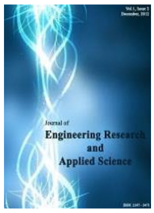
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 14 (2), December 2025, pp 234-249
ISSN 2147-3471 © 2025



Petrography, mineral chemistry and crystallization conditions of Eocene aged Hasan Dağ Pluton (Kürtün Gümüşhane, NE Turkey)

Emre Aydınçakır[1,*], Abdullah Kaygusuz[1], Cem Yücel[2], Z. Samet Güloğlu[3], Ahmet Dündar Şen[1]

[1]Geological Engineering, Gümüşhane University, Gümüşhane, Türkiye
[2]Mining Engineering, Gümüşhane University, Gümüşhane, Türkiye
[3]Mining and Mineral Extraction, Zonguldak Bülent Ecevit University, Zonguldak, Türkiye

Accepted 24 December 2025

Abstract
The Eastern Pontides are home to a wide variety of plutonic rocks that vary greatly in composition and age. The Eocene Hasan Dağ Pluton, exposed around Kürtün in northeastern Turkey, stands out among them due to its distinctive petrographic and mineralogical characteristics. This study aims to determine the physicochemical conditions (temperature, pressure, and oxygen fugacity) under which the Hasan Dağ magma crystallized based on petrographic and mineralogical data. The Hasan Dağ pluton extends approximate in a NE–SW direction and covers an area of about 15 km². The studied rocks are fine- to medium-grained and primarily consist of granodiorite, tonalite, and diorite compositions. The plutonic rocks display granular, poikilitic, monzonitic, graphic, and, rarely, porphyritic textures. The main mineral assemblage includes plagioclase ($An_{14–56}$), hornblende (Mg# = 0.78–0.85), biotite, orthoclase, quartz, and Fe-Ti oxides. Thermobarometric calculations indicate crystallization temperatures of 636–1075 °C, pressures of 0.2–5.1 kbar, and oxygen fugacities (fO_2) ranging from −13 to −10. Water contents estimated from hornblende compositions range from 3.3 to 5.0 wt.%. These results suggest that the Hasan Dağ pluton crystallized and was emplaced at mid- to shallow crustal depths corresponding to approximately 3–12 km.

Keywords: *Geothermobarometry; Petrography; Mineral chemistry; Eastern Pontides; Hasan Dağ Pluton*

1. Introduction
The Eastern Pontide Orogenic Belt (EPOB), situated in the eastern part of the Sakarya Zone (NE Türkiye, Figure 1), represents one of the most complex and geodynamically significant segments of the Alpine–Himalayan system due to successive subduction and collision events. The belt is generally regarded as a well-preserved continental magmatic arc developed by northward subduction of the Neo-Tethyan oceanic crust beneath the Eurasian Plate (Figure 1). Numerous studies have addressed the geodynamic evolution of this region [1–10]. Detailed investigations have revealed four main intrusive periods within the EPOB: Paleozoic (Carboniferous), Jurassic, Late Cretaceous, and Eocene (Fig. 1).
The Paleozoic plutons intruded into metamorphic basement rocks [11–17]. Jurassic plutons intruded into pre-Jurassic basement units [18–21], whereas Late Cretaceous plutons cut volcanic and/or volcaniclastic rocks associated with subduction-related magmatism [22–31]. Finally, Eocene plutons intruded all the preceding units [32–41].
This study aims to investigate the crystallization conditions and magmatic evolution of the Hasan Dağ Pluton located in the Kürtün area (Gümüşhane), through detailed petrographic and mineral chemical analyses. The results are integrated with regional geological data to better understand the magmatic processes and crustal evolution responsible for the emplacement of this Eocene pluton.

2. Regional Geology
The Eastern Pontide Orogenic Belt, which is part of the Sakarya Zone, contains the oldest basement rock formations, including Early to Middle Carboniferous gneisses, schists, amphibolites, marbles, and minor meta-peridotites [14,44–46] (Fig. 1). These metamorphic rocks are intruded by small- to medium-sized Carboniferous-to-Early Permian plutons [13–16,47–50]. The Jurassic succession of the Eastern Pontides consists mainly of pyroclastic rocks interlayered with clastic sediments and limestone blocks [51–54]. During the Late Jurassic–Early Cretaceous period, the region experienced limited

*Corresponding author: aydincakir61@gmail.com

tectonic and magmatic activity, with widespread carbonate deposition.

The Eastern Pontides, including the study area, are predominantly composed of plutonic and volcanic rocks of Late Cretaceous age [2,22,24,30,55,56]. High-K calc-alkaline magmatism is widespread throughout the region [40,57–62]. During the Late Paleocene–Early Eocene, the collision between the Anatolide–Tauride blocks and the Pontides occurred [2]). Early Eocene (54–48 Ma) magmatism, characterized by both adakitic and non-adakitic signatures, is generally associated with the final stages of arc–continent collision [58,63,64] [65–67]. In the Eocene, post-collisional magmatism is represented by high-K calc-alkaline to shoshonitic plutonic rocks and their volcanic equivalents [5–7,9,34,36,39,68–74]. After the Eocene, clastic sedimentary rocks and Neogene alkaline volcanics became dominant in the region [2,75].

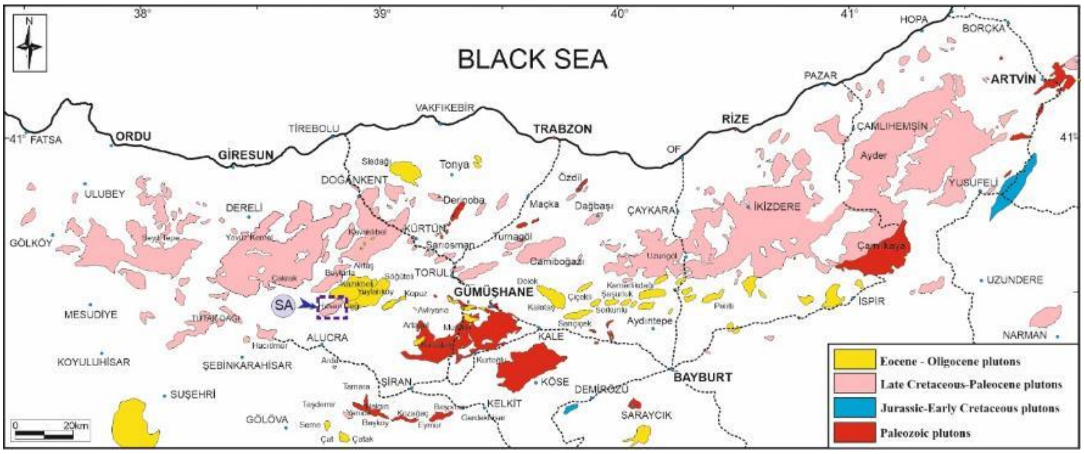


Figure 1. Distribution of plutonic rocks in the Eastern Pontides Orogenic Belt (modified from [42,43] and the proposed study area (SA)

3. Materials and Methods

During the fieldwork, a systematic rock sampling was conducted from the Hasan Dağ Pluton and its surrounding country rocks. The location of each sample was recorded using a GPS, and important outcrops were photographed and documented. Based on the field data, a detailed, 1:25,000-scale geological map of the area was created (Fig. 2). For petrographic analysis, thin sections were prepared from representative rock samples. Slabs measuring approximately 0.5 × 2 × 4 cm were cut, ground, and mounted on 2.5 × 5 cm glass slides using Canada balsam. The samples were then polished and thinned to approximately 0.025 mm for optical examination under a polarizing microscope. Thin-section preparation was carried out in the Thin Section Laboratory of the Department of Geological Engineering at Gümüşhane University's Faculty of Engineering and Natural Sciences.

Quantitative in situ analyses of major elements in mineral phases were performed using a JEOL JXA-8230 electron probe microanalyzer (EPMA) at Wuhan SampleSolution Analytical Technology Co., Ltd. in Wuhan, China. The analytical conditions included an accelerating voltage of 15 kV, a beam current of 20 nA, and a beam diameter of 1 μm. Calibration was performed using 53 mineral standards, 44 pure elemental standards, and 15 rare earth element standards supplied by the SPI Company. Data were corrected using JEOL's ZAF method.

4. Results

4.1. Stratigraphy and Petrology of the Study Area

The study area is located around Hasan Dağ and its vicinity, where both plutonic and volcanic rocks are exposed (Fig. 2). The exposed lithological units range in age from Late Cretaceous to Quaternary. From the youngest to the oldest, the stratigraphic sequence consists of: alluvium (Quaternary), Eocene plutonic rocks forming the Hasan Dağ Pluton, Kabaköy Formation (Eocene), Çatak Formation (Late Cretaceous). Previous studies [76] referred to the plutonic bodies in the region as Kaçkar Granitoid-I and Kaçkar Granitoid-II. The largest of these bodies extensively crops out in the study area and has been redefined in this study as the Hasan Dağ pluton, named after its most exposed location.

