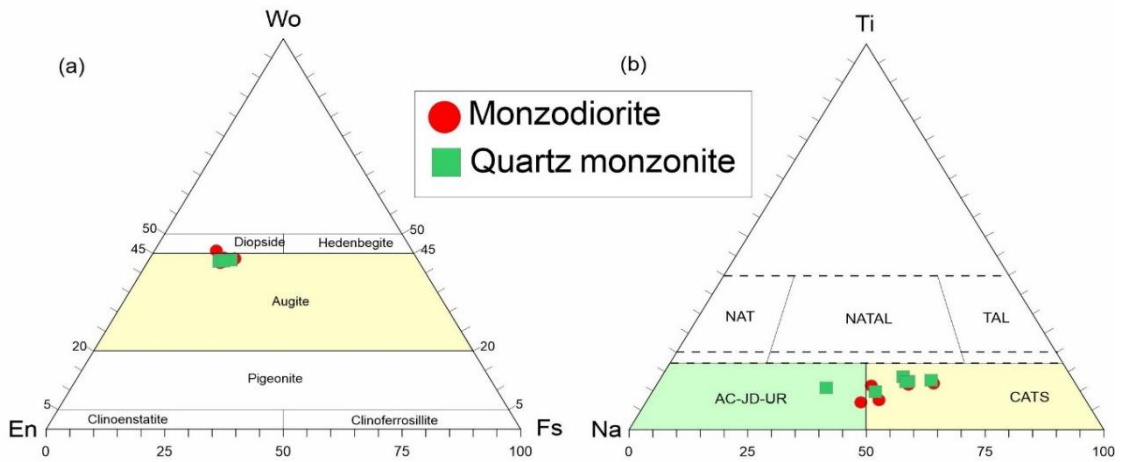


Fig. 8 (a-b) Wo-En-Fs and Ti-Na-Al<sup>(IV)</sup> ternary diagrams (Morimoto, 1988).

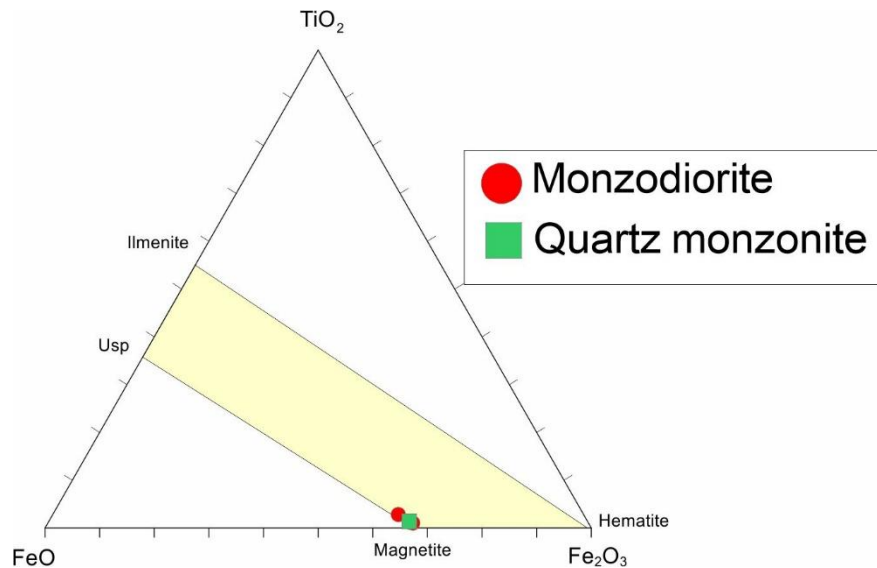


Fig. 9 Compositions of Fe-Ti oxides in the studied rocks (Bacon and Drituit, 1988).

$$\text{Temperature (T)} = 0.667 * P - 48.98 + \frac{Y}{-0.0429} - 0.008314 * \text{LnK}$$

Thermobarometric calculations were based on analyses of amphibole crystal cores, which preserve primary magmatic compositions. Rim analyses were excluded to avoid the potential effects of subsolidus re-equilibration. Amphibole–plagioclase pairs were selected from texturally equilibrated, touching mineral pairs. The application of this thermometer requires equilibrium crystallization between amphibole and plagioclase, accompanied by biotite, quartz, K-feldspar, pyroxene, Fe–Ti oxides ± sphene. In the rocks constituting the Arslandede Pluton, temperatures calculated using the amphibole–plagioclase thermometer of Blundy and Holland (1990) range between 737 and 812 °C, with values of 745–788 °C in monzodiorites and 737–812 °C in quartz monzonites (Table 1)