The Hasan Dağ Pluton extends throughout most of the study area (Sheet Gümüşhane H41-b2) and generally exhibits a NE–SW elongation. It is cut by 10–20 cm thick aplite dikes and shows localized jointing and fracturing (Fig. 3a–b). Although the pluton is largely fresh and massive, minor weathering is observed in some zones, where the rocks are friable and soil-like in texture (Fig. 4a). Mafic microgranular enclaves (MMEs) are widespread throughout the pluton (Fig. 4b); they are darker and finer-grained than the host rocks, indicating magma mingling and mixing processes. Plutonic rocks can be easily distinguished from their surrounding country rocks due to their contrasting lithology and color. Along the fractures, evidence of surface alteration and clay formation is apparent. Fresh rock surfaces are light pink to reddish-brown, while weathered surfaces are paler due to kaolinization.

Modal analyses were conducted on nine representative samples collected from the Hasan Dağ Pluton, and the results are presented in Table 1. According to modal data, the pluton is mainly composed of granodiorite, tonalite, and diorite.

- **Granodiorites** contain 45–55% plagioclase, 22–31% quartz, and 7–16% K-feldspar.
- **Tonalites** contain 60–62% plagioclase, 21–24% quartz, and 3–5% K-feldspar.
- **Diorites** contain 66–77% plagioclase, 2–3% quartz, and 3–5% K-feldspar.

When plotted on the Q–A–P [77] diagram, the samples cluster within the diorite, tonalite, and granodiorite fields (Fig. 4).

Granodiorite is the dominant lithology, typically occurring in the outer zones of the pluton and surrounding the tonalitic cores. It is gray to light gray in color and exhibits holocrystalline, hypidiomorphic granular textures (Fig. 5a–c). The grain size varies from fine to medium, and some samples show poikilitic, myrmekitic, and rarely micrographic textures. The rocks are composed mainly of plagioclase, quartz, K-feldspar, hornblende, and biotite, with accessory apatite, zircon, and opaque minerals. Secondary minerals include chlorite, calcite, clay minerals, and sericite (Table 1).

Plagioclase occurs as subhedral to anhedral tabular crystals and displays oscillatory zoning and albite twinning (Fig. 5). K-feldspar (mainly orthoclase) appears as subhedral to anhedral perthitic grains commonly containing inclusions of plagioclase and biotite. Quartz occurs as irregular, anhedral grains with undulatory extinction. Hornblende is subhedral to euhedral, sometimes enclosing plagioclase and opaque minerals as poikilitic inclusions (Fig. 5). Biotite forms reddish-brown lamellar crystals, showing pleochroism from light to dark brown. Accessory minerals include needle-shaped apatite inclusions within plagioclase and short prismatic zircon crystals.

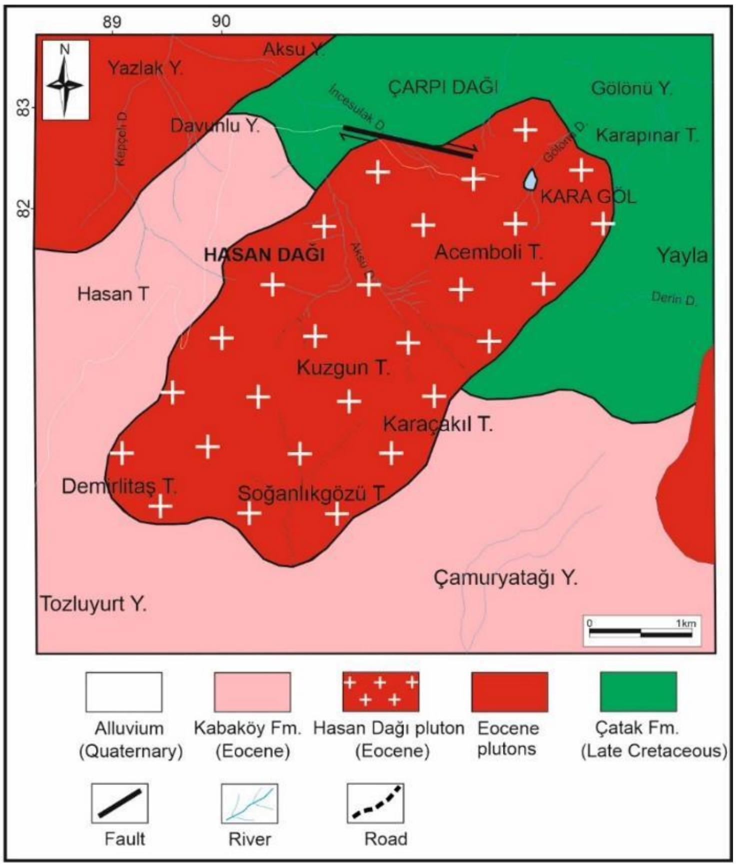


Figure 2. Geological map of the study area (modified from [78])

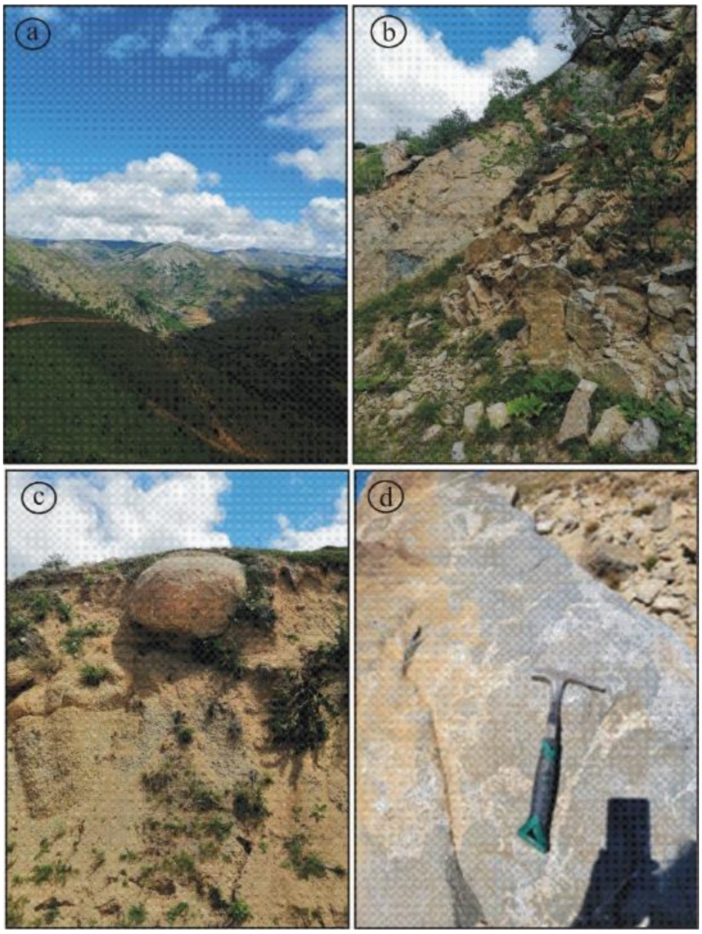


Figure 3. (a) General field view of the study area, (b) fracture systems within Eocene plutonic rocks, (c) weathered surfaces showing arenization, (d) mafic enclaves within the plutonic rocks.

Tablo 1. Results of modal analysis of samples from the Hasan Dağ Pluton.

Rock	Plagioclase	Quartz	Orthoclase	Amphibole	Biotite	Opaque mineral
Granodiorite						
S118	52.10	22.30	7.20	6.80	8.90	2.70
T8	55.40	29.50	8.70	3.70	1.60	1.10
T14	50.50	30.40	12.30	3.80	1.70	1.30
T16	45.20	30.80	16.10	2.10	3.20	2.60
Tonalite						
T4	60.20	20.50	3.40	11.90	1.30	2.70
T11	61.70	22.70	4.30	7.50	1.50	2.30
T15	60.10	24.30	5.30	6.20	2.20	1.90
Diorite						
S119	66.40	1.70	2.90	20.10	3.40	5.50
S120	76.80	2.80	4.60	11.40	1.10	3.30

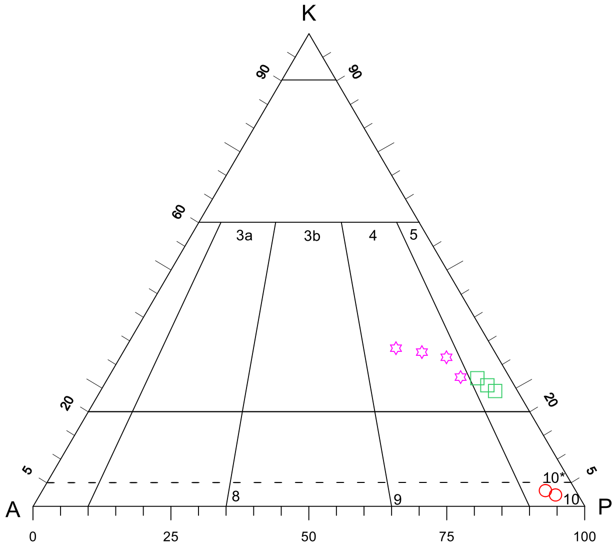


Figure 4. Modal composition of Hasan Dağ Pluton samples plotted on the Q–A–P diagram (after [77]).

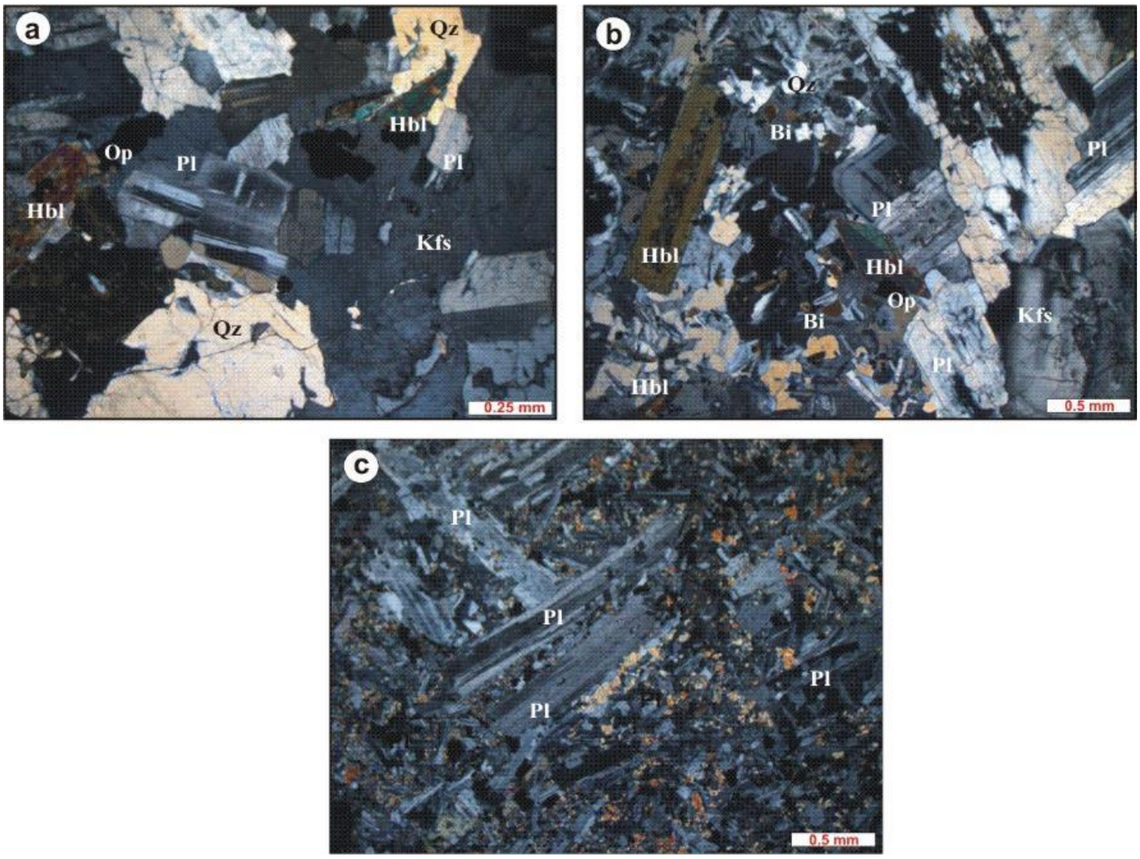


Figure 5. Photomicrographs showing textural features: (a) medium-grained granodiorite containing hornblende, plagioclase, and opaque minerals; (b) oscillatory zoning in plagioclase; (c) diorite with coarse plagioclase phenocrysts and microcrystalline plagioclase–amphibole–biotite groundmass. (Abbreviations: Pl = plagioclase, Hbl = hornblende, Bi = biotite, Kfs = K-feldspar, Qz = quartz, Op = opaque mineral).

4.2. Mineral Chemistry

4.2.1. Plagioclase

Plagioclase occurs as the principal felsic phase in almost all rock types of the Hasan Dağ Pluton, commonly associated with hornblende. The crystals are generally euhedral to subhedral, elongated, and prismatic, and many exhibit distinct oscillatory zoning (Fig. 6). Detailed microprobe analyses indicate that most plagioclase grains display normal compositional zoning patterns (Fig. 6c–d).

Representative microprobe analyses and calculated mineral formulae are presented in Table 2. The anorthite (An) contents of plagioclase vary between $An_{0.1}$ and $An_{52.3}$ (n = 14) in granodioritic samples. Based on the Ab–An–Or classification diagram [79]; Fig. 7), the plagioclase compositions fall predominantly within the oligoclase–andesine fields, with minor occurrences of labradorite. Both rock types also contain K-feldspar of orthoclase composition.

A compositional profile taken from a representative plagioclase crystal in the granodiorite sample (S118) shows that the core composition is $An_{44}Ab_{53}Or_3$, while the rim composition shifts to $An_{14}Ab_{83}Or_3$, indicating progressive normal zoning toward more sodic compositions during crystallization.

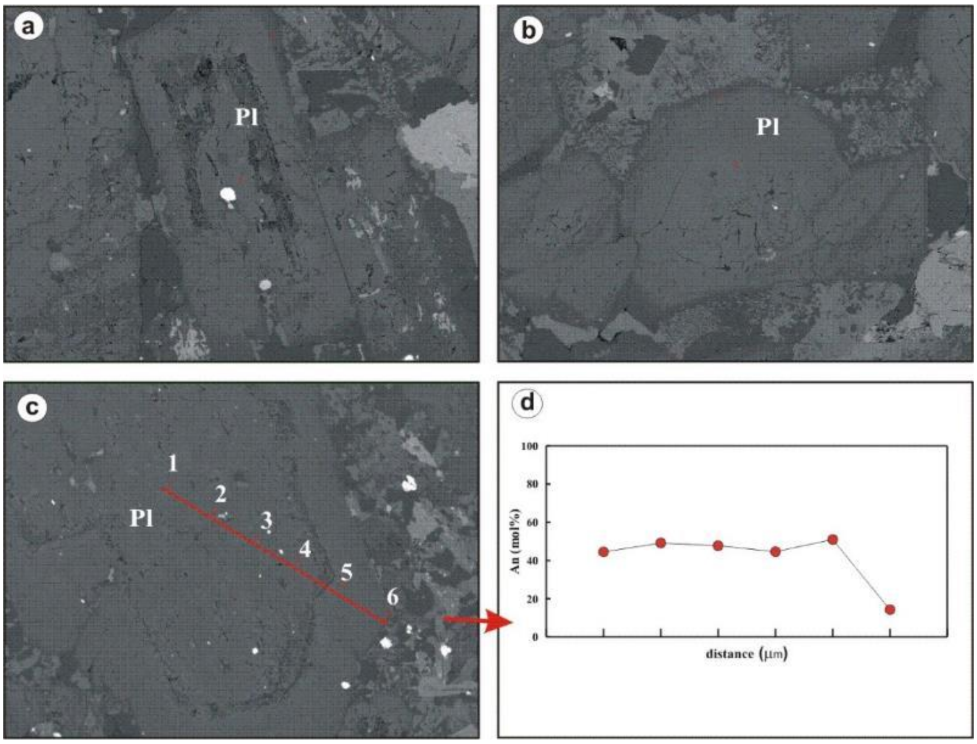


Figure 6. (a) Elongated prismatic plagioclase crystals; (b) cross section perpendicular to the c-axis; (c) zoned plagioclase in sample S118; (d) compositional profile showing variations in An (mol%) content from core to rim

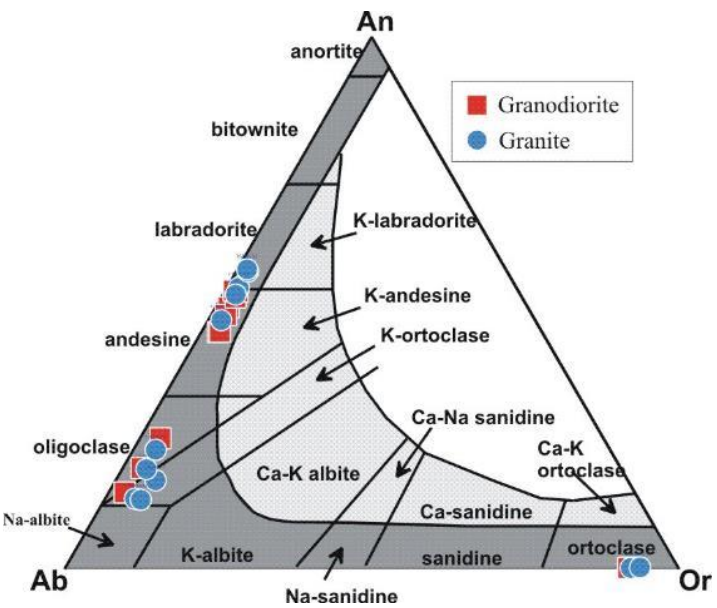


Figure 7. Ab–An–Or ternary diagram showing plagioclase compositions of the Hasan Dağ Pluton (after [79]).