In plutonic rocks, pressure estimations were made using calibrations based on the Al<sup>(T)</sup> content of hornblendes, as given below:

$$\begin{aligned} \text{Pressure (P, kbar)} &= 4.76 * \text{Al(T)} - 3.01 \text{ from Schmidt (1992);} \\ \text{Pressure (P, kbar)} &= 5.03 * \text{Al(T)} - 3.92 \text{ from Hammarstrom and Zen (1986);} \\ \text{Pressure (P, kbar)} &= 5.64 * \text{Al(T)} - 4.76 \text{ from Hollister et al. (1987)} \end{aligned}$$

The crystallization pressures calculated for the rocks of the Arslandede Pluton using the above formulations yield comparable values (Table 1). The crystallization pressures of the investigated plutonic rocks range between 0.09 and 1.61 kbar, with values of 0.1–1.61 kbar for monzodiorites and 0.2–1.37 kbar for quartz monzonites (Table 1).

**Table 1** Pressure (P) and temperature (T) estimates calculated using amphibole and amphibole–plagioclase for the Arslandede Pluton.

	P (kbar) <sup>1</sup>	P (kbar) <sup>2</sup>	P (kbar) <sup>3</sup>	T (°C) <sup>4</sup>
<b>Minerals</b>				
<b>Amphibole – Plagioclase</b>				
<b>Monzodiorite</b>				
Min	0.20	0.09	0.89	745
Max	0.97	0.72	1.61	788
Avg	0.48	0.44	1.16	772
SD (±)	0.31	0.32	0.29	16
Min Depth (km)	0.74	0.35	3.29	
Max Depth (km)	3.58	2.66	5.97	
<b>Quartz monzonite</b>				
Min	0.15	0.35	0.84	737
Max	0.71	0.43	1.37	812
Avg	0.29	0.39	0.97	776
SD (±)	0.21	0.06	0.20	28
Min Depth (km)	0.54	1.30	3.10	
Max Depth (km)	2.63	1.59	5.07	

**Max:** Maximum, **Min:** Minimum, **SD (±):** Standard deviation, **Avg:** Average. Depth for the continental crust has been taken as 1 kbar = 3.7 km from Tulloch and Challis (2000).

<sup>1</sup> from Hammarstrom and Zen (1986); <sup>2</sup> from Hollister et al. (1987); <sup>3</sup> from Schmidt (1992); <sup>4</sup> from Blundy and Holland (1990)

## DISCUSSION

### COMPARISON WITH REGIONAL MIDDLE EOCENE PLUTONS

The Middle Eocene magmatism in the Eastern Pontides is represented by numerous plutonic bodies with similar ages and geochemical characteristics (e.g., Kaygusuz et al., 2020; Topuz et al., 2011–2020; Temizel et al., 2018; Table 2). The comparison of the Arslandede Pluton with other coeval Middle Eocene plutons in the Eastern Pontides aims to evaluate whether these plutonic bodies share a common magmatic source and crystallization history, or whether systematic depth-related variations exist across the southern Eastern Pontides. As discussed below, the mineral chemistry and thermobarometric data suggest a broadly unified magmatic evolution controlled by a common post-collisional extensional regime.

The Arslandede Pluton shows remarkable similarities with other Middle Eocene plutons in the region in terms of mineral chemistry and crystallization conditions. Amphibole Mg# values (0.63–0.73) fall within the typical range observed in the Gököy (0.58–0.71), Ağvanis (0.62–0.75), Havza (0.60–0.70). Similarly, biotite Mg# values (0.52–0.62) are comparable to those of other regional plutons. The crystallization temperatures (737–812 °C) and pressures (0.09–1.61 kbar) are also consistent with the regional pattern, indicating relatively uniform magmatic conditions across the southern Eastern Pontides during the Middle Eocene.