Table 2. Representative microprobe analyses of plagioclase and hornblende from the Hasan Dağ Pluton

Plagioclase			Hornblende		
Rock types	Granodiorite (n=14)		Rock types	Granodiorite (n=8)	
	min	max		min	max
SiO2	54.78	65.69	SiO2	44.12	48.03
Al2O3	18.49	28.43	TiO2	1.62	2.79
FeO	0.01	0.45	Al2O3	6.52	9.65
CaO	0.02	10.57	FeO	10.87	12.01
Na2O	0.73	9.49	MnO	0.27	0.49
K2O	0.24	15.76	MgO	14.39	15.61
Total	99.20	100.93	CaO	11.00	11.26
Si	2.48	3.00	Na2O	1.48	2.07
Al	1.00	1.51	K2O	0.68	0.83
Fe+2	0.00	0.02	Total	96.51	97.58
Ca	0.00	0.51	Si	6.43	7.17
Na	0.07	0.81	Ti	0.18	0.31
K	0.01	0.93	Alıv	1.05	1.57
An	0.08	52.26	Alvı	0.01	0.12
Ab	6.55	83.07	Fe+2	0.61	0.88
Or	1.43	93.45	Fe+3	0.53	0.78
*** structural formula on the basis of 8 oxygen atoms**			Mn	0.03	0.06
			Mg	3.14	3.37
			Ca	1.70	1.77
			Na	0.41	0.59
			K	0.13	0.16
			Mg#	0.78	0.85
			*** structural formula on the basis of 23 oxygen atoms**		

* n= sample number, min: minimum values, max: maximum values

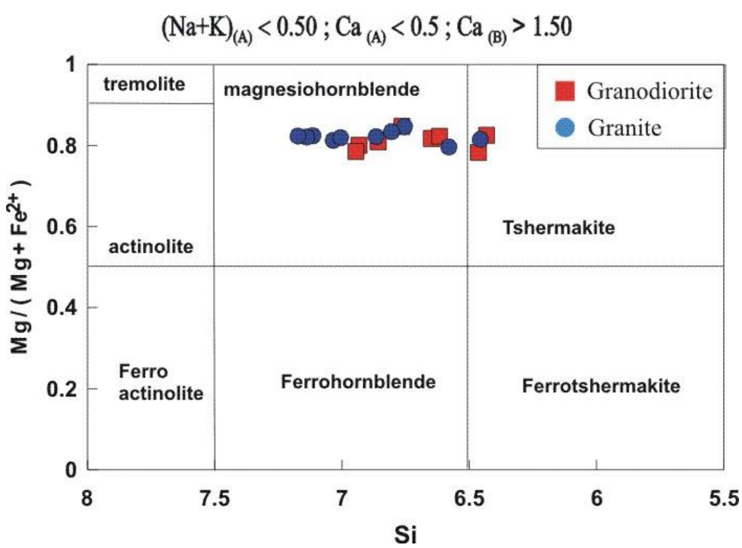


Figure 8. Classification diagram of calcic amphiboles (CaB ≥ 1.5; (Na + K)A < 0.50; CaA < 0.50) after [80].(CaB = Ca content in the B-site; (Na + K)A = total alkali content in the A-site; CaA = Ca content in the A-site).

4.2.2. Amphibole

Hornblende represents the dominant mafic mineral phase in the Hasan Dağ Pluton, particularly within granodioritic rocks. Representative EPMA data and calculated structural formulae are given in Table 2.

According to the classification scheme of [80], the amphiboles belong to the calcic group ($CaB \geq 1.5$ and $NaB < 0.5$) (Fig. 8). The amphiboles have $Mg/(Mg + Fe^{2+})$ ratios greater than 0.5, and their Si contents are generally below 6.5 apfu, suggesting a magnesiohornblende composition.

5. Discussion

5.1. Crystallization Conditions of the Hasan Dağ Pluton

The coexistence of amphibole and plagioclase in calc-alkaline plutonic rocks makes this mineral pair particularly suitable for thermobarometric calculations [81–86]. The mineral assemblage of the Hasan Dağ Pluton, which contains both amphibole and plagioclase, allows for reliable application of these approaches. However, post-magmatic processes such as actinolitization, chloritization, or the development of opaque minerals can modify the original hornblende composition [81]. Therefore, altered grains were excluded from the thermobarometric dataset.

5.1.1. Feldspar Thermometry

The Ab–An–Or ternary system of feldspars is a valuable geothermometric tool for magmatic rocks [87]. Applying this method to the plagioclase in the Hasan Dağ plutonic rocks indicates crystallization temperatures between 750°C and 900°C and estimated pressures ranging from 0.5 to 1 kbar (Fig. 9).

5.1.2. Amphibole–Plagioclase Thermobarometry

The amphibole–plagioclase mineral pair is widely used in geothermobarometric studies of calc-alkaline volcanic and plutonic systems. The presence of both minerals in the Hasan Dağ granodiorites provides a suitable basis for such calculations. However, variations in temperature and chemical composition between these minerals must be carefully considered [81,88].

Experimental calibrations based on total Al content in hornblende (AlT) have been used to estimate crystallization pressures [89]. Hornblende crystals with $Al^T < 0.79$ generally yield unreliable or negative pressure values [90]. In the Hasan Dağ samples, Al^T values range from 0.90 to 1.70 (n = 17), indicating that all are suitable for pressure estimation. Applying the experimental calibrations of [81–83,85] to the Hasan Dağ hornblendes yields pressure values between 1.3 and 4.8 kbar, with mean values of approximately 3.25 ± 1.3 kbar (Table 3).

Similarly, crystallization temperatures calculated using the formulations of [84,86] range from 810°C to 884°C, with an average of ~848°C (Table 3). These results correspond to magma crystallization at mid- to shallow-crustal depths.

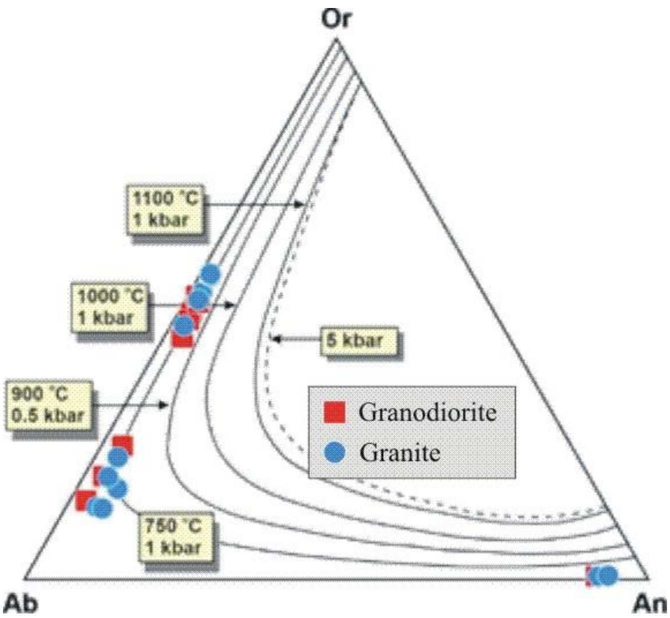


Figure 9. Determination of crystallization temperatures for plagioclase in the Hasan Dağ Pluton based on the Ab–An–Or ternary diagram (isotherms from [91]).

Table 3. Comparison of estimated pressures (Al-in-hornblende barometer) and temperatures (hornblende–plagioclase thermometer) for rocks of the Hasan Dağ Pluton.

Method	**Al in Hornblende (Al-Hbl) Barometer**		
Pressure *P* (kbar)	P_{min}	P_{max}	P_{avg} **(n= 8)**
[81]; P_1	1.7	4.4	2.9±1.3
[82]; P_2	1.5	4.5	2.9±1.5
[83]; P_3	1.3	3.5	2.3±1.1
[85]; P_4	2.3	4.84	3.5±1.3
	Hbl-Pl Thermometer*		
Temperature *T* (°C)	T_{min}	T_{max}	T_{avg} **(n= 18)**
[84]	810	884	848±31
[86]	815	884	800±32

P_1= -3.92+5.03Al^T; P_2= -4.67+5.64Al^T; P_3= -3.46+4.23Al^T; P_4= -3.01+4.76Al^T; P_5= 4.76Al^T–3.01–[(T–675)/85] x [0.53Al^T+0.005294 x (T–675)].

Table 4. Amphibole Thermobarometer, Oxygen Fugacity (fO₂), Water Content in Melt (H₂O_(melt)), and Formation Depths of Plutonic Rocks of the Hasan Dağ Pluton [93]

Amphibole Thermometer		
T_{min} (°C)	T_{max} (°C)	T_{avg} (n= 8)
802	904	850±22
P_{min} (kbar)	P_{max} (kbar)	P_{avg} (n= 8)
0.67	2.23	1.26±0.14
Oxygen Fugacity (fO_2)		
fO_{2min}	fO_{2max}	fO_{2avg} (n= 8)
–12.3	–10.7	–11.5±0.4
ΔNNO_{min}	ΔNNO_{max}	ΔNNO_{avg}
0.9	1.7	1.4±0.3
Water content in melt (H_2O_{melt})		
H_2O_{melt} (wt. %)$_{min}$	H_2O_{melt} (wt. %)$_{max}$	H_2O_{melt} (wt. %)$_{avg}$
3.4	4.3	3.9±0.4
Emplacement Depth		
Depth$_{min}$ (km)	Depth$_{max}$ (km)	Depth$_{avg}$ (km)
2.5	8.0	4.8±1.9

5.1.3. Amphibole Thermobarometry, Oxygen Fugacity, and Water Content

Oxygen fugacity (fO_2) represents a measure of the partial pressure of oxygen during magmatic crystallization and provides key constraints on the redox conditions of magma evolution. It is closely related to temperature and pressure variations, influencing the stability fields of mineral assemblages [92,93].

The amphibole-based thermobarometric formulations of [93] were applied to the Hasan Dağ samples to estimate temperature (T), pressure (P), oxygen fugacity (fO_2, ΔNNO), water content (H_2O_melt, wt.%), and emplacement depth. The results are summarized in Table 4. Calculated amphibole temperatures range from 802°C to 904°C (average 850 ± 22°C, n = 8), and pressures from 0.67 to 2.23 kbar (average 1.26 ± 0.14 kbar). Oxygen fugacities vary between –12.3 and –10.7 log units, with an average of –11.5 ± 0.4. The calculated water contents of the melt are 3.4–4.3 wt.% (average 3.9 ± 0.4 wt.%).

Assuming a lithostatic gradient of 1 kbar ≈ 3.78 km (Tulloch and Challis, 2000), the calculated pressures correspond to emplacement depths of 2.5–8.0 km, with an average of ~4.8 ± 1.9 km, consistent with a mid- to shallow-crustal magma chamber.

5.2. Magma Evolution

The Eastern Pontides (EP) have experienced a compressional tectonic regime since the Paleozoic–

Mesozoic transition. This regime has produced fracture systems trending NE–SW and NW–SE, influencing the placement and orientation of plutonic bodies. The axes of plutons within the EP are generally parallel to these fracture patterns, indicating tectonic control on magma ascent and intrusion. The presence of Early Eocene (ca. 55 Ma) adakitic rocks in the EP marks the terminal stage of arc–continent collision and is related to syn- or post-collisional magmatism [32,33,35,94]. During the Middle Eocene (46–40 Ma), I-type rocks were found, and the region's crust thickened. This was followed by tectonic activity after collision.

Previous geochemical studies [5,7,32,34,95–97] indicate that these plutons' parental magmas came from a metasomatized lithospheric mantle source and/or lower continental crustal melts, with possible magma mixing between mantle- and crust-derived magmas. The Eocene magmatism of the Eastern Pontides is interpreted as being associated with a post-collisional extensional regime, crustal thickening, and lithospheric delamination following slab break-off [5,7,68–70,97]. Following the break-off of the subducted Neo-Tethyan slab, lithospheric delamination likely triggered asthenospheric upwelling and localized thermal anomalies. The resultant heating induced partial melting of the metasomatized lithospheric mantle, producing the parental magmas responsible for the formation of the Hasan Dağ Pluton and other contemporaneous Eocene intrusions. Lithospheric delamination following slab breakup is proposed as a mechanism for the formation of the Hasan Dağ plutonic rocks. The developing delamination facilitated the upward movement of the asthenosphere (local or regional); it led to a hot asthenosphere thermal anomaly, causing partial melting of the chemically enriched lithospheric mantle and generating the magmas that formed the Middle Eocene rocks. Subsequently, tectonic extension caused thinning and fracture systems in the crust, allowing these melts to move upward within the crust. During the upward movement of the magma, a chamber formed at a depth of approximately 8–16 km, where fractional crystallization and magma mixing events occurred. Barometric estimates based on mineral compositions and petrographic characteristics (Table 3) suggest that these magma chambers existed at depths between 8 and 16 km. Magma mixing is also supported by textural features such as sieve texture and zoning. Finally, oxygen fugacity estimates indicate that oxidation conditions prevailed during crystallization at this depth.

6. Conclusions

1- The Eocene Hasan Dağ Pluton, located in the southern zone of the Eastern Pontides near Gümüşhane (NE Türkiye), intrudes the Late Cretaceous Çatak Formation and the Eocene Kabaköy Formation. The pluton is elliptical in shape, extends in a NE–SW direction, and covers an area of approximately 14 km².
2- The investigated rocks are mainly diorite, tonalite, and granodiorite in composition. Their primary mineral assemblage consists of plagioclase (An_{14-56}), orthoclase, quartz, hornblende, biotite, and minor Fe–Ti oxides, with accessory apatite and zircon.
3- According to geothermobarometer calculations from the rocks that form the Hasan Dağ pluton, the temperature ranges from 802 to 904 °C, and the pressure ranges from 2 to 4 kbar. Based on all the obtained data, the examined rocks are found to be within the medium-shallow continental crust (~8–16 km).

Acknowledgement

This research was financially supported by the Scientific Research Projects Foundation of Gümüşhane University (Project No. 21.F5114.01.02). The authors express their sincere gratitude to Dr. Eric and his laboratory technicians for their analytical assistance, and to Wuhan SampleSolution Analytical Technology Co., Ltd. (China) for conducting the microprobe analyses. An anonymous reviewer is thanked for their general improvement of the manuscript.

References

[1] Şengör AMC, Yılmaz Y. Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 1981;75:181–241.
[2] Okay A, Şahintürk Ö. Geology of the eastern Pontides. In: Robinson AG (Ed.) Regional and petroleum geology of the Black Sea and surrounding region. American Association of Petroleum Geologists (AAPG) Memoir 1997;68:291–311.
[3] Yılmaz Y, Tüysüz O, Yiğitbaş E, S.C. G, Şengör AMC. Geology and tectonics of the Pontides: In: Robinson AG (ed) Regional and petroleum geology of the Black Sea and surrounding region. American Association of Petroleum Geologists (AAPG) Memoir 1997;68:183–226.
[4] Keskin M, Genç SC, Tüysüz O. Petrology and geochemistry of post-collisional Middle Eocene volcanic units in North-Central Turkey: evidence for magma generation by slab breakoff following the

closure of the Northern Neotethys Ocean. Lithos 2008;104:267–305.
[5] Arslan M, Temizel İ, Abdioğlu E, Kolaylı H, Yücel C, Boztuğ D, Şen C. 40Ar–39Ar dating, whole-rock and Sr–Nd–Pb isotope geochemistry of post-collisional Eocene volcanic rocks in the southern part of the Eastern Pontides (NE Turkey): implications for magma evolution in extension-induced origin. Contributions to Mineralogy and Petrology 2013;166:113–42. https://doi.org/10.1007/s00410-013-0868-3.
[6] Aydınçakır E, Sen C. Petrogenesis of the post-collisional volcanic rocks from the Borçka (Artvin) area: Implications for the evolution of the Eocene magmatism in the Eastern Pontides (NE Turkey). Lithos 2013;172–173:98–117. https://doi.org/10.1016/j.lithos.2013.04.007.
[7] Yücel C, Arslan M, Temizel İ, Abdioğlu Yazar E, Ruffet G. Evolution of K-rich magmas derived from a net veined lithospheric mantle in an ongoing extensional setting: Geochronology and geochemistry of Eocene and Miocene volcanic rocks from Eastern Pontides (Turkey). Gondwana Research 2017;45:65–86. https://doi.org/10.1016/j.gr.2016.12.016.
[8] Dokuz A, Aydın F, Karslı O. Postcollisional transition from subduction- to intraplatetype magmatism in the eastern Sakarya zone, Turkey: Indicators of northern Neotethyan slab breakoff. Bulletin of the Geological Society of America 2019;131:1623–42. https://doi.org/10.1130/B31993.1.
[9] Aydınçakır E, Yücel C, Ruffet G, Gücer MA, Akaryalı E, Kaygusuz A. Petrogenesis of post-collisional Middle Eocene volcanism in the Eastern Pontides (NE, Turkey): Insights from geochemistry, whole-rock Sr-Nd-Pb isotopes, zircon U-Pb and 40Ar-39Ar geochronology. Geochemistry 2022:125871. https://doi.org/10.1016/j.chemer.2022.125871.
[10] Kaygusuz A, Yücel C, Aydınçakır E, Gücer MA, Ruffet G. 40Ar–39Ar dating, whole-rock and Sr-Nd isotope geochemistry of the Middle Eocene calc-alkaline volcanic rocks in the Bayburt area, Eastern Pontides (NE Turkey): Implications for magma evolution in an extension-related setting. Mineral Petrol 2022;116:379–99. https://doi.org/10.1007/s00710-022-00788-w.
[11] Yılmaz Y. Petrology and structure of the Gümüşhane granite and surrounding rocks, NE Anatolia. 1972.
[12] Çoğulu E. Gümüşhane ve Rize granitik plutonlarının mukayeseli petrojeolojik ve jeokronolojik etüdü. Unpublished Dissertation Thesis, İstanbul Technical University 1975.
[13] Topuz G, Altherr R, Siebel W, Schwarz WH, Zack T, Hasözbek A, Barth M, Satir M, Şen C. Carboniferous high-potassium I-type granitoid magmatism in the Eastern Pontides: The Gümüşhane pluton (NE Turkey). Lithos 2010;116:92–110. https://doi.org/10.1016/j.lithos.2010.01.003.
[14] Dokuz A. A slab detachment and delamination model for the generation of Carboniferous high-potassium I-type magmatism in the Eastern Pontides, NE Turkey: The Köse composite pluton. Gondwana Research 2011;19:926–44. https://doi.org/10.1016/j.gr.2010.09.006.
[15] Kaygusuz A, Arslan M, Siebel W, Sipahi F, Ilbeyli N. Geochronological evidence and tectonic significance of Carboniferous magmatism in the southwest Trabzon area, eastern Pontides, Turkey. Int Geol Rev 2012;54:1776–800. https://doi.org/10.1080/00206814.2012.676371.
[16] Kaygusuz A, Arslan M, Sipahi F, Temizel İ. U–Pb zircon chronology and petrogenesis of Carboniferous plutons in the northern part of the Eastern Pontides, NE Turkey: Constraints for Paleozoic magmatism and geodynamic evolution. Gondwana Research 2016;39:327–46. https://doi.org/10.1016/j.gr.2016.01.011.
[17] Ustaömer T, Robertson AHF, Ustaömer PA, Gerdes A, Peytcheva I. Constraints on Variscan and Cimmerian magmatism and metamorphism in the Pontides (Yusufeli-Artvin area), NE Turkey from U-Pb dating and granite geochemistry. Geol Soc Spec Publ 2013;372:49–74. https://doi.org/10.1144/SP372.13.
[18] Eyuboğlu Y, Dudas FO, Santosh M, Xiao Y, Yi K, Chatterjee N, Wu FY, Bektaş O. Where are the remnants of a Jurassic ocean in the eastern Mediterranean region? Gondwana Research 2016;33:63–91. https://doi.org/10.1016/j.gr.2015.08.017.
[19] Karslı O, Dokuz A, Kandemir R. Zircon Lu-Hf isotope systematics and U–Pb geochronology, whole-rock Sr-Nd isotopes and geochemistry of the early Jurassic Gokcedere pluton, Sakarya Zone-NE Turkey: a magmatic response to roll-back of the Paleo-Tethyan oceanic lithosphere. Contributions to Mineralogy and Petrology 2017;172:31. https://doi.org/10.1007/s00410-017-1346-0.
[20] Aydınçakır E, Gündüz R, Yücel C. Emplacement conditions of magma(s) forming Jurassic plutonic rocks in Gümüşhane (Eastern Pontides, Turkey). Bulletin of the Mineral Research and Exploration 2020;162:175–96. https://doi.org/10.19111/bulletinofmre.649808.
[21] Aydınçakır E, Yücel C, Kaygusuz A, Bilici Ö, Yi K, Jeong YJ, Güloğlu ZS. Magmatic evolution of