**Table 2** Comparison of Middle Eocene plutons in the Eastern Pontides.

Pluton	Amph Mg#	Biot Mg#	T (°C)	P (kbar)	Reference
Arslandede	0.63-0.73	0.52-0.62	737-812	0.09-1.61	This study
Gölköy	0.58-0.71	0.48-0.60	720-795	0.5-2.0	Temizel et al. (2018)
Ağvanis	0.62-0.75	0.50-0.65	750-830	1.0-3.0	Topuz et al. (2011)
Havza	0.60-0.70	0.55-0.63	735-805	0.8-2.5	Temizel et al. (2020)

### TECTONIC IMPLICATIONS AND REGIONAL SIGNIFICANCE

The Middle Eocene plutonic magmatism in the Eastern Pontides, including the Arslandede Pluton, is interpreted to have formed during a post-collisional extensional regime following the closure of the Neo-Tethys Ocean (Topuz et al., 2011; Kaygusuz et al., 2020). The shallow emplacement depths (0.3-6.0 km) and low crystallization pressures are characteristic features of plutons emplaced in extensional tectonic settings, where lithospheric thinning and asthenospheric upwelling facilitate magma ascent to shallow crustal levels.

The mineral chemistry data of the Arslandede Pluton are consistent with a calc-alkaline, I-type affinity (high Mg# in amphibole and biotite, relatively oxidizing conditions), suggesting a mantle-influenced mafic magma source that underwent fractional crystallization and crustal contamination during ascent. This interpretation is further supported by the whole-rock geochemical and isotopic data reported for the Arslandede Pluton in previous studies (Güloğlu, 2017; Güloğlu et al., 2018; Güloğlu and Kaygusuz, 2024; Kaygusuz et al., 2024), as well as by comparable findings from other coeval plutons in the Eastern Pontides (Kaygusuz et al., 2020; Topuz et al., 2011). It should be noted that a detailed re-evaluation of whole-rock geochemical and isotopic data is beyond the scope of the present mineral chemistry study; such an integrated assessment is recommended for future work. The presence of two distinct facies (monzodiorite and quartz monzonite) within the pluton indicates progressive magma differentiation, possibly through in-situ fractional crystallization or mixing of mafic and felsic magmas.

The BaO contents of K-feldspars in the Arslandede Pluton range from 0.04 to 0.40 wt%, reflecting the compatible behavior of Ba during feldspar crystallization. Barium preferentially partitions into K-feldspar relative to plagioclase due to its ionic radius similarity with K<sup>+</sup>, and thus elevated BaO values in orthoclase are indicative of early-stage feldspar fractionation from a Ba-enriched parental magma. The relatively wide range of BaO (0.04–0.40 wt%) observed in the K-feldspars of the Arslandede Pluton suggests that crystallization occurred over a broad interval of magmatic differentiation, consistent with the progressive fractionation model inferred from the coexistence of monzodiorite and quartz monzonite facies.

Furthermore, the decreasing BaO trend with increasing or content implies continuous feldspar fractionation during magma evolution, corroborating the calc-alkaline differentiation trend documented in previous whole-rock geochemical studies of this pluton (Güloğlu et al., 2018; Kaygusuz et al., 2024).

The regional consistency in mineral chemistry and crystallization conditions among Middle Eocene plutons suggests a common tectonic control and magma source. This widespread magmatism represents an important phase in the tectonic evolution of the Eastern Pontides, marking the transition from compressional to extensional tectonics during the Eocene. The significance of this study lies in providing detailed mineralogical and thermobarometric constraints that contribute to understanding the regional magmatic evolution and crustal processes during this transitional period.

### CONCLUSIONS

The Arslandede Pluton is an elliptically shaped pluton extending in a northwest–southeast direction. It covers an area of 7 km<sup>2</sup> and exhibits lithological variations ranging from monzodiorite to quartz monzonite. The plutonic rocks are mainly composed of plagioclase (Anorthite content: 25–48 %), orthoclase (Orthoclase content: 69–88 %), quartz, biotite, amphibole, pyroxene, and Fe–Ti oxides. The Mg# values of amphiboles in the Arslandede Pluton range between 0.63 and 0.73, whereas biotites display Mg# contents from 0.52 to 0.62. Crystallization temperatures calculated from amphibole data vary between 737 °C and 812 °C, while the pressure estimates range from 0.09 to 1.61 kbar.

Considering all of the field, petrographic, and thermobarometric data, it can be concluded that the studied pluton was emplaced at shallow levels of the continental crust 0.3–6.0 km.

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### ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study does not involve human subjects or animals, therefore ethics approval and consent to participate are not applicable.

**CONSENT FOR PUBLICATION**

This study does not contain any individual person's data in any form, therefore consent for publication is not applicable.

**CONFLICTS OF INTEREST**

The authors declare that they have no conflicts of interest.

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