the Calc-alkaline Middle Jurassic igneous rocks in the eastern pontides, NE Turkey: insights from geochemistry, whole-rock Sr-Nd-Pb, in situ zircon Lu-Hf isotopes, and U-Pb geochronology. Int Geol Rev 2023;65, 20:3146–67. https://doi.org/10.1080/00206814.2023.2177890.

[22] Kaygusuz A, Aydınçakır E. Mineralogy, whole-rock and Sr-Nd isotope geochemistry of mafic microgranular enclaves in Cretaceous Dagbasi granitoids, Eastern Pontides, NE Turkey: Evidence of magma mixing, mingling and chemical equilibration. Chemie Der Erde 2009;69:247–77. https://doi.org/10.1016/j.chemer.2008.08.002.

[23] Kaygusuz A, Aydınçakır E. Petrogenesis of a Late Cretaceous composite pluton from the eastern Pontides: The Dağbasi pluton, NE Turkey. Neues Jahrbuch Fur Mineralogie, Abhandlungen 2011;188:211–33. https://doi.org/10.1127/0077-7757/2011/0201.

[24] Kaygusuz A, Siebel W, Şen C, Satır M. Petrochemistry and petrology of I-type granitoids in an arc setting: The composite Torul pluton, Eastern Pontides, NE Turkey. International Journal of Earth Sciences 2008;97:739–64. https://doi.org/10.1007/s00531-007-0188-9.

[25] Kaygusuz A, Arslan M, Temizel İ, Yücel C, Aydınçakır E. U–Pb zircon ages and petrogenesis of the Late Cretaceous I-type granitoids in arc setting, Eastern Pontides, NE Turkey. Journal of African Earth Sciences 2021;174:104040. https://doi.org/10.1016/j.jafrearsci.2020.104040.

[26] Liu Z, Zhu DC, Wang Q, Eyuboğlu Y, Zhao ZD, Liu SA, Xu LJ. Transition From Low-K to High-K Calc-Alkaline Magmatism at Approximately 84 Ma in the Eastern Pontides (NE Turkey): Magmatic Response to Slab Rollback of the Black Sea. J Geophys Res Solid Earth 2018;123:7604–28. https://doi.org/10.1029/2018JB016026.

[27] Eyuboğlu Y, Dudas FO, Zhu DC, Liu Z, Chatterjee N. Late Cretaceous I- and A-type magmas in eastern Turkey: Magmatic response to double-sided subduction of Paleo- and Neo-Tethyan lithospheres. Lithos 2019;326–327:39–70. https://doi.org/10.1016/j.lithos.2018.12.017.

[28] Temizel İ, Arslan M, Yücel C, Abdioğlu Yazar E, Kaygusuz A, Aslan Z. U-Pb geochronology, bulk-rock geochemistry and petrology of Late Cretaceous syenitic plutons in the Gölköy (Ordu) area (NE Turkey): Implications for magma generation in a continental arc extension triggered by slab roll-back. J Asian Earth Sci 2019;171:305–20. https://doi.org/10.1016/j.jseaes.2019.01.004.

[29] Temizel İ, Arslan M, Abdioğlu Yazar E, Aslan Z, Kaygusuz A, Baki Eraydın T. Zircon U-Pb geochronology and petrology of the tholeiitic gabbro from the Kovanlık (Giresun) area: Constraints for the Late Cretaceous bimodal arc magmatism in the Eastern Pontides Orogenic Belt, NE Turkey. Lithos 2022;428–429:106840. https://doi.org/10.1016/j.lithos.2022.106840.

[30] Yücel C, Aydınçakır E, Kaygusuz A, Arslan M, Yi K, Jeong YJ, Cicerali D. Petrogenesis of Late Cretaceous A-type plutonic rocks from the Eastern Pontides Orogenic Belt (NE Turkey): constraints from zircon U-Pb geochronology, zircon Lu-Hf and whole-rock Sr-Nd-Pb-Hf isotopes. Int Geol Rev 2024;66:2055–78. https://doi.org/10.1080/00206814.2023.2269447.

[31] Oğuz-Saka S, Aydin F, Karsli O, Dokuz A, Aiglsperger T, Miggins DP, Şen C, Kandemir R, Sarı B, Koppers AAP. Two-stage bimodal volcanism in a Late Cretaceous arc/back-arc setting, NE Turkey: Constraints from volcano-stratigraphy, zircon U–Pb and 40Ar/39Ar geochronology and whole-rock elemental and Sr-Nd-Pb isotope geochemistry. Lithos 2023;440–441. https://doi.org/10.1016/j.lithos.2023.107018.

[32] Topuz G, Altherr R, Schwarz WH, Siebel W, Satır M, Dokuz A. Post-collisional plutonism with adakite-like signatures: The Eocene Saraycik granodiorite (Eastern Pontides, Turkey). Contributions to Mineralogy and Petrology 2005;150:441–55. https://doi.org/10.1007/s00410-005-0022-y.

[33] Topuz G, Okay AI, Altherr R, Schwarz WiH, Siebel W, Zack T, Satir M, Sen C. Post-collisional adakite-like magmatism in the Agvanis Massif and implications for the evolution of the Eocene magmatism in the Eastern Pontides (NE Turkey). Lithos 2011;125:131–50. https://doi.org/10.1016/j.lithos.2011.02.003.

[34] Karslı O, Chen B, Aydın F, Şen C. Geochemical and Sr-Nd-Pb isotopic compositions of the Eocene Dölek and Sariçiçek Plutons, Eastern Turkey: Implications for magma interaction in the genesis of high-K calc-alkaline granitoids in a post-collision extensional setting. Lithos 2007;98:67–96. https://doi.org/10.1016/j.lithos.2007.03.005.

[35] Karslı O, Ketenci M, Uysal İ, Dokuz A, Aydın F, Chen B, Kandemir R, Wijbrans J. Adakite-like granitoid porphyries in the Eastern Pontides, NE Turkey: Potential parental melts and geodynamic implications. Lithos 2011;127:354–72. https://doi.org/10.1016/j.lithos.2011.08.014.

[36] Eyuboğlu Y, Dudas FO, Thorkelson D, Zhu DC, Liu Z, Chatterjee N, Yi K, Santosh M. Eocene granitoids of northern Turkey: Polybaric magmatism in an evolving arc–slab window system. Gondwana Research 2017;50:311–45. https://doi.org/10.1016/j.gr.2017.05.008.

[37] Eyuboğlu Y, Dudas FO, Santosh M, Eroğlu-Gümrük T, Akbulut K, Yi K, Chatterjee N. The final pulse of the Early Cenozoic adakitic activity in the Eastern Pontides Orogenic Belt (NE Turkey): An integrated study on the nature of transition from adakitic to non-adakitic magmatism in a slab window setting. J Asian Earth Sci 2018;157:141–65. https://doi.org/10.1016/j.jseaes.2017.07.004.
[38] Kaygusuz A, Yücel C, Arslan M, Temizel İ, Yi K, Jeong YJ, Siebel W, Sipahi F. Eocene I-type magmatism in the Eastern Pontides, NE Turkey: insights into magma genesis and magma-tectonic evolution from whole-rock geochemistry, geochronology and isotope systematics. Int Geol Rev 2020;62:1406–32. https://doi.org/10.1080/00206814.2019.1647468.
[39] Kaygusuz A, Güloğlu ZS, Aydınçakır E, Yücel C, Vural A, Saydam Eker Ç, Cicerali D. Zircon U-Pb geochronology and Sr-Nd-Pb-Hf-O isotope signatures of Middle Eocene high-K plutons from the Eastern Pontides Orogenic Belt, NE Turkey: implications for parental magma sources and magmatic processes. Int Geol Rev 2025;67:1322–52. https://doi.org/10.1080/00206814.2024.2435059.
[40] Özdamar Ş, Roden MF, Billor MZ. Petrology of the shoshonitic Çambaşı pluton in NE Turkey and implications for the closure of the Neo-Tethys Ocean: Insights from geochemistry, geochronology and Sr–Nd isotopes. Lithos 2017;284–285:477–92. https://doi.org/10.1016/j.lithos.2017.04.025.
[41] Temizel İ, Arslan M. Zircon U-Pb geochronology and petrogenesis of Middle Eocene monzonitic plutons in NE Turkey: constraints for generation of post-collisional I-type shoshonitic magmas. Int Geol Rev 2023. https://doi.org/10.1080/00206814.2023.2286636.
[42] Güven İH. Doğu Pontidlerin 1/100.000 Ölçekli Kompilasyonu. Ankara: MTA Genel Müdürlüğü; 1993.
[43] Güloğlu ZS, Kaygusuz A. Petrochemistry and geochronology of Middle Eocene high-K calc-alkaline I-type Kazıkbeli pluton, NE Turkey: implications from zircon U-Pb ages and Sr-Nd-Pb-Lu-Hf isotope data. Mineral Petrol 2025;119:73–103. https://doi.org/10.1007/s00710-024-00881-2.
[44] Topuz G, Altherr R, Kalt A, Satir M, Werner O, Schwarz WH. Aluminous granulites from the Pulur complex, NE Turkey: A case of partial melting, efficient melt extraction and crystallisation. Lithos 2004;72:183–207. https://doi.org/10.1016/j.lithos.2003.10.002.
[45] Topuz G, Altherr R, Schwarz WH, Dokuz A, Meyer HP. Variscan amphibolite-facies rocks from the Kurtoğlu metamorphic complex (Gümüşhane area, Eastern Pontides, Turkey). International Journal of Earth Sciences 2007;96:861–73. https://doi.org/10.1007/s00531-006-0138-y.
[46] Okay A, Satır M, Siebel W. Pre-Alpide Palaeozoic and Mesozoic orogenic events in the Eastern Mediterranean region. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 2006;32:389–405.
[47] Çoğulu E. Gümüşhane ve Rize bölgelerinde Petrolojik ve Jeokronometrik Araştırmalar. İstanbul Teknik Üniversitesi Yayını 1975;1034:112.
[48] Karslı O, Dokuz A, Kandemir R. Subduction-related Late Carboniferous to Early Permian Magmatism in the Eastern Pontides, the Camlik and Casurluk plutons: Insights from geochemistry, whole-rock Sr–Nd and in situ zircon Lu–Hf isotopes, and U–Pb geochronology. Lithos 2016;266–267:98–114. https://doi.org/10.1016/j.lithos.2016.10.007.
[49] Dokuz A, Külekçi E, Aydınçakır E, Kandemir R, Cihat Alçiçek M, Pecha M. E, Sünnetçi K. Cordierite-bearing strongly peraluminous Cebre Rhyolite from the eastern Sakarya Zone, NE Turkey: Constraints on the Variscan Orogeny. Lithos 2017;278–281:285–302. https://doi.org/10.1016/j.lithos.2017.02.002.
[50] Kaygusuz A. Geochronological age relationships of Carboniferous Plutons in the Eastern Pontides (NE Turkey). Journal of Engineering Research and Applied Science 2020;9:1299–307.
[51] Ağar Ü. Demirözü (Bayburt) ve Köse (Kelkit) bölgesinin jeolojisi. Yayınlanmamış Doktora Tezi. İstanbul Üniversitesi, 1977.
[52] Dokuz A, Tanyolu E, Genç S. A mantle- and a lower crust-derived bimodal suite in the Yusufeli (Artvin) area, NE Turkey: Trace element and REE evidence for subduction-related rift origin of Early Jurassic Demirkent intrusive complex. International Journal of Earth Sciences 2006;95:370–94. https://doi.org/10.1007/s00531-005-0046-6.
[53] Şen C. Jurassic volcanism in the Eastern Pontides: Is it rift related or subduction related? Turkish Journal of Earth Sciences 2007;16:523–39.
[54] Saydam Eker Ç, Sipahi F, Kaygusuz A. Trace and rare earth elements as indicators of provenance and depositional environments of Lias cherts in Gumushane, NE Turkey. Geochemistry 2012;72:167–77. https://doi.org/10.1016/j.chemer.2011.11.004.
[55] Karslı O, Caran Ş, Dokuz A, Çoban H, Chen B, Kandemir R. A-type granitoids from the Eastern Pontides, NE Turkey: Records for generation of hybrid A-type rocks in a subduction-related environment. Tectonophysics 2012;530–531:208–24. https://doi.org/10.1016/j.tecto.2011.12.030.

[56] Aydın F. Geochronology, geochemistry, and petrogenesis of the maçka subvolcanic intrusions: Implications for the Late Cretaceous magmatic and geodynamic evolution of the eastern part of the Sakarya Zone, northeastern Turkey. Int Geol Rev 2014;56:1246–75. https://doi.org/10.1080/00206814.2014.933364.

[57] Altherr R, Topuz G, Siebel W, Şen C, Meyer HP, Satir M, Lahaye Y. Geochemical and Sr-Nd-Pb isotopic characteristics of Paleocene plagioleucitites from the Eastern Pontides (NE Turkey). Lithos 2008;105:149–61. https://doi.org/10.1016/j.lithos.2008.03.001.

[58] Eyuboğlu Y. Late Cretaceous high-K volcanism in the eastern Pontide orogenic belt: Implications for the geodynamic evolution of NE Turkey. Int Geol Rev 2010;52:142–86. https://doi.org/10.1080/00206810902757164.

[59] Gülmez F, Genç C, Prelević D, Tüysüz O, Karacik Z, Roden MF, Billor Z. Ultrapotassic Volcanism from the Waning Stage of the Neotethyan Subduction: A Key Study from the Izmir-Ankara-Erzincan Suture Belt, Central Northern Turkey. Journal of Petrology 2016;57:561–93. https://doi.org/10.1093/petrology/egw021.

[60] Aydınçakır E. Subduction-related Late Cretaceous high-K volcanism in the Central Pontides orogenic belt: constraints on geodynamic implications. Geodinamica Acta 2016;28:379–411. https://doi.org/10.1080/09853111.2016.1208526.

[61] Aydınçakır E. Taşlıyayla (Çaykara, Trabzon, KD Türkiye) Civarı Geç Kretase Yaşlı Kalk-alkali Volkanik Kayaçların Petrografik ve Jeokimyasal Özellikleri Petrographical and Geochemical Features of Late Cretaceous Calc-alkaline Volcanics Around Taşlıyayla (Çaykara, Trabzo. GÜFBED/GUSTIJ 2017;7:51–78. https://doi.org/10.17714/gufbed.2017.07.005.

[62] Şen C, Aydınçakır E, Yağcıoğlu UC, Bak T. Sakarya Zonunun Güney Kesiminde Yüzeylenen Geç Kretase Alkalen Volkanitlerinin Jeokimyasal Özelliklerinin Karşılaştırılması. Gümüşhane Üniversitesi, Fen Bilimleri Enstitüsü Dergisi 2019;9(1):1–15.

[63] Eyuboğlu Y, Dudas FO, Santosh M, Yi K, Kwon S, Akaryalı E. Petrogenesis and U-Pb zircon chronology of adakitic porphyries within the Kop ultramafic massif (Eastern Pontides Orogenic Belt, NE Turkey). Gondwana Research 2013;24:742–66. https://doi.org/10.1016/j.gr.2012.11.014.

[64] Karslı O, Uysal İ, Dilek Y, Aydın F, Kandemir R. Geochemical modelling of early Eocene adakitic magmatism in the Eastern Pontides, NE Anatolia: continental crust or subducted oceanic slab origin? Nternational Geology Review 2013;55(16):2083–95.

[65] Dokuz A, Uysal I, Siebel W, Turan M, Duncan R, Akçay M. Post-collisional adakitic volcanism in the eastern part of the Sakarya Zone, Turkey: Evidence for slab and crustal melting. Contributions to Mineralogy and Petrology 2013;166:1443–68. https://doi.org/10.1007/s00410-013-0936-8.

[66] Aydınçakır E. The petrogenesis of Early Eocene non-adakitic volcanism in NE Turkey: Constraints on the geodynamic implications. Lithos 2014;208:361–77. https://doi.org/10.1016/j.lithos.2014.08.019.

[67] Temizel İ, Arslan M, Yücel C, Abdioğlu Yazar E, Kaygusuz A, Aslan Z. Eocene tonalite–granodiorite from the Havza (Samsun) area, northern Turkey: adakite-like melts of lithospheric mantle and crust generated in a post-collisional setting. Int Geol Rev 2020;62:1131–58. https://doi.org/10.1080/00206814.2019.1625077.

[68] Karslı O, Dokuz A, Uysal I, Ketenci M, Chen B, Kandemir R. Deciphering the shoshonitic monzonites with I-type characteristic, the Sisdaĝi pluton, NE Turkey: Magmatic response to continental lithospheric thinning. J Asian Earth Sci 2012;51:45–62. https://doi.org/10.1016/j.jseaes.2012.02.003.

[69] Aslan Z, Arslan M, Temizel İ, Kaygusuz A. K-Ar dating, whole-rock and Sr-Nd isotope geochemistry of calc-alkaline volcanic rocks around the Gümüşhane area: Implications for post-collisional volcanism in the Eastern Pontides, Northeast Turkey. Mineral Petrol 2014;108:245–67. https://doi.org/10.1007/s00710-013-0294-2.

[70] Temizel İ, Arslan M, Ruffet G, Peucat JJ. Petrochemistry, geochronology and Sr–Nd isotopic systematics of the Tertiary collisional and post-collisional volcanic rocks from the Ulubey (Ordu) area, eastern Pontide, NE Turkey: Implications for extension-related origin and mantle source characteristi. Lithos 2012;128–131:126–47. https://doi.org/10.1016/j.lithos.2011.10.006.

[71] Aydınçakır E, Yücel C, Kaygusuz A, Bilici Ö, Yilmazer S, Ruffet G. Eocene magmatism related to postcollisional extension in the Eastern Pontides (NE Türkiye): 40Ar-39Ar geochronology, geochemistry, and whole-rock Sr-Nd-Pb-Hf isotopes. Turkish Journal of Earth Sciences 2024;33:530–56. https://doi.org/10.55730/1300-0985.1928.

[72] Kaygusuz A, Güloğlu ZS, Aydınçakır E, Yücel C, Vural A, Siebel W, Jeong YJ. U–Pb zircon dating, Sr-Nd whole-rock and Lu-Hf zircon isotope analyses of the Eocene Arslandede pluton, Eastern Pontides, NE Turkey: Implications for mantle source

and magma evolution. Geochemistry 2024;84:126080. https://doi.org/10.1016/j.chemer.2024.126080.
[73] Temizel İ, Arslan M. Zircon U-Pb geochronology and petrogenesis of middle eocene monzonitic plutons in NE Turkey: Constraints for generation of post-collisional I-type shoshonitic magmas. Int Geol Rev 2024;66(13):2495–515.
[74] Güloğlu ZS, Kaygusuz A, Aydinçakir E, Yücel C. Mineral chemistry, petrography and crystallization conditions of the Middle Eocene Kazıkbeli Pluton (Eastern Pontides, NE Türkiye). Bulletin of the Mineral Research and Exploration 2024;175:83–109. https://doi.org/10.19111/bulletinofmre.1529525.
[75] Yücel C. Geochronology, geochemistry, and petrology of adakitic Pliocene–Quaternary volcanism in the Şebinkarahisar (Giresun) area, NE Turkey. Int Geol Rev 2019;61:754–77. https://doi.org/10.1080/00206814.2018.1461029.
[76] Güven İH. Doğu Pontidlerin 1:25000 ölçekli kompilasyonu. MTA Genel Müdürlüğü, Ankara 1993.
[77] Streckeisen A. To each plutonic rock its proper name. Earth Science Review 1976;12:1–33.
[78] Aydınçakır E, Kaygusuz A, Yücel C, Güloğlu ZS. Geç Kretase yaşlı Hasan Dağı Plutonunun (Kürtün, Gümüşhane) Sr–Nd–Pb izotop karakteristikleri ve U–Pb zirkon jeokronolojisi. GÜ Araştırma Fonu Proje No: 21F51140102 2023.
[79] Smith JV, Brown WL. Feldspar Minerals I: Crystal structures, physical, chemical and microtextural properties. Springer Verlage, New York 1988.
[80] Leake EB, Wooley AR, Arps CES, Birch WD, Gilbert MC, Grice JD, Hawthorne FC, Kato A, Kisch HJ, Krivovichev VG, Linthout K, Laird J, Mandarino J, Maresch WV, Nickhel EH, Rock NMS, Schumacher JC, Smith DC, Stephenson NCN, Ungaretti L, Whittaker EJW, Youzhi G. Nomenclature of amphiboles report of the subcommittee on amphiboles of the International Mineralogical Association Commission on New Minerals and Mineral Names. Eur J Mineral 1997;9:623–51.
[81] Hammarstrom JM, Zen E. Aluminum in hornblende: An empirical igneous geobarometer. American Mineralogist 1986;71:1297–313.
[82] Hollister LS, Grisson GC, Peters EK, Stowell HH, Sisson VB. Confirmation of the empirical calibration of aluminum in amphibole with pressure of solidification of calc-alkaline plutons. American Mineralogist 1987;34:243–56.
[83] Johnson MC, Rutherford MJ. Experimental calibration of the aluminiun inhornblende geobarometer with application to Long Valley Caldera (California) volcanic rocks. Geology 1989;17:837–841.
[84] Blundy JD, Holland TJB. Calcic amphibole equilibria and a new amphibole-plagioclase geothermometer. Contributions to Mineralogy and Petrology 1990;104:208–24. https://doi.org/10.1007/BF00306444.
[85] Schmidt MW. Amphibole composition in tonalite as a function of pressure: An experimental calibration of the Al-in-hornblende barometer. Contributions to Mineralogy and Petrology 1992;110:304–10.
[86] Holland TJB, Blundy JD. Non-ideal interactions in calcic amphiboles and their bearing on amphibole- plagioclase thermometry. Contribution to Mineralogy and Petrology 1994;116:433–47.
[87] Deer WA, Howie RA, Zussman J. An Introduction to the rock-forming minerals. Longman, 528 Pp 1992.
[88] Laird J, Albee AL. Pressure, temperature, and time indicators in mafic schist: their application to reconstructing the polymetamorphic history of Vermont. Am J Sci 1981;281:127175.
[89] Ghent ED, Nicholls J, Siminy PS, Sevigny HH, Stout MZ. Hornblende Geobarometry of the Nelson bath-olith, Southeastern British Columbia: Tectonic Implications. Canadian Journal of Earth Science 1991;28:1982–91.
[90] Leake BE. On Aluminous and Edenitic Hornblendes. Mineral Mag 1971;38:389–407.
[91] Fuhrman ML, Lindsley DH. Ternary-Feldspar Modeling and Thermometry. American Mineralogist 1988;73:201–15.
[92] Wones DR. Significance of the assemblage titanite+magnetite+quartz in granitic rocks. Am Miner 1989;74:744–9.
[93] Ridolfi F, Renzulli A, Puerini M. Stability and chemical equilibrium of amphibole in calc-alkaline magmas: An overview, new thermobarometric formulations and application to subduction-related volcanos. Contributions to Mineralogy and Petrology 2010;160:45–66.
[94] Karslı O, Dokuz A, Uysal I, Aydın F, Kandemir R, Wijbrans J. Generation of the Early Cenozoic adakitic volcanism by partial melting of mafic lower crust, Eastern Turkey: Implications for crustal thickening to delamination. Lithos 2010;114:109–20. https://doi.org/10.1016/j.lithos.2009.08.003.
[95] Boztuğ D, Jonckheere R, Wagner GA, Yeğingil Z. Slow Senonian and fast Palaeocene-Early Eocene uplift of the granitoids in the Central Eastern Pontides, Turkey: Apatite fission-track results.

Tectonophysics 2004;382:213–28. https://doi.org/10.1016/j.tecto.2004.01.001.

[96] Arslan M, Aslan Z. Mineralogy, petrography and whole-rock geochemistry of the Tertiary granitic intrusions in the Eastern Pontides, Turkey. J Asian Earth Sci 2006;27:177–93. https://doi.org/10.1016/j.jseaes.2005.03.002.

[97] Kaygusuz A, Arslan M, Siebel W, Şen C. Geochemical and Sr-Nd isotopic characteristics of post-collisional calc-alkaline volcanics in the eastern pontides (NE Turkey). Turkish Journal of Earth Sciences 2011;20:137–59. https://doi.org/10.3906/yer-1002-8